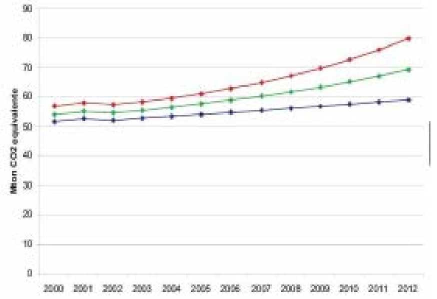
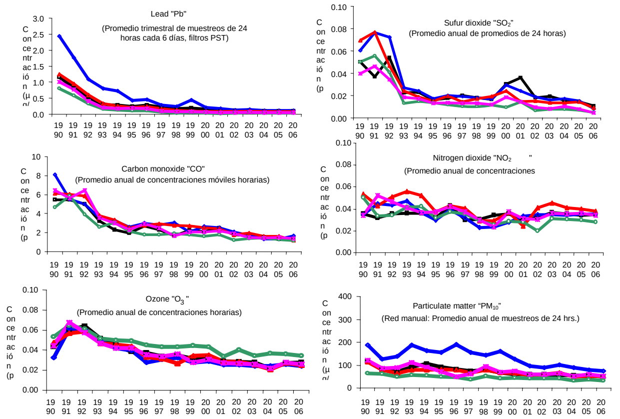
Latin America and Caribbean Region
Sustainable Development Working Paper 29

Transport and Climate:
Lessons from the Partnership between Mexico City and the World Bank

Projected City GHG Emissions



Evolution of local criteria pollutants



May 2007

By:
Walter Vergara
Seraphine Haeussling

The World Bank
Latin America and the Caribbean Region
Sustainable Development Department (LCSSD)

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Acronyms

AQS1	Air Quality Compliance
BRT	Bus Rapid Transit
CAFÉ	Corporate Automobile Fleet Efficiency
CAM	Comisión Ambiental Metropolitana (Metropolitan Environmental Commission)
CDM	Clean Development Mechanism
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COI	Cost of Illness
CVM	Contingent Valuation Method
ETC	European Traffic Cycle
EU	European Union
FDDA	Four-Dimensional Data Assimilation
GEF	Global Environment Facility
GHG	Greenhouse Gas
GMT	Greenwich Mean Time
GNP	Gross National Product
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LPG	Liquified Petroleum Gas
LRT	Light Rail Transit
MCMA	Mexico City Metropolitan Area
MCCM	Mesoscale Chemistry and Climate Model
MCS	Mexico City Cycle
MOP	Meeting of the Parties
NCAR	National Center for Atmospheric Research
N_2O	Nitrous Oxide
NOx	Nitrogen Oxide
OECD	Organisation for Economic Co-operation and Development
PJ	Petajoules
PM	Particulate Matter
PROAIRE	Program of Air Quality Improvement for the Metropolitan Area of the Valley of Mexico
RAVEM	Ride-Along Vehicle Emission Measurement System
SMA	Ministry of Environment (Secretaría de Medio Ambiente del Distrito Federal)
STE	Servicios de Transportes Eléctricos
SUV	Sport Utility Vehicle
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Compounds
WRI	World Resources Institute
WTP	Willingness to Pay

Summary

Climate change represents a major challenge to the integrity of the global ecosystem and is caused by increases in greenhouse gas concentrations in the atmosphere. The Fourth Assessment Report, Summary for Policymakers of the Intergovernmental Panel for Climate Change (IPCC-SPM 2007), concluded that the global average surface warming, following a doubling of carbon dioxide concentrations over preindustrial levels, is *likely* to be in the range 2 to 4.5°C with a best estimate of about 3°C, and is *very unlikely* to be less than 1.5°C. A temperature increase of this magnitude is unprecedented. CO_2 is now expected to double within this century. As a result of changes in mean climatic conditions, the biosphere potentially faces irreversible and catastrophic system impacts. There is now consensus that drastic actions are required to avert these scenarios. Climate change is the most serious challenge being faced by the global ecosystem.

Transport is a major contributor to greenhouse gas (GHG) emissions, accounting for about 14 percent of the global total, and is the only sector of the world economy in which carbon emissions have risen consistently since 1990. Indeed, transport sector emissions grew by 1.4 billion tons (31 percent) worldwide between 1990 and 2003. This has resulted in an increase in transport's share of CO_2 emissions from 22 percent in 1990 to 24 percent in 2003. Over 70 percent of the emissions from the transport sector and 10 percent of the global greenhouse gas emissions are linked to surface (road) transport, and most of these come from industrial nations and China.

The transport sector's large carbon footprint is characterized by vehicle fuel efficiency, modal split, and type of fuel used. Other factors indirectly influence the carbon footprint, including population density and urban design. **Besides being a major contributor to greenhouse gas emissions, the transport sector has also long been associated with issues of air quality and the emissions of air toxics.**

The partnership with Mexico City started in the early 1990s when air pollution was of growing concern. Airborne pollutants at the time still routinely exceeded local and widely accepted international standards. Because of geographic and location factors (Mexico City as an elevated bowl due to surrounding mountains), temperature inversions and stagnant air masses contributed to higher concentrations of local criteria pollutants and worsened the local population's exposure.

By then, the transport sector's significant contribution to the air quality problem had already been recognized. Fuel quality, vehicle emission standards, and growing congestion were understood to contribute to large emissions of NOx and VOCs, which reacted in the city's airshed to generate ozone. Directly emitted particles from diesel trucks and buses, added to those generated through building and road construction, open-air refuse burning, some manufacturing industries, and resuspension of road dust, contributed to high levels of airborne concentrations. The Transport and Quality Management Project for the Mexico City Metropolitan Area was developed as part of the response to these challenges.

Still, the need to develop information and tools to tackle the problem in a comprehensive manner had led the City to develop integrated air quality management plans. The Third Air Quality Management Plan, in part supported by the Bank, was intended as a continuation of these efforts while bringing a multisectoral, long-term approach that would also link air quality efforts to climate change issues and provide the required scientific and analytical basis to formulate further action. The Plan had the support of a blue-ribbon panel, with the participation of world-renowned specialists.

By most indicators air quality in Mexico City has improved over time. These improvements must be credited to the city administration's implementation of comprehensive, multisectoral air quality management programs, assisted in part by the formulation of air quality management plans and the Air Quality and Transport Project.

The effort to address air quality issues also led to the formulation and approval of the first transport and climate operation under GEF financing worldwide (Mexico: Introduction of Climate-friendly Measures in Transport, P059161), as well as the World Bank's first carbon finance project in the transport sector (Mexico City Insurgentes Bus Rapid Transit System Carbon Finance Project, P082656). The GEF-funded project has resulted in: a) the formulation of a citywide climate change strategy; b) the restructuring of the regulatory and business structure framework for surface transport in the city; and c) the implementation of the first Bus Rapid Transit System.

The central tenet of Mexico City's Climate Change Strategy is to seek reductions of GHG emissions through the implementation of measures designed to make better use of natural resources, the regulation and efficient use of installed equipment, fuel substitution, and the use of new technologies and alternative sources of energy. The strategy also seeks an increase in GHG sinks in the city through an ambitious reforestation program and better land-use planning. Mexico City is the first in Latin America to draft a comprehensive climate change strategy.

The efforts that coalesced under the GEF-funded project were instrumental in causing a reform of the policy framework for the city's transport sector. The core of the reforms was enabled by the program to develop the Bus Rapid Transit System. The reforms included the necessary institutional, business management, and regulatory improvements required to operate the proposed corridors. The adoption of a modernized transport scheme facilitated the development of the METROBUS system and the implementation of its first route along Insurgentes Avenue.

The METROBUS operation has been a resounding success from an operational and environmental perspective. The system began operating in November 2005. During its first year it was credited with having changed the momentum for a transport system in the city, while transporting 10 million passengers and resulting in GHG reductions estimated at around 30,000 tons of CO_2 equivalent per year. The METROBUS operation has also been credited with substantial reductions in exposure to air toxics and local criteria pollutants for system users and the population in the project's area of influence.

Although limited in volume of resources, the combined involvement of the **GEF and Carbon Finance** must be credited, at least partially, with providing key leverage for substantial policy, regulatory, and market reforms for surface transport in Mexico City.

The widespread adoption of bus rapid transit systems in Latin American countries and the associated reductions in emissions of local and global concern stand in contrast with increases in the energy intensity of passenger transport in industrialized North America. The potential application of the experience of such systems should be of interest to urban planners and policy makers in those countries.

These systems respond to the need for cost-effective mass transport and serve to advance the goals of low carbon footprint and reduced loads of air toxics and local criteria pollutants. However, the BRTs cannot be seen as the only solution and cannot be developed in isolation from existing modes of transport. The impacts on congestion and quality of transport by BRTs will be maximized, provided these are developed in concert and in coordination with the existing mass transport infrastructure.

The proposed expansion of METROBUS will correspondingly increase the net reduction in greenhouse gases in Mexico City. A 10-corridor system has the potential to reduce annual emissions by between 300,000 and 500,000 tons per year, more if low carbon bus technologies (hybrid drives) are deployed. The combination of modal shift and reduced congestion with low-carbon, low air toxic vehicles will place the city at the forefront of developments in climate- and health-responsive BRTs worldwide.

The Role of Urban Transport in Emissions of Global and Local Concern

Background: The climate challenge

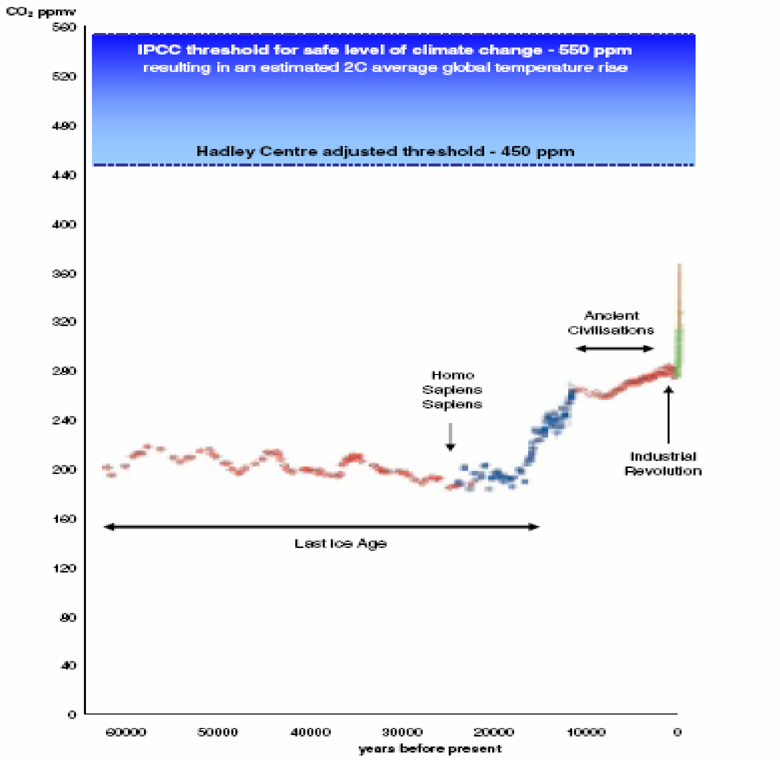
Climate change represents a major challenge to the integrity of the global ecosystem and is caused by increases in greenhouse gas concentrations in the atmosphere. The Fourth Assessment Report, Summary for Policymakers of the Intergovernmental Panel for Climate Change (IPCC-SPM 2007), concluded that the global average surface warming, following a doubling of carbon dioxide concentrations over preindustrial levels, is *likely* to be in the range 2 to 4.5°C with a best estimate of about 3°C, and is *very unlikely* to be less than 1.5°C. A temperature increase of this magnitude is unprecedented. The report also indicated that in 2005 the current CO_2 concentration in the atmosphere greatly exceeded the natural range during the last 650,000 years (see Figure 1). CO_2 is now expected to double within this century.

A recent analysis of current trends (Schellnhuber et al. 2006) concludes that the planet will face dangerous climate change consisting of irreversible and drastic impacts on the biosphere, possibly crossing critical thresholds in the near future. Along with changes in mean climatic conditions, the biosphere potentially faces irreversible and catastrophic system impacts associated, for example, with the reduction of thermo-haline circulation, the melting of the Greenland ice sheet (Epstein 2005), the subsidence of small islands and coastal wetlands, the collapse of coral reefs and associated marine ecology, increases in intensity of hurricanes (Webster et al. 2005), acidification of oceans, and others. Global warming will affect all species and exacerbate the stresses already being experienced by ecosystems. There is now consensus that drastic actions are required to avert these scenarios. Climate change is the most serious challenge being faced by the global ecosystem.

In Latin America, the urgency of the challenge is illustrated by major impacts already being felt. These include:

(a) a loss of 20 percent of ice cover in the tropical glaciers of the Andes and an expectation of continuous, accelerated glacier retreat in the Andes, with consequences for water and power supply and ecosystem integrity (Vergara et al. 2007);
(b) record coral bleaching events, including the one experienced during 2005 which led to wholesale bleaching of corals in the Caribbean basin with implications for fisheries and tourism;
(c) increased exposure to tropical vector diseases in mountain populations;
(d) intensification of hurricanes in the Caribbean basin and coastal zones in the Gulf of Mexico, threatening coastal populations and infrastructure (Webster et al. 2005); and
(e) damages to the integrity of the Amazon rainforest (Levy et al. 2004).

Figure 1. Concentration of CO_2 in the atmosphere during the last 650,000 years



Source: School of Environmental Science, as cited in ECMT 2007.

These and other changes jeopardize the prospects for sustainable development in Latin America and are akin to a climate tax on a region that has otherwise contributed relatively little to greenhouse gas emissions. In contrast to the significant impacts anticipated in the region, all of Latin America emits only about 6 percent of global greenhouse gases (Table 1) caused by fuel combustion and release of industrial gases. On the other hand, it is estimated that 25 percent of global deforestation takes place in the region, mostly in Brazil and Mexico.

Table 1. Global emissions of greenhouse gases by region/country

Country	***Total (BTA)***	***Ton/$Mppp***	***Tons per capita***
USA	6.9	720	24.6
EU-25	4.7	450	10.5
Japan	1.3	400	10.4
China	4.9	1020	3.9
Mexico	0.5	590	5.2
Brazil	0.8	680	5.0
Argentina	0.3	660	8.1
Latin America	1.9 (6%)		3.4
World Total	33.6		4.8

Source: WRI 2006; Dow and Downing 2007

Most of the international community has endorsed the need for forceful action to reduce greenhouse gas emissions, first through the Kyoto Protocol and more recently by the

European Union's (EU's) endorsement of further reductions (Table 2). Additional commitments for future reductions under the process started through the Kyoto Protocol are anticipated and are the subject of discussions in the context of the Meeting of the Parties (MOP) of the UNFCCC. Nevertheless, only major changes in energy use, particularly in energy-intensive societies such as the United States and China, will enable the drastic reductions that are required to stabilize GHG concentrations in the atmosphere and prevent dangerous climate change.

Table 2. Emission reductions pledged by the EU

EU GHG reduction targets in relation to 1990 levels	**Status**
8% in first commitment period (up to 2012)	Kyoto Protocol commitment
20% by 2020	Approved by the EU in March 2007
60–80% by 2050	Position of the Council of the EU's Environment Ministers position

The role of transport in greenhouse gas emissions

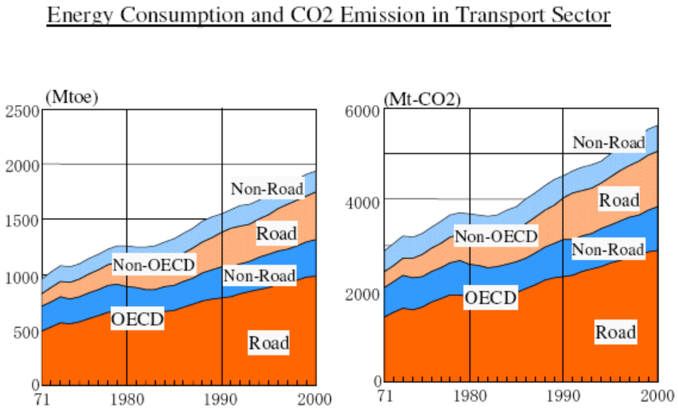
Transport is a major contributor to GHG emissions, accounting for about 14 percent of the global total, and is the only sector of the world economy in which carbon emissions have consistently risen since 1990 (WRI 2005). In fact, transport sector emissions grew by 1.4 billion tons (31 percent) worldwide between 1990 and 2003 (EMCT 2007). This has resulted in an increase in transport's share of CO_2 emissions in all regions of the world: from 22 percent in 1990 to 24 percent in 2003. Transport's share is highest in OECD countries (30 percent in 2003).

More specifically, over 70 percent of emissions from the transport sector and 10 percent of global greenhouse gas emissions are linked to surface (road) transport, and most of these come from industrial nations and China. Table 3 indicates that when counted together, the U.S., the European Union, Japan, and China account for two-thirds of global transport greenhouse gas emissions.

The quick rise in emissions from the transport sector reflects a global increase in mobility. However, most of the increase has taken place in industrial nations where demand for passenger cars and light trucks, including sport utility vehicles (SUVs), has until now continuously gained a share of the vehicle market. On a regional level, transport emissions are the highest in industrial North America, with the U.S. alone contributing 30 percent (International Energy Agency [IEA] 2007).

Projections made by the IEA (2004) anticipate that emissions in the U.S. will steadily grow and be at an additional 30 percent over current levels by 2020 under a business-as-usual scenario. The same report anticipates an increase of close to 150 percent for transport emissions from China. These increases alone would make it unlikely for global emission reductions to be achieved. The choice of highly inefficient modes of passenger transport in the U.S. and the weight that these emissions have on global emissions, highlight the urgent actions that need to be taken in this country and place in question the market wisdom and signals for the sector.

Figure 2. The CO_2 footprint of the transport sector



Source: IPCC Draft Fourth Assessment Report 2007

In the developing world, the rapidly increasing motorization of transport is also a reflection of expanding human mobility. In the year 2000, the transport sector accounted for 24 percent of world energy-related GHG emissions in developing nations. Passenger transport currently accounts for 65 percent of total transport energy consumption and GHG emissions while freight movement comprises the remaining 35 percent. Transport energy use in the developing world increased at a faster rate (2.6 percent) than that in the developed world (2.1 percent) and is projected to grow from 32 percent now to 46 percent of world transport energy use by 2030, when China is counted in the total tally (IPCC 2007 [4th AR, Draft]).

The share of GHG transport emissions from Latin America stands at about 7 percent; the largest contributors, Mexico and Brazil, represent about 5 percent of global emissions. Although some projections indicate a significant long-term increase in the region's transport emissions, recent developments in urban transport (the emergence of bus rapid transit systems and the increased use of ethanol as a vehicle fuel in the region) may curtail the projected rate of increase).

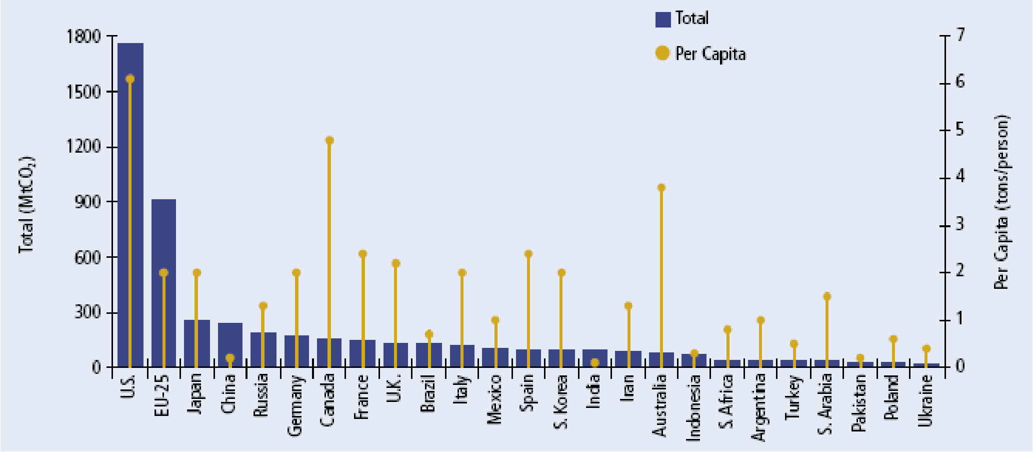
Table 3. CO_2 emissions from the transport sector

Country	Transport sector emissions (% of global)	Estimated change 1990–2002 (%)
United States	36	24
European Union	18	23
Japan	5	20
China	5	101
Brazil	3	60
Mexico	2	21
Total ($MTCO_2$)	4,600	28

Source: WRI 2006 and own estimates

On a per capita basis, the transport-related emissions from the U.S. exceed those from any other region and are over 6 tons per person/year (see Figure 3**)**. This again reflects the high energy intensity of the transport sector in the U.S. The implications of this energy intensiveness go beyond the emissions in the country, because the technology signal that originates in this country tends to be copied in many other regions.

Figure 3. Per capita emissions in the transport sector



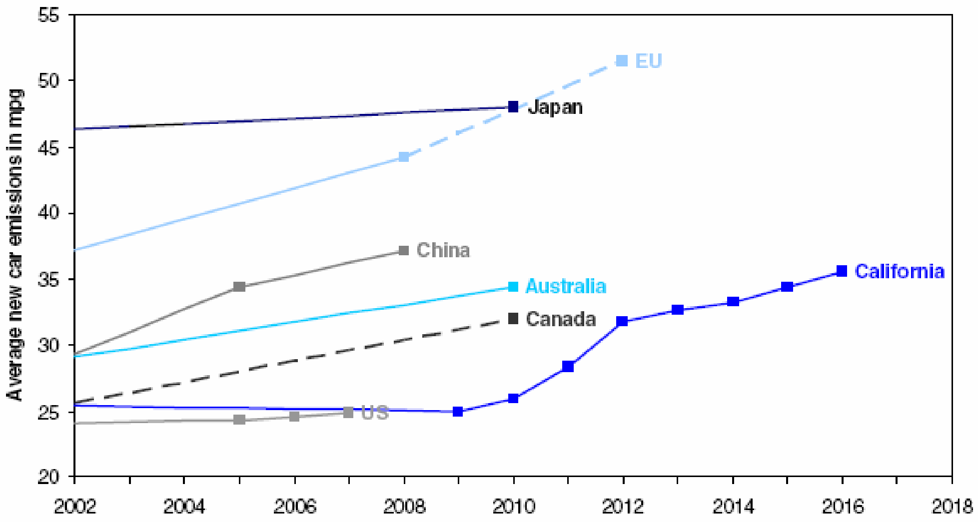
Source: WRI 2005

The nature of the transport sector's carbon footprint

The transport sector's carbon footprint can be characterized through vehicle fuel efficiency, modal split, and type of fuel used. Other factors indirectly influence the carbon footprint, including population density and urban design. Oil commands an overwhelming share of fuel usage in the sector (96 percent). Natural gas, biomass, and coal account for the balance.

Vehicle fuel efficiency is the result of the type of engine and drive system. Regrettably, although there is great potential for improvements, vehicle manufacturers have not improved vehicle fuel efficiency with the urgency demanded by the large impact of transport on greenhouse gas emissions. The U.S., Japan, and China have regulations for passenger car fuel efficiency, and Japan also regulates heavy-duty vehicle fuel economy. On the other hand, the EU and its member states, together with Switzerland, Australia, and Canada, all employ voluntary targets for car manufacturers and importers. Japan has by far the most ambitious regulatory standards, but the EU's voluntary targets are similar. U.S. standards are far less ambitious, with the exception of the new standards adopted by California in 2006 followed by other states in early 2007 (Figure 4).

Figure 4. Worldwide passenger car fuel economy (miles per gallon, normalized on the basis of CAFÉ standards

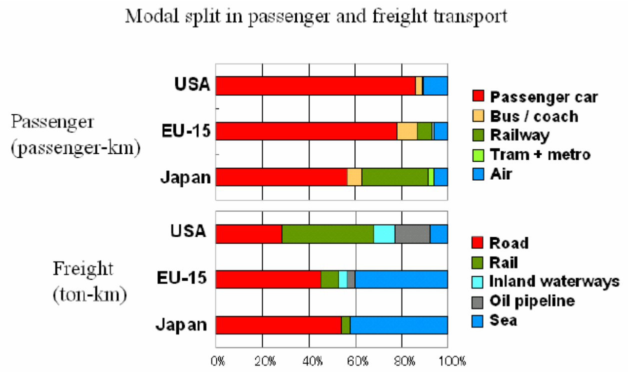


Note: Dotted lines indicate proposed standards or targets.

Source: S. Davies and S. Dieguel, 2006

Modal split. Modal split refers to the market share of each mode of transport. It is measured on the basis of a percentage of total transport activity. Some modes of transport are less carbon and energy intensive than others for an equivalent journey (they use less energy per unit of weight and distance traveled). All other factors being equal, if these trips can be switched to a less energy-intensive mode, fuel use and corresponding CO_2 emissions would be reduced per load over a unit distance. The modal split in an urban area is determined by the participation of alternative modes of transport, including passenger cars, subways, buses, rail, and trucks. The modal split in developed nations is heavily skewed toward passenger vehicles (see Figure 5 below) and reflects higher per capita incomes.

Figure 5. Modal split in industrial countries



Source: IPCC 2007

Modal shift measures can be very effective when they are well integrated with demand-management measures. However, these measures, including congestion charges, traffic guidance systems, and parking policies that deter the use of private cars, have an influence on CO_2 emissions but are not traditionally considered an integral part of climate policies. Table 4 below summarizes the estimated energy intensity (in gms CO_2/ton per km) for different modes of transportation. Passenger cars are the most energy-intensive mode.

Typically, in Latin American urban areas, there is a component of mass transport that is associated with high energy efficiency and thus lower emissions of greenhouse gases per passenger per unit of distance traveled. This component is frequently made up of various modes of public transport including buses, light rail, and in some cities subway systems. There is also a strong momentum in the region's urban areas, typified by the developments of Bus Rapid Systems (BRTs, such as the Transmilenio in Bogotá, METROBUS in Mexico, and the pioneering experience in Curitiba) to change the structure of passenger mobility in urban areas. The genesis of these systems also has a strong linkage with progressive policies on access to public space. Although the bus rapid transit systems in most of these cities were primarily designed to address issues of congestion and urban planning, their effect can also be felt in an improvement in energy efficiency and, if properly managed, in net reductions in greenhouse gas and local airborne pollutants. A common feature of these systems is the development of policies to restrict automobiles from dedicated mass transport corridors.

BRTs are one of several integrated transport systems. In some cities, the BRT is one of several mass transport alternatives (metro, light rail), and must be integrated with those systems. The overall gains in emissions and mobility depend on the ability to integrate all available systems, organize a common structure to avoid bottlenecks, and streamline their common operation.

Table 4. Energy intensity for different modes of transportation

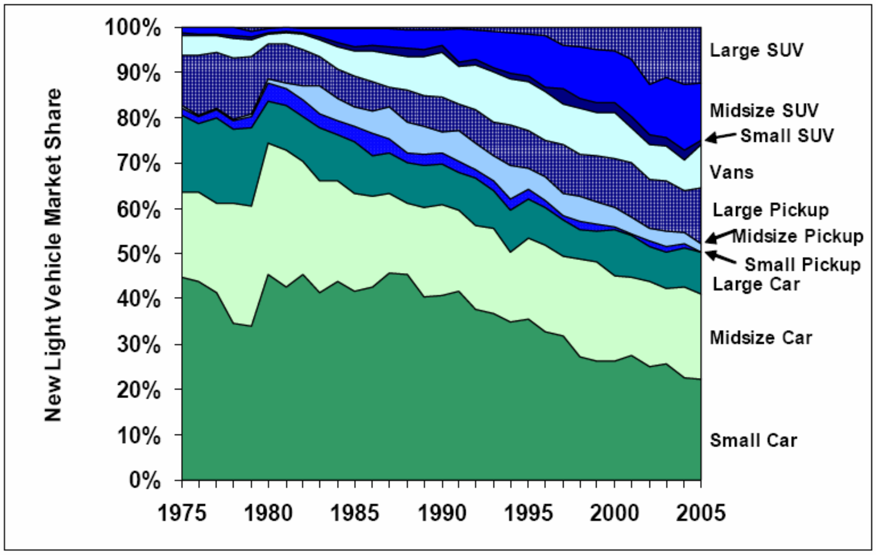
Mode	Energy Intensity (grams of CO2/t-km)
Maritime	43.5
Rail	43.7
Road	118.4
Passenger cars	126.2
Buses	66.1

Source: ECMT 2007

In the United States, on the other hand, there has been a marked tendency toward the least efficient modes of transportation. Figure 6 below presents the growing market share of SUVs and other light trucks in the new light vehicle market's total share. The SUV segment increased from 6 percent in 1975 to 22 percent by 2005.

The increase in large, fuel-inefficient vehicles has reflected negatively on the equivalent fleet efficiency in the United States. The national Corporate Automobile Fleet Efficiency (CAFÉ) estimates for the combined light truck and car fleet ranged from 23.1 miles per gallon in 1980 to 25.4 in 1990, 24.8 in 2000, and 25.2 in 2005. This represents an improvement of less than 9 percent over a quarter century. During the same period, U.S. consumption of petroleum products by the light truck and car segment of the transport sector increased from about 5 million barrels per day to over 8 million barrels per day.

Figure 6. Evolution of passenger vehicle market share in the United States



Source: S. Davis and S. Diegel 2006

Fuel type. Carbon intensity of fuels is measured in grams of CO_2 emitted per unit of energy consumption, on a full-cycle basis (i.e., all the CO_2 emissions associated with producing the fuel used, as well as direct emissions when a vehicle is driven). Carbon intensity can be reduced either by replacing nonrenewable fuels with renewable substitutes, or by switching to fuels with a lower carbon-to-hydrogen ratio. Fuels with a low carbon-to-hydrogen ratio produce less CO_2 during combustion for the unit of work delivered. CO_2 emissions from combustion of fuels produced from renewable feedstocks such as biofuels make no direct net contribution to the atmospheric concentration of CO_2 provided the inputs required for their production are carbon neutral or do not exceed the CO_2 emissions associated with the fuels they are intended to displace. Biofuels can have very low or zero carbon intensities, as is the case of ethanol from sugar cane in established cropland in Brazil. However, if crops for biofuels are the result of energy- or resource-intensive agriculture, this would not be case.

Table 5. Carbon content for alternative transport fuels

Fuel	Carbon content (% weight)
Gasoline	85–88
Diesel #2	84–87
Methanol	37.5
Ethanol	46.1
Propane	44.1
Methane	16.0
Hydrogen	0

In countries with rapid motorization, fuel-efficient vehicles and incentives for efficient transport technology and alternative fuels are important components of a strategy to reduce GHG emissions (IPCC 2007). However, efforts to reduce GHG emissions in the Latin American transport sector can only have a limited global impact, unless energy-intensive societies also share in the effort.

Urban planning and city layout have as much influence on energy intensity of transport as other factors. The same is true of efforts to integrate urban development with transport policy, as exemplified by the cases of Bogotá and Curitiba, among other cities in the region. Cities with a higher population density tend to have lower per capita emissions. Cities that integrate transport, air quality, and urban policies have the potential to reduce these further.

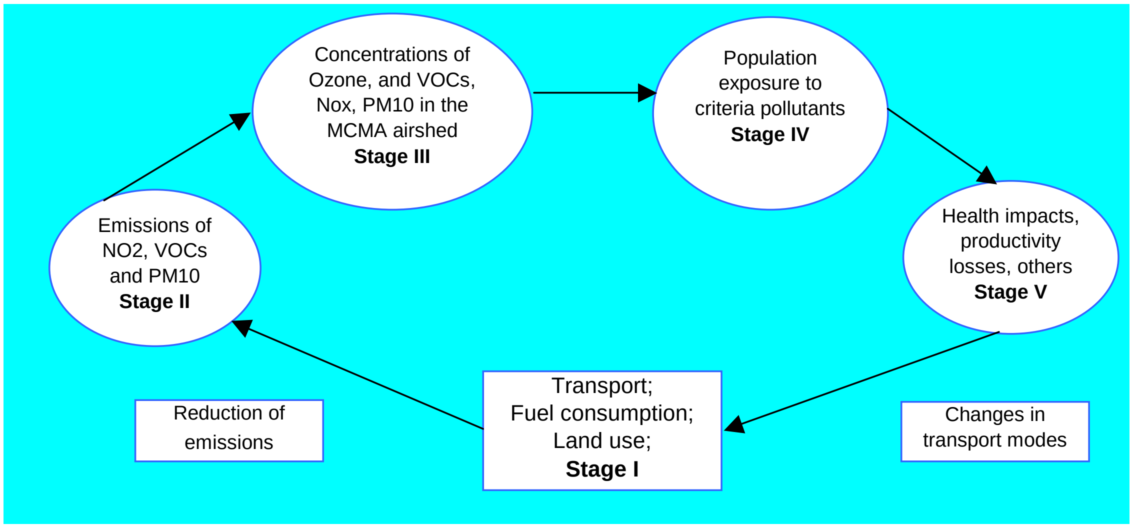
Local airborne pollution from the transport sector

Besides being a major contributor to greenhouse gas emissions, the transport sector is also associated with issues of air quality and the emissions of air toxics. Ozone air pollution is formed from the emissions of NOx and VOCs. The amount produced depends on the amount and location of emitted pollutants; background pollution levels; atmospheric chemistry; geographical, climatological, and meteorological characteristics; and atmospheric transport characteristics. Moreover, the chemistry of ozone formation is quite complicated and nonlinear: under certain conditions, an increase in NOx emissions can *reduce* ozone concentrations. Most NOx and VOC emissions in an urban environment can be traced back to the use of fossil fuels and derivatives.

The origins of particulate pollution (PM) are less clear. PM_{10} may be emitted directly or formed from SO_2 and NOx reacting with other substances in the atmosphere (secondary particle formation). The ambient concentration of air pollutants depends on the amount and location of emissions; the source-dependent physical characteristics of emitted PM_{10} and PM_{10} precursors such as SO_2 and NOx; background pollution levels (especially of ammonia); atmospheric chemistry; geographical, climatological, and meteorological characteristics; and atmospheric transport characteristics.

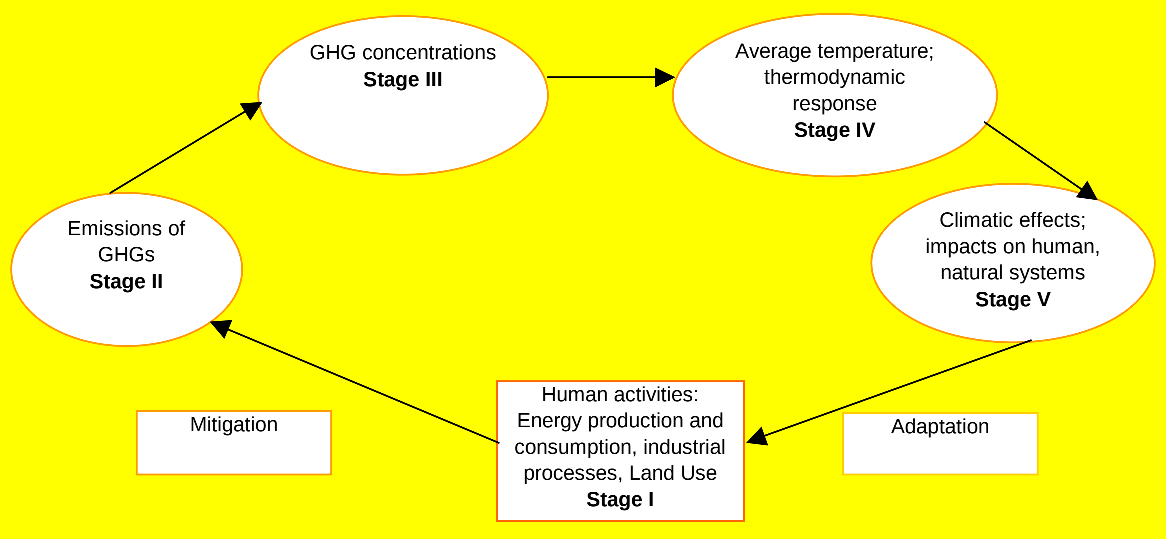
Atmospheric concentrations of particulate matter and ozone in urban airsheds are known to have health consequences and in the case of PM have been associated with increases in mortality. Figures 7 and 8 illustrate the correspondence of efforts to deal with airborne pollutant and greenhouse gas emissions in a coordinated manner.

Figure 7. Feedback cycle for emission of local criteria pollutants in an urban airshed



In terms of greenhouse gas generation, most of the sources and processes are the same ones that cause air pollution. Greenhouse gases are generated during the use of primary energy sources for power generation and steam generation, or refined fuels for industry and transport. Volumes generated are affected by changes in efficiency of use. Greenhouse gas emissions can also result from changes in land-use patterns as the city environment is urbanized. Thus, there is a considerable potential correspondence between measures that are intended to improve air quality and those designed to mitigate GHG emissions.

Figure 8. Feedback cycle for greenhouse gas emissions in an urban airshed



Transport and Air Quality in Mexico City

The partnership with Mexico City started at a time (early 1990s) when air pollution was of growing concern. At the time, airborne pollutants routinely exceeded local and widely accepted international standards. Because of geographical and locational factors (Mexico City as an elevated bowl surrounded by mountains), temperature inversions and stagnant air masses contributed to higher concentrations of local criteria pollutants and worsened the local population's exposure to them. Cooperation with Mexico City on air quality and transport issues began in 1992 under this context and with the approval of the Transport and Quality Management Project for the Mexico City Metropolitan Area.[1]

The need to develop information and tools to tackle the problem in a comprehensive manner had led the City to develop integrated air quality management plans. The Third Air Quality Management Plan (CAM 2002), in part supported by the Bank, was intended as a continuation of these efforts. It brought a multisectoral, long-term approach that could link air quality efforts to climate change issues and provide the required scientific and analytical basis. The Plan had the support of a blue-ribbon panel, with the participation of world-renowned specialists. The Plan was also seen as an opportunity to bring in the climate change dimension and its linkage to the root causes of poor air quality in the city.

Under the Third Air Quality Management Plan, cooperation with the Bank resulted in an assessment of economic consequences of the failure to address air quality issues in the metropolitan area, the review of opportunities for harmonization of air quality and climate change concerns for the city, and the development of modeling tools to simulate air quality in the metropolitan area**.** The information and tools developed, as well as efforts made in parallel by other groups, enabled the launching of specific efforts to address the combined challenges posed by air quality and climate change in the city.

These efforts ultimately led to the formulation and approval of the first transport and climate operation under GEF financing worldwide (Mexico: Introduction of Climate-friendly Measures in Transport, P059161), now under implementation, as well as the World Bank's first carbon finance project in the transport sector (Mexico City Insurgentes Bus Rapid Transit System Carbon Finance Project, P082656). The scope of these projects gravitates around BRTs, which need to be seen as part but not all of the solution for the transportation and environmental issues in the city.

Table 6 provides a chronology of the Bank's partnership with Mexico City. The following sections of the report describe the findings and results of these efforts and of the extensive analytical and operational work that underpins transport and climate operations in the city.

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[1] A loan in the amount of US$220.0 million equivalent for the Transport Air Quality Management Project for the Mexico City Metropolitan Area was approved on December 15, 1992 and made effective on June 27, 1994.

Although limited in volume of resources applied, the combined involvement of the **GEF and Carbon Finance** must be credited, at least partially, with providing key leverage for substantial policy, regulatory, and market reforms for surface transport in Mexico City.

Table 6. Summary of results from the partnership with Mexico City

Period	**Mexico City's decisions**	**World Bank's participation**	**Key results**
1970–1990	Mexico City takes a proactive approach to control a deteriorating air quality situation. City enacts the first and second air quality management plans.		Major reductions in key local criteria pollutants are measured.
1994–2002	Measures identified in the second air quality management plan are targeted for implementation.	World Bank finances some measures under the Transport and Air Quality Management Project for the Mexico City Metropolitan Area.	City makes regulatory and policy decisions to reduce further emissions of airborne pollutants. Loan is used to finance fleet modernization and measures to reduce VOCs and PM emissions.
2002	A new regional air quality plan is drafted. It recognizes the role of GHG in air quality issues.	World Bank supports aspects of the analytical base for the plan and the identification of priority measures.	Updated local pollutant emissions inventory; GHG inventory; assessment of avoided health costs; air quality modeling tools are further developed.
2003–	City opts for implementation of climate-related measures in transport.	World Bank as implementing agency provides GEF financing for first climate and transport operation under OP 11.	Citywide climate change strategy is drafted. Testing of alternative public transport vehicles is undertaken.
2005–	City decides to design and implement BRT system.	World Bank provides carbon finance and technical assistance for the development of the BRT along Insurgentes Avenue.	METROBUS is created and operates in a satisfactory manner. Barriers for the entry of a BRT system are addressed. METROBUS operation causes reductions in greenhouse gas emissions and local criteria pollutants.
2007	City decides to expand METROBUS, adding 9 additional corridors to build on the success of the Insurgentes experience.	Proposed	

Transport and Air Quality Management Project for the Mexico City Metropolitan Area (P007694)

This project was formulated to support efforts to address the growing concerns related to air quality in the city under a comprehensive air quality management program known as PROAIRE. Launched in 1994, the project's specific project objectives included:

- (i) reducing the growth of emissions of nitrogen oxides (NOx), volatile organic compounds (VOC), carbon monoxide (CO), lead, and particulate matter (PM) from transport sources;
- (ii) developing a policy framework to support transport and air quality objectives;
- (iii) improving the scientific base underlying air quality program development and management; and
- (iv) strengthening institutional capabilities to effectively plan and implement air quality programs over the long term.

In order to achieve these objectives, the project supported five activities: (i) a vehicle component to support high-use vehicle modernization, emission control retrofit, and the acquisition of inspection equipment in private garages through lines of credit; emission standards development and enforcement, and upgrading the inspection, maintenance, and vehicle registration systems; (ii) a fuel component to establish vapor recovery systems and carry out an alternative fuel pilot program; (iii) studies to help prepare an integrated transport and air quality management strategy for the Mexico City Metropolitan Area (MCMA); (iv) a scientific base component to improve the level of scientific knowledge regarding air pollution in the MCMA; and (v) an institutional strengthening component. The Gasoline Project and its vehicle and fuel components were expected to reduce the growth of emissions from transport sources. The other project components were related directly to the project's other stated objectives.

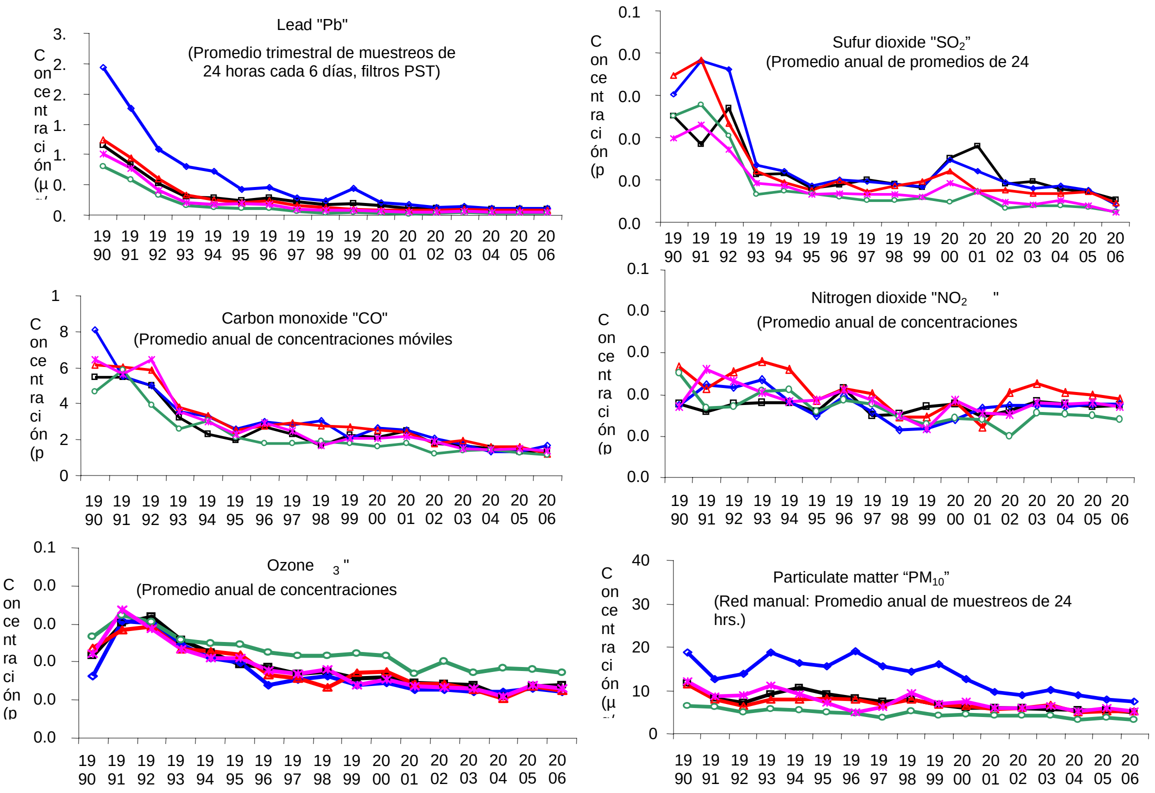
The growth of air pollution in the MCMA was controlled, as a result of abatement activities undertaken by the city since 1990, and in some ways significantly reduced. The institutional arrangements and systems for continuing to deal with air quality issues were firmly established and later proved essential for further actions, and the ground was prepared for further improvements to transport and air quality in the MCMA (World Bank 2002, ICM).

Indeed, during the project implementation period, and as a result of a number of other activities undertaken by local authorities, significant progress was made to reduce air pollution in the MCMA. Ambient lead concentrations were reduced by 98 percent, sulfur dioxide was reduced sufficiently to reach healthy levels, and few violations of the CO air quality standard remain. On the other hand, air quality concentrations of ozone remained high on most days, often exceeding acceptable levels by a factor of two or more. PM_{10}

levels also continued to be high, especially in heavily industrialized areas and traffic- and erosion-influenced zones.

Despite continuing growth in population and the number of vehicles, there is strong evidence of progress for these serious pollutants. There is a downward trend in the highest concentrations of ozone and PM_{10}. In terms of ozone, for example, concentration went from 0.276 ppm to 0.200 in 2000 and to 0.158 by the end of 2006. Correspondingly, the number of days under compliance with ozone norms went from 30 in 1990 to 58 in 2000 and to 156 in 2006 (Dirección General de Gestión de Calidad del Aire 2007).

Figure 9. Evolution of air quality in Mexico City



Source: SMA 2006

To achieve these goals a number of measures were implemented in support of PROAIRE, the most important of which were the following:

(i) tax policies were used to reduce the price differential between unleaded and leaded gasoline in order to reduce improper fueling and encourage the introduction of clean natural gas vehicles;

(ii) exemptions from the one-day-a-week ban on the use of vehicles were used as an incentive to modernize the vehicle fleet;
(iii) a surcharge on gasoline was used to finance the installation of vapor recovery equipment in service stations, a highly cost-effective way of reducing emissions;
(iv) improvements in the refining process financed by the Gasoline Project have allowed the production of unleaded gasoline and an important reformulation of gasoline which have reduced emissions from vehicles in the MCMA;
(v) demonstration projects were carried out on the use of alternative fuels for vehicles;
(vi) the inspection/maintenance (I/M) system in the MCMA was significantly upgraded by the move to a completely centralized system and expanded testing for CO, HC, and NOx;
(vii) upgraded emission standards for new vehicles have been established; and
(viii) policies for high-use vehicles (taxis, microbuses, trucks) and programs to finance them have accelerated the modernization of these fleets.

By most indicators the quality of air in Mexico City has improved over time, with major improvements made on SO_2, ozone, and CO. Although some improvements have also been made in PM and N_2O, these remain at relatively high concentrations in the atmosphere. Figure 9 illustrates the dramatic improvements obtained by the city in local air quality since 1980 and how these efforts continued to be sustained. These improvements must ultimately be credited to the implementation of multisectoral, comprehensive air quality management programs.

The Third Air Quality Management Plan, 2002–2012 (P072508)

In 2002 the city administration decided to continue this work through the formulation, design and implementation of the Third Air Quality Management Plan in the MCMA (AQM-III, 2002–2010) to build on results already achieved under PROAIRE. The thrust of the effort was: "to improve health indicators through reductions in exposure of populations to airborne pollutants."

The AQM-III, supported in part by the World Bank, was published in February 2002 (CAM 2002). It provided a strategic framework to guide necessary immediate interventions and to further define goals and priorities, while identifying barriers and required reforms. The plan merges a significant amount of dispersed information on air quality issues in Mexico City. These valuable materials have been integrated into a comprehensive assessment that provides the basis for a long-term strategy to address air quality in the MCMA. Priority is given to efforts to reduce particulates and ozone, both of which have been shown to have unsustainable impacts on health and the environment. The AQM-III recognized the transport sector as a priority area for efforts to curb air pollution and its pivotal role in the emission of greenhouse gases, and identified 47 measures out of a total of 108 that are related to the transport sector and to the improvement of air quality.

The plan established goals for the ten-year duration of the program. These goals, provided in quantitative form, are: (i) a substantial reduction in ozone concentrations and exposure (eliminating any concentrations above twice the allowable standard) and a significant reduction in average concentrations; (ii) a reduction in the concentration of PM_{10} and $PM_{2.5}$; and (iii) a reduction in average concentrations of SO_2 and CO.

Under the AQM-III, the city identified over 85 air pollution and greenhouse gas emission-reduction actions to be implemented over the eight-year period. Although these include energy efficiency improvements and protection of forests and green spaces, the plan identified the transport sector as a priority area for efforts to curb air pollution. One of the outstanding measures identified was the adoption of transport corridors. The Bank aided in the plan's formulation through:

(i) support to the modernization of an emissions inventory of local airborne pollutants, and assistance in the development of a greenhouse gas emissions inventory;
(ii) quantification of the health impacts associated with poor air quality;
(iii) formulation of harmonization measures that could jointly address local air quality issues and greenhouse gas emissions (climate change); and
(iv) modeling of air quality in the metropolitan area and of the respective measures.

Key results of these efforts are summarized below.

Examples the Third Air Quality Management Plan's achievements so far include the installation of approximately 95,478 catalytic converters, the renovation of 100 percent of the RTP fleet (1,279 buses), the modernization of the taxi fleet (46,807 taxis have been replaced), the finalization of major parts of the cycle lanes (approximately 90 km), the replacement of 3,982 microbuses (to date 11,807 microbuses are running with LPG and 949 with natural gas), and the implementation of the first transport corridor in Mexico City.

Completion of a local emissions inventory

A comprehensive emissions inventory has been part of the city's database for the last 17 years. The project provided technical support for the modernization of measurements and estimates, which were first reflected in the 2000 inventory. The table below indicates the air quality measurements for the base year of 1990 and the reductions achieved by the city since then. Progress has been made on all air quality indicators.

Table 7. City air quality measurements (1990–Dec. 2006)

Year	Ozone (ppm) max-min average	SO_2 (ppm) max-min average	PM_{10} (micrograms/ m^3)	$PM_{2.5}$ (micrograms/ m^3)	Suspended Particles (micrograms/ m^3)
1990	0.111–0.207	0.04–0.069	64.2–186.5		1353
2000	0.117–0.162	0.01–0.03	43.7–125.0		634
Dec 2006	0.092–0.127	0.004–0.011	31.7–70.7	17.5–27.2	358

Source: Dirección General de Gestión Ambiental del Aire 2007

Greenhouse gas inventory

Another result of the inventory was an assessment of greenhouse gas emissions in the metropolitan area. Although Mexico only accounts for about 2 percent of global GHG emissions, a large share of these are concentrated in the MCMA. With 18.6 million inhabitants, approximately 35,000 industries, and a vehicle fleet of 3.5 million, the MCMA contributes 7.8 percent to national GHG emissions. In 2000, the transportation sector was the largest contributor to CO_2 emissions in Mexico City, with a 37 percent share of the total (Urban Transport and the Environment 2004, p. 332).

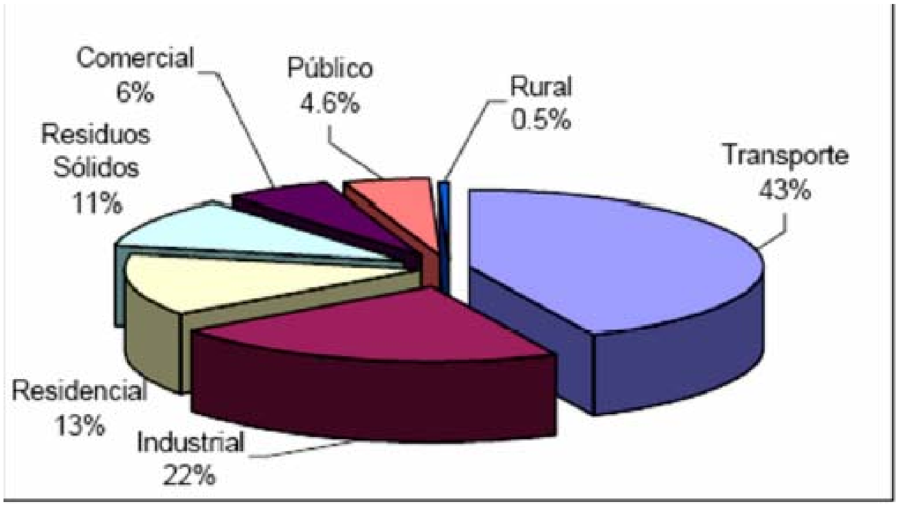
Table 8. GHG inventory for Mexico City

GHG	2000	2006
CO_2 (MT)	33.5	36.0
CH_4 (KT)	157	178
N_2O (KT)	230	226
MCMA (total, MT CO2 e):	54	56

Source: Dirección General de Gestión Ambiental del Aire 2007

The inventory of greenhouse gases was first estimated for 2000 and has been renewed since then. The city is one of the first urban centers to have completed and maintained a detailed account of GHG. The total emissions of GHG in 2000 were estimated at 33 million tons (1.6 tons per capita). It is now estimated that in 2006, these increased to 36 million tons. The sector allocation of GHG emissions for 2000 is presented in Figure 10 below.

Figure 10. Emissions of CO_2 equivalent by sector in 2000



Source: SMA, 2006. Estrategia Local de Acción Climática de la Ciudad de México 2006

Economic valuation of health impacts from air pollution

Mexico City has for years experienced high levels of ozone and particulate air pollution. From 1995 to 1999 the entire population of the MCMA was exposed to annual average concentrations of fine particulate pollution (particulates with a diameter of less than 10 micrometers, or PM_{10}) exceeding 50 micrograms per cubic meter, the annual average standard in both Mexico and the United States. Two million people were exposed to annual average PM_{10} levels of more than 75 micrograms per cubic meter. The daily maximum one-hour ozone standard was exceeded at least 300 days per year.

In 2001, as part of these efforts the World Bank supported a study on the economic benefits of reducing pollution in the MCMA (World Bank 2002b). The main economic rationale for controlling emissions was defined as the welfare gain from improvements in air quality. This study focused on the two most important economic impacts of air pollution: health impacts and restrictions imposed on economic activities through environmental contingencies.

The health hazards associated with ozone and PM_{10} were studied because these substances are the most important in terms of violating pollution standards.

During 1995–1999, the highest concentration observed for ozone—0.349 ppm—was measured at the Pedegral station in the southwest zone of the MCMA. The Chapingo station in the northeastern zone was the least polluted, with a daily 1-hour maximum concentration of 0.210 ppm. The daily average air quality standard for PM_{10} is 150 µg/m^3 and the annual average standard is 50 µg/m^3. All stations violated both standards with the exception of the annual average standard at the Pedregal and Coacalco stations. The highest concentrations were in the east of the MCMA with a daily maximum of 335 µg/m^3 at the Netzahualcóyotl station. The highest annual average of 94 µg/m^3 was observed at the Xalostoc station. In 1995, over 1.2 million people were exposed to concentrations above the environmental contingency Stage I level of 300 µg/m^3 at least once during the year.

The baseline scenario for 2010 assumes emissions of NOx and VOCs, precursors of ozone and PM_{10}, to be the same as at the end of the 1990s. Likewise, the study assumes air quality in 2010 with respect to ozone and PM_{10} to be the same as the levels observed at the end of the 1990s. This assumption, however crude, seemed the most appropriate one in the absence of an integrated model of emission projections for 2010 for fixed and mobile sources in Mexico City. Four alternative air pollution reduction scenarios for 2010 are evaluated. The study did not appraise the policies needed to achieve concentration reductions. The four scenarios are listed below (population-weighted exposure reductions are presented in Table 9):

- a 10-percent reduction in PM_{10} and ozone;
- a 20-percent reduction in PM_{10} and ozone;
- improved air quality compliance at an air quality standard of 50 µg/m^3 for PM_{10} and 0.11 ppm 1-hour maximum for ozone in all MCMA locations (AQS1);
- an air quality standard superimposing the required decrease in concentrations in the most polluted areas (Xalostoc for PM_{10} and Pedregal for ozone) across the MCMA (68 and 47 percent reduction in ozone and PM_{10} concentrations, respectively) (AQS2).

Table 9. Reduction in population-weighted exposure for the analyzed scenarios

Scenario	**Population-weighted exposure to PM_{10} (µg/m^3/person)**	**Population-weighted exposure to ozone (ppm/person)**
10-percent exposure reduction	6.41	0.0114
20-percent exposure reduction	12.81	0.0227
AQS compliance in each area–AQS1	14.06	0.0702
AQS compliance in worst area–AQS2	29.99	0.0778

The health risks due to air pollution (specifically ozone and PM_{10}) are quantified by estimating the linkage between adverse health effects and air quality. To this end, a number of quantitative estimates of exposure-response relations of known health effects from various cities have been pooled together (meta-analysis). Health impacts include eye irritation, respiratory diseases, cardiovascular effects, and premature death. This analysis assesses a wide range of the health benefits of reducing air pollution:

(i) reduced cost of illness (COI);
(ii) reduced losses in productivity;
(iii) willingness to pay (WTP) for reduced acute and chronic morbidity effects; and
(iv) WTP for mortality effects associated with acute and chronic exposure. In each case the WTP concept captures aspects of the value of avoiding death and illness (for example, the pain and suffering avoided) above and beyond foregone earnings and COI (used here to refer to avoided medical costs).

The largest single contributor to the benefit estimate is WTP for premature death. Because of the debate over using WTP for valuing health benefits, in particular when WTP is estimated using the Contingent Valuation Method (CVM), the study computes the health benefits both including and excluding this benefit category. Specifically, the study presents three sets of benefit estimates. The "high estimate" includes WTP to avoid illness, as well as avoided illness costs (COI) and reduced losses in productivity to value reduced morbidity. Avoided premature mortality is valued using WTP.

The "central estimate" includes the same comprehensive measure of the value of reduced morbidity, but values avoided premature mortality using foregone earnings, a lower bound to WTP. The "low estimate" values morbidity, using COI and productivity measures alone and premature mortality using foregone earnings. The high and central estimates vary depending on the income elasticity used to transfer WTP estimates for morbidity and mortality from other countries to Mexico. Income elasticities of 1.0 and 0.4 are presented; however, the study views the 1.0 elasticity as its central estimate. Table 10 summarizes the benefits of each control scenario, where results for ozone and PM_{10} are added together. The central estimate of the annual benefits of a 10-percent reduction in ozone and PM_{10} is US$759 million.

High and low estimates of the value of a 10-percent reduction are US$1.6 billion and US$154 million, respectively. Obtaining air quality compliance (AQS1) offers benefits of approximately US$2 billion per year, with high and low estimates of benefits of some US$4 billion and US$400 million, respectively.

The estimates presented in Table 10 clearly show that the calculated benefits associated with air pollution reduction provide a strong basis and economic rationale to justify expenditures to further reduce polluting emissions. The exact amount is open to debate. Ideally, such a study on economic benefits should be combined with estimates of emission abatement costs to determine an economically justifiable level of abatement (World Bank 2002b). Thus, the next logical step is to develop a cost-benefit model.

Table 10: Summary of benefits from each scenario for ozone and PM_{10} combined (in US$ million per year, 2010 values in 1999 prices, income elasticity 1.0)

Estimates	10%	20%	AQS1	AQS2
High	1607	3184	3952	7636
Medium	759	1489	1928	3580
Low	154	275	368	618

Source: World Bank 2002b

Table 11 presents alternate estimates of health benefits, as well benefits from avoiding environmental contingencies, for ozone and PM_{10} separately. This is particularly useful because it shows that the health benefits of PM_{10} reductions are roughly an order of magnitude higher than those of ozone.

Table 11: Benefits from reducing air pollution—Four scenarios for ozone and PM_{10} (in US$ million per year, 2010 value in 1999 prices, 3% discount rate)

	Scenario							
	10%		20%		AQS1		AQS2	
Income elasticity	**1.0**	**0.4**	**1.0**	**0.4**	**1.0**	**0.4**	**1.0**	**0.4**
Ozone								
Health benefit estimate 1, including morbidity (Prod. Loss + COI + WTP) and WTP for mortality	116	183	232	365	717	1129	794	1250
Health benefit estimate 2, including morbidity (Prod. Loss + COI + WTP) and human capital losses for mortality	75	114	151	228	465	706	515	782
Health benefit estimate 3, including morbidity (Prod. Loss + COI) and human capital losses for mortality	18	18	35	35	109	109	121	121
Environmental contingencies benefits	36	36	45	45	45	45	45	45
PM_{10}								
Health benefit estimate 1, including[1] morbidity (Prod. Loss + COI + WTP) and WTP for mortality	1451	2549	2903	5098	3186	5595	6793	11931
Health benefit estimate 2, including: morbidity (Prod. Loss + COI + WTP) and human capital losses for mortality	644	1184	1289	2367	1414	2598	3016	5540
Health benefit estimate 3, including: morbidity (Prod. loss + COI) and human capital losses for mortality	96	96	191	191	210	210	448	448
Environmental contingencies benefits	4	4	4	4	4	4	4	4
Prod. Loss = Productivity Losses; COI = Direct Cost of Illness; WTP = Willingness to Pay.								

Source: World Bank 2002b

Harmonization of climate and air quality issues

Measures to improve air quality and reduce greenhouse gas emissions have many commonalities. Local criteria pollutants involved in the generation of ozone, such as volatile organic compounds and nitrous oxide, are normally associated with combustion of fossil fuels, which also originate GHG. Thus, addressing one issue frequently results in improvements in the other, or in the attainment of co-benefits.

The objective of the studies on specific measures to control air pollution and mitigate climate change was to identify opportunities for harmonization of local/global air initiatives, and to propose pilot projects[2] that could be used to illustrate a common strategy. Assessments were made by roughly following simple general steps:

a) definition of the project and its costs (harmonization opportunity) and identification of the associated baseline costs ("business-as-usual scenario");
b) calculation of incremental cost, resulting from the difference in costs between the project scenario and baseline scenario;
c) estimation of the emissions of local criteria airborne pollutants and greenhouse gas emissions associated both with the project and baseline scenarios.

Table 12 summarizes the harmonization measures identified. The analysis found that the transport sector is the largest user of energy in the MCMA and is linked to the largest release of CO and NOx, to important emissions of PM_{10} and HC (as documented in the emission inventory) and to GHG emissions, as shown in the previous section. From an energy-efficiency point of view (joules/passenger-km traveled), increased use of the mass transport sector (Metro system and surface rail) offers a key option for improvements and results in the highest reduction in emissions of both pollutants. The development of bus rapid transit systems was also identified as a measure to reduce the carbon footprint of the transport sector in the city and reduce exposure to air toxics.

Key findings:

- A regional energy balance for the MCMA has been completed. It was found that the annual energy supply to the metropolitan area in 1998 was equivalent to 648 petajoules (PJ) and that it consumes 592 PJ. The consumption is equivalent to about 9 percent of the nation's energy consumption.

A regional greenhouse gas inventory has been completed. It was found that in 1998, anthropogenic activities in the MCMA released about 45 million tons of CO_2 equivalent or about 10 percent of national emissions. The amount for 2006 was later estimated at 53 million tons of CO_2 equivalent.

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[2] With the exception of the more general study on options to reduce NO_x emissions at local power plants.

- Overall energy intensity in the metropolitan area, measured in terms of unit of energy/US$ of regional GNP, has declined by 26 percent over the 1990–1999 period. The transport sector appears to have increased its energy intensity per passenger-km over the period.

- From a desk review of previous experiences, hybrid buses (diesel-electric) were found to be an alternative with lower overall greenhouse gas emissions (kg of CO_2 emitted per km) than diesel and CNG vehicles had lower overall emissions of local criteria pollutants (PM and VOCs). Field tests and additional field experience were recommended to confirm these gains.

- The development of transport corridors (BRTs) has the potential to simultaneously contribute to the reduction of local criteria pollutants and greenhouse gases. However, the BRTs cannot be seen as the only solution and cannot be developed in isolation from the existing modes of transport, in particular the Metro. The impacts on congestion and quality of transport by BRTs will be maximized, provided these are developed in concert and in coordination with the existing mass transport infrastructure. Metro systems have a longer life and eliminate traffic congestion.

- A program for the adoption of energy-efficient measures in a sample of large buildings (such as improvements in illumination, air conditioning, heating, and thermal insulation) has been assessed. This assessment concluded that compared to a baseline of no program, the measures are, on the aggregate, associated with negative incremental costs of abatement. Actions to remove barriers to the implementation of this program are recommended.

- An assessment of a pilot program for the use of solar energy, displacing LPG, in water heating in the domestic sector has concluded that this program's implementation, compared with the business-as-usual scenario, is associated with negative incremental costs of US$164/ton of CO_2 equivalent and negative costs of US$205/ton of NOx equivalent. An initiative to remove barriers to the implementation of this program is recommended.

- A number of options to reduce emissions from power plants in the metropolitan area have been identified but require additional assessment before a course of action can be recommended.

Table 12. Some measures with potential to improve air quality and reduce greenhouse gas emissions

Measure	Local Air Quality Issue	Global Climate Change Linkage
Introduction of hybrid buses	Transport sector is largest user of combustion fuels and is linked to large emissions of NOx, VOCs, CO, and PMs; advanced bus technologies combined with efforts to promote modal shift can reduce volume of emissions of NOx, and PMs per passenger-km traveled.	Hybrid engines increase fuel efficiency and therefore reduce emissions of CO_2 per unit of work delivered.
Bus Rapid	Reduction of congestion, increased capacity of	Reduced congestion and increased

Measure	Local Air Quality Issue	Global Climate Change Linkage
Transit Corridors	transport over modified infrastructure, leading to reduced emissions of local criteria pollutants.	capacity result in lowering of GHG emissions per passenger-km.
Energy efficiency in buildings	Improvements in electricity use in the MCMA will reduce need for power generation, which itself is linked to various emissions of local criteria pollutants.[3] Public buildings offer a homogeneous target, facilitating replication.	Improvements in energy use lead to reduction of emissions of CO_2 and of local criteria pollutants from thermal power generation.
Solar-based water heating systems for households	Water heating primarily uses LPG in the MCMA. The concentration of LPG components (low molecular weight hydrocarbons) is high in the local airshed and contributes to the generation of ozone. Solar energy could replace some of the LPG and reduce its associated VOC load into the atmosphere.	Use of solar energy would replace LPG, diesel, and fuel oil and therefore reduce the generation of associated CO_2.
Reducing LPG leaks and efficiency in household installations	Reduction of fugitive emissions and leaks would complement the solar water heating initiative through improvements in the efficiency of LPG use.	Combustion of LPG at pilot burners contributes to CO_2 emissions. Although the radiative potential of VOCs has not yet been determined, it is known that these compounds contribute to global warming.
Reduction of emissions at regional power plants	Power plants in the region account for about 12% of NOx emissions.	Efficient fuel use will result in reduction of CO_2 emissions. Reduction in ozone precursors may reduce generation of tropospheric ozone.

Air quality modeling

To estimate the environmental costs/benefits of mitigation strategies, it is necessary to have quantitative information on air pollutant concentrations, especially on ozone and PM_{10}, which frequently exceed their pollution standards in the Mexico City Metropolitan Area (MCMA). This information can be obtained by using numerical models that are able to simulate the transport, dispersion, and chemical transformation of pollutants in complex terrain. Given the geographical and air quality situation in the MCMA, CAM and the World Bank agreed to cooperate on the use of the Multiscale Climate Chemistry Model (MCCM)[4] developed by the Fraunhofer Institute for Atmospheric Environmental Research (IFU) in Garmisch-Partenkirchen, Germany, as an instrument for identifying and simulating scenarios on air quality in the Mexico City Metropolitan Area. MCCM

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[3] Some of these emissions will not accrue in the MCMA because the power grid draws power from outside the region.

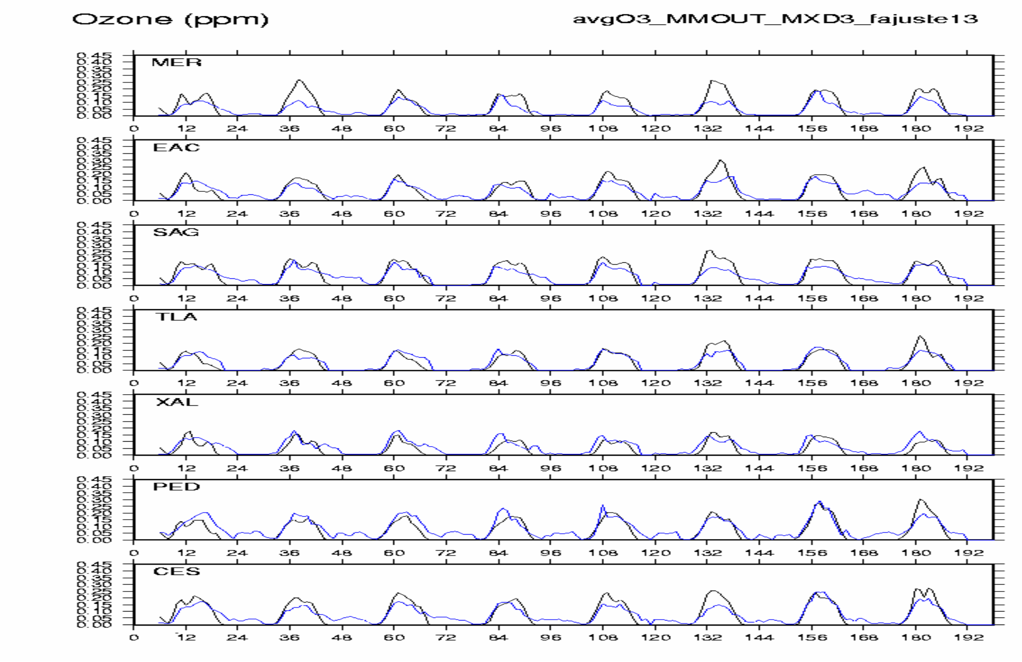
[4] MCCM is based on the Fifth-Generation NCAR/Penn State Mesoscale Model, MM5. MM5 already includes a multiple-nesting capability, nonhydrostatic dynamics, and a four-dimensional data assimilation (FDDA) capability as well as many other options for modeling microphysical processes. Additionally, two separate detailed gas-phase chemistry mechanisms (RADM2 and RACM) with 39 and 47 chemical species, respectively, and particulate matter (PM_{10}) as a passive tracer are included. Both mechanisms are well tested and can be applied over a wide range of reactant concentrations. In association with the gas phase chemistry submodels, 22 photolysis frequencies are computed depending on cloud cover, ozone, temperature, and pressure in the model atmosphere.

was used to simulate the spatial and temporal concentration patterns of ozone and PM_{10} in the MCMA (IFU 2002).

In order to validate the modeling tool, CAM selected a meteorological episode of nine days with relatively high ozone and PM_{10} concentrations to simulate the baseline case and the scenarios. The episode considered began on May 3, 1998, 6 h Mexican winter time (12 h GMT) and ended on May 11, 6 h Mexican winter time, totaling 192 hours. These data were also the basis for the model test runs with four-dimensional data assimilation (FDDA).

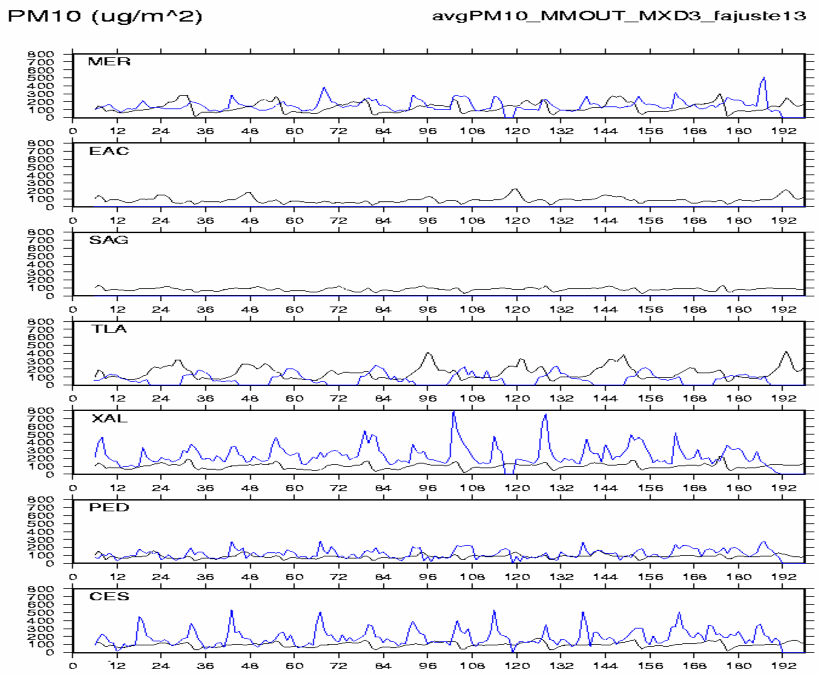
The results of a model based on a grid structure such as MCCM always give average values over a grid box (dimensions of case 2000 m x 2000 m x 15 m for the lowest box), whereas the observations represent values obtained at the observation point. The figure below shows a comparison between simulated and observed ozone concentrations at various observation sites. The agreement is generally good in the temporal behavior as well as in magnitude, although calculated ozone concentrations tend to be somewhat higher than observed ones.

Figure 11. Observed and modeled ozone concentrations in Mexico City at 7 locations



The figure below shows the results for PM_{10} simulations. Except for the TLA site, the simulated values are significantly lower than the observed ones. The most pronounced difference occurs at the XAL site, where the observed value exceeds the simulated value by a factor of about 2.5. The site description mentions that in the neighborhood of this site, there are unpaved roads whose dust emissions may be a reason for the high PM_{10} concentrations observed. Therefore, an obvious conclusion is that there are PM_{10} sources not accounted for in the emission data, such as dust from roads, from agricultural activities, and from wind erosion. These sources are difficult to quantify, but attempts should be made in order to improve the predicted PM_{10} concentrations (IFU 2002).

Figure 12. Observed and modeled PM_{10} concentrations in Mexico City at 7 locations

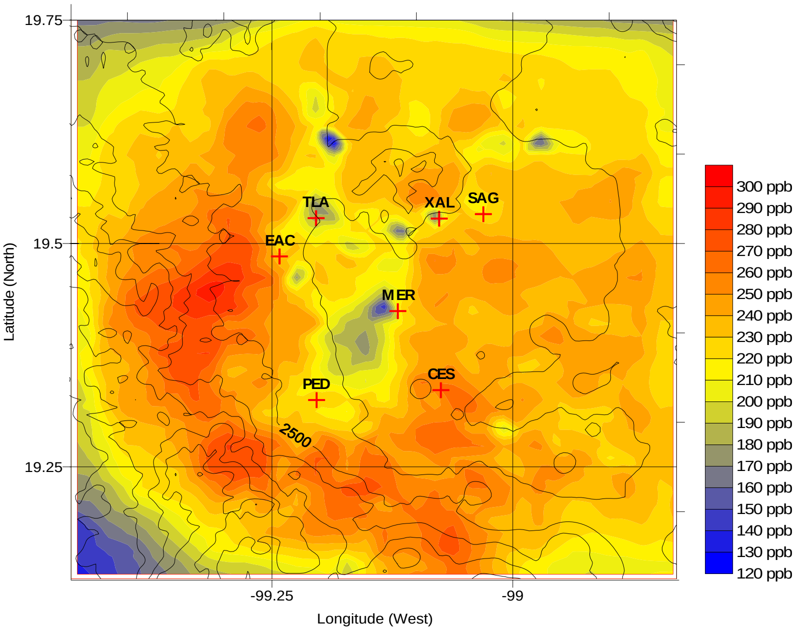


Secondary aerosols (sulfate) were accounted for in the simulations and are included in the concentrations shown. However, the main contribution to the total PM_{10} concentration comes primarily from emitted aerosols. Simulations for ozone and PM_{10} concentrations were made, successfully representing actual observations over the MCMA.

Once validated, the model was used to estimate future concentrations of criteria pollutants by 2010 if no actions to abate airborne pollutants were undertaken. This would serve as a baseline for estimating benefits from individual measures. These emissions were then distributed over the grid cells of the model. The information on the emissions was provided as emission reductions relative to the baseline case.

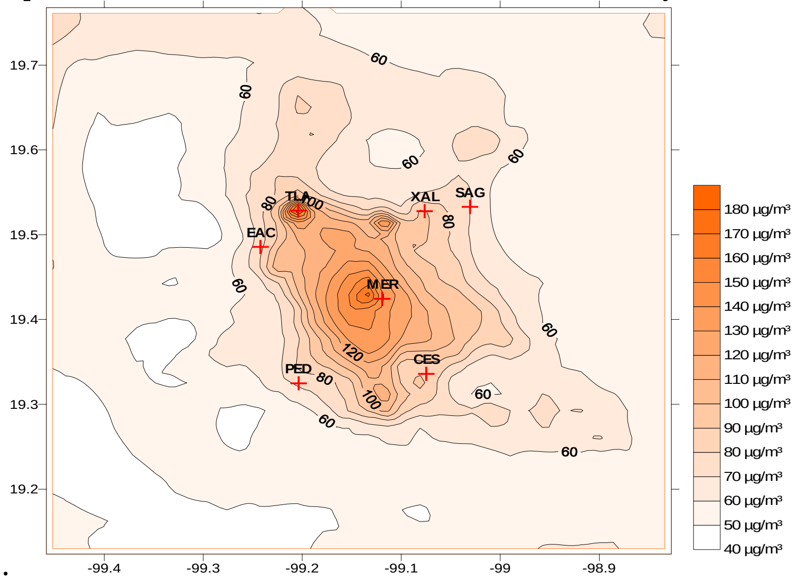
Figure 13 shows the estimated average daily maximum ozone concentration for the baseline 2010 case. Figure 14 shows the corresponding concentrations for PM_{10}. The future predicted through the modeling provided the elements of a baseline of concentration that could be used to estimate the relative impact of measures taken to reduce airborne pollutants.

Figure 13. Episode average daily maximum ozone concentration for the baseline 2010 case. For orientation, contour lines of orographic height are shown and the positions of some RAMA observation sites are marked by crosses.



Source: IFU 2002

Figure 14. Episode average PM_{10} concentration for the baseline 2010 case. For orientation, the positions of some RAMA observation sites are marked by crosses.



Source: IFU 2002

The results obtained support the inclusion of the MCCM as a tool to aid in the modeling of air quality and the estimate of exposures, which can be used to assess the benefits and costs of alternative abatement measures.

The Internalization of Climate Issues. Mexico: Introduction of Climate-friendly Measures in Transport (P059161)

Based on the studies undertaken as part of the AQM-III, in 2002 the Ministry of Environment of Mexico City, together with the World Bank, began to develop a comprehensive strategy for addressing greenhouse gas emissions in the city on the basis of a harmonization effort that could also result in reduction of local pollutants. This was the result of increasing awareness of transport and climate issues as well as of the priority measures identified under the AQM-III and the 2002–2006 transport plan. The result was one of the first transport and climate projects financed under the GEF (the first under the operational program for transport, OP-11).[5]

The project's objective was to promote the development of an enabling environment for the internalization of climate issues in the transport sector. In October 2002 the GEF approved a US$5.8 million grant in support of the Introduction of Climate-Friendly Measures in Transport Project. The GEF grant is being implemented by the Ministry of Environment in close coordination with the STE (Servicios de Transportes Eléctricos) for an original implementation period of five years; it is now expected to close by June 2009. Cofinanciers included the World Resources Institute, Shell Foundation, bus manufacturers, and fuel suppliers.

The project focused on the development of policies and measures that would assist in a long-term modal shift toward more efficient, less polluting, and less carbon-intensive transport in the Mexico City Metropolitan Area (MCMA). These policies and measures were consistent with the GEF Operational Program on Sustainable Transport (OP-11) and the AQM-III.

Promotion of a modal shift is a central part of the government's strategy. The key measure under consideration was the development of transport corridors on which high-capacity, low-polluting vehicles would operate. These corridors were conceived as measures that would make more efficient use of infrastructure, move passengers in an integrated manner with the Metro at higher speeds, lower costs per passenger, and lower emissions per passenger-kilometer, and at the same time alleviate traffic congestion. The modal shift was expected to contribute to a reduction in the emission of greenhouse gases per passenger-kilometer.

A key element in the promotion of the modal shift is the use of low-emission, low-carbon-emitting vehicles. This is being achieved by attracting ridership to the Metro and

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[5] GEF Operational Policy 11 (OP11) was established to finance climate-change activities in the transport sector. The project, Mexico: Introduction of Climate-Friendly Measures in Transport, was the first operation to be financed through the OP.

the light rail line, and by plans for the introduction of novel bus technologies. New-technology buses may also be specified for the busway corridors, but first there is a need to obtain solid information on which to base the decision.

The project has financed the following activities: (a) the harmonization of sectoral plans merged into a local climate action strategy; (b) the support of a regulatory and business environment that would enable the development of transport corridors (bus rapid transit systems); and (c) a field test of alternative bus technologies.

In parallel, the World Bank provided two grants (through its Policy and Human Resources Development Fund (PHRD) and the German Trust Fund) in support of the preparation of this project. These grants were coordinated by the SMA and the Federal District Government's Secretariat of Transportation and Roads. Its main objectives were to:

(a) define the strategic public transportation corridors that were most viable in the MCMA, providing financing for the basic design of the first corridor to be implemented (Insurgentes Avenue), including an assessment of environmental and social impacts; and
(b) strengthen institutional capacity for carrying out these projects as well as for strengthening the management of the financial schemes that will enable the implementation of projects included in PROAIRE 2002–2010.

Harmonization of sectoral strategies on air quality issues and Integrated Climate Action Plan for Transport for Mexico City.

Although metropolitan authorities had adopted comprehensive sectoral policies that already identified priority areas in transport, air quality, and urban development, there was a need to harmonize the different programs on transport, air quality, and land-use issues. Moreover, although awareness and activism in international forums have increased, climate-change issues had not been fully integrated into sectoral planning and decision making. Successful incorporation of climate-friendly policies and measures was judged dependent on the extent to which sectoral planning recognizes the harmonization potential between climate change and sector policies, and on the realization of local co-benefits from actions on climate-change concerns.

In response to these issues the first component of the GEF project supported the harmonization of sectoral strategies on air-quality issues under an integrated strategy.

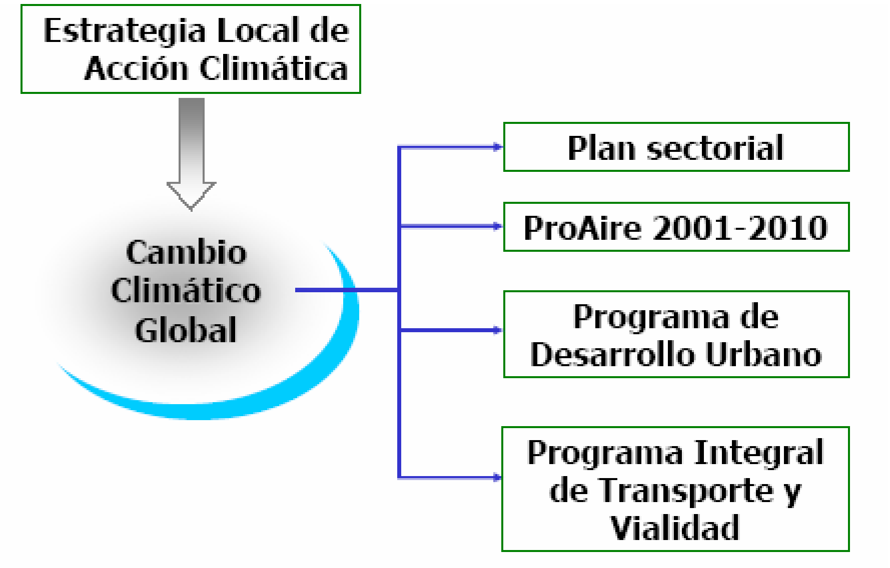
Mexico City's Strategy on Climate Change

The first citywide Climate-Change Action Strategy in Latin America, with goals, timetable, programs identified, and budget requirements, was completed and published in 2006 (SMA 2006). It reflects a commitment by the Mexico City Government to reduce greenhouse gas emissions, in synergy with the local policies for reduction of local criteria pollutants, in the context of the UNFCCC's goals.

This initiative concentrates various actions of the 2002–2006 Program of Environmental Protection for Mexico City implemented by the *Secretaría del Medio Ambiente* (Secretariat of Environment), particularly for the 2002–2010 Program of Air Quality Improvement for the Metropolitan Area of the Valley of Mexico (PROAIRE) and for the Program of Ecological Restoration of Conservation Land in Mexico City.

The City Climate-Change Strategy represents a policy commitment to reduce GHG emissions in synergy with policies designed to reduce local airborne pollution, within the context of the UNFCCC and the Kyoto Protocol. The central tenet of the strategy is to seek reductions of GHG emissions through the implementation of measures designed to make better use of natural resources, the regulation and efficient use of installed equipment, fuel substitution, and the use of new technologies and alternative sources of energy. The strategy also seeks an increase in GHG sinks in the city through an ambitious reforestation program and better land-use planning. Figure 15 below illustrates the relationship between the strategy and sectoral development plans.

Figure 15. The local climate change strategy and the sector development plans



Source: SMA 2006

In addition, the strategy also includes an assessment of vulnerability to the anticipated impacts of climate change and actions to reduce vulnerability, through the adoption of preventive measures.

The Government of Mexico identified several options in its local climate-change strategy in order to mitigate greenhouse gases from the transport sector. These options include:

(i) the introduction of transport corridors, the regulation of public transport timetables, the design of direct or express routes, and the promotion of cycle lanes. Among new measures to organize traffic, the government identified the broadening and improvement of streets, the improvement of the public transport network including exclusive bus lanes, the regulation of microbuses and taxis, and the extension of the Metro network. The aim of these measures is to transport a high number of passengers with the lowest possible fuel consumption. Other measures include controlling of the number of circulating vehicles, and organizing taxis.

(ii) the use of fossil fuels with low carbon content such as compressed natural gas; the use of renewable fuels including biodiesel;
(iii) the introduction of climate-friendly technologies such as hybrid, fuel cell, and electric vehicles, and the renovation of the public transport fleet; and
(iv) the establishment of norms that allow emissions to be controlled.

The strategy provides a blueprint for future action and is now central to discussions on implementing broad-based actions to reduce the city's carbon footprint.

Development of a policy and institutional framework for the implementation of a Rapid Bus Transit System in Mexico City

The traditional business structure of bus services in the MCMA had led to highly inefficient operations, resulting in a costly, unsafe, and environmentally unsustainable public transport system. The key issues were:

(a) lack of an organizational model that would facilitate efficient public transport operation in the metropolitan area;
(b) dispersed operations that hinder the effective control of bus services and contribute to traffic congestion;
(c) inefficient use of vehicles;
(d) deficiencies in bus inspection and maintenance;
(e) lack of professional management among bus operators;
(f) lack of coordination between transport operations in the State of Mexico and the City;
(g) a fare system that penalizes transfers and thus discourages intermodal movements; and
(h) a systematic decline in the number of Metro passengers since 1989 despite a 35 percent network extension during that period. These barriers are significant and require substantial efforts at the policy and regulatory levels.

Under the second component of the GEF project, an enabling environment to facilitate the implementation of sustainable surface transport strategies was defined. In order to achieve the enabling environment, the project supported:

(a) a review of management and business organization measures required to promote the adoption, design, and use of corridor infrastructure, including a system of business organization, concessions for specific bus line operations, and structuring of integrated fares;

(b) technical assistance to identify, improve, and facilitate the adoption of economic incentives and regulatory system reforms required to overcome barriers to the adoption of high-capacity and nonmotorized transport;
(c) the reform of public transport regulations for the proposed corridors;
(d) the definition of an institutional framework for the corridors including integration with the Metro;
(e) identification of measures to promote Metro ridership;
(f) an assessment of organizational measures proposed by the Mexico City authorities to improve air quality and public transport efficiency; and
(g) an action plan for nonmotorized transport (promotion of bicycle use).

Regulatory and institutional reform for BRTs

The efforts brought together through the GEF-funded project were instrumental in causing reforms to the policy, institutional, and regulatory framework for the transport sector in the city. A summary of these reforms is presented in Table 13. The core of the reforms was enabled by the program to develop the Bus Rapid Transit System. These included the necessary institutional, business management, and regulatory improvements required to operate the proposed corridors.

Specifically, the support provided led to the creation of METROBUS, a decentralized public entity with independent legal status and independent management, under the Secretariat of Transport. METROBUS's primary focus is the management and planning of the corridor program. It also monitors the program's performance and assists in replicating the experience. METROBUS supervises the fare collection and prepayment system. It contracted a specialized company to provide, install, and maintain the necessary payment collection system. The city committed to the adoption of a reform program, summarized below:

Table 13. Policy, institutional, and regulatory framework reforms caused by the Transport Corridors Program

	Baseline	**Reform caused**
Policy		
Overall transport plan	No inclusion of transport corridors or modal shift measures.	Transport corridors were made part of the AQM and transport plans, and were acknowledged as a modal shift measure.
Institutional		
	No entity responsible for transport corridors.	Creation of METROBUS as a dedicated, independently managed institution for management, monitoring, and planning of transport corridors.
	Bus operators along Insurgentes Corridor based on individual, disorganized, small-scale operators.	Creation of CISA, a commercial operator; financially sound, small-scale operators form a single company.

Business environment		
	Fare structure does not meet efficiency criteria and discourages intermodal transfers.	An integrated fare has been developed, corresponding to actual fare. No subsidies are implied. Efficiency gains through the corridor program allowed the fare to be kept at current levels.
	Poor application of regulations	METROBUS will monitor and manage the corridor. SETRAVI has frozen licenses for new microbuses.
Environmental and social impacts		
	Current structure of bus operations is polluting.	First transport corridor realizes modal shift (toward modern bus technologies), thereby reducing global and local pollutants.
	Bus operators on Insurgentes work under difficult conditions.	Working conditions for bus operators improve considerably in terms of time (1 working shift per day [12–14 hours] replaced by 1 [8-hour] shift) and safety.

The operation of the corridor includes the following elements, which were developed taking into account the experience with Transmilenio:

(a) one entity in charge of administration, planning, and verification (METROBUS);
(b) two corridor operating companies (RTP and CISA) over Insurgentes Avenue under a well-defined regulatory and management structure, representing a significant departure from the chaos of a multiple small companies working under a loose regulatory structure;
(c) physical infrastructure for bus transport;
(d) a modern fare collection system; and
(e) a private trust fund for revenue administration.

Field test of advanced bus technologies

Although there was information on alternative bus technologies and a growing amount of data on field tests of new types of vehicles (most notably in New York, Toronto, and São Paulo), information on operation under real conditions at Mexico City's altitude was not available. Running a field test in Mexico City was considered timely and complementary to existing information on the basis of:

(a) the magnitude of the air quality problem;
(b) the recently completed comprehensive Third Air Quality Management Plan;
(c) the availability of a modeling tool, focused on the characteristics of the metropolitan area to simulate and evaluate impacts of the proposed measures;
(d) the presence of bus manufacturers; and
(e) available data on local and greenhouse gas emissions (inventories) that provide the current baseline.

In particular, the test results were expected to benefit from the availability of the Multiscale Climate and Chemistry Model, adopted by the metropolitan authorities to simulate the impact on air quality and human exposure to specific air quality measures, developed during the formulation of the air quality management plan. The field test yields data on emissions information for the different types of buses and also provides data on bus operation and maintenance. This would complement and validate information already available (Table 14).

Table 14. Alternative bus technologies

Technology-Based Strategy	**Capital Cost**	**Total Cost**	**% CO_2 Equivalent Reduction**	**Cost ($/ton) of Carbon Equivalent Reductions**	**Reduction of local criteria pollutants**
LPG Vehicles	Low	Minimal to negative due to lower fuel cost	~ At least 15% for gasoline and diesel replacement	Minimal to negative for diesel and gasoline	None
Natural Gas Vehicles	Conversion: $1500 to $4000; New: 20–40% higher than diesel buses	Minimal to negative due to lower fuel cost (gasoline); high for diesel	~15%–20% for gasoline replacement; ~0 for diesel replacement	Minimal to negative for gasoline; high for diesel	Elimination of PM, and reduction of VOCs
Hybrid Diesel-Electric Vehicles	~50%–150% higher than diesel at low volumes; may be lower once large commercial production is achieved	Operating costs should be lower, total costs may be comparable to diesel	At least 15%; potentially higher (30%) depending on driving cycles	Good at present to potentially very good	Reduction reflecting increase in fuel efficiency
Hybrid CNG-Electric Vehicles	Uncertain; could be in the range of Hybrid Diesel-Electric	Operating costs should be lower, total costs may be comparable to diesel	Marginal	Minimal relative to diesel and gasoline	Elimination of PM and reduction of VOCs
Fuel Cells	300% or more than diesel	High	Modest at present; could exceed 70–80% in future	Modest at present to very good in future	High

Sources: STAPPA/ALAPCO 1999 and own data.

The project supported the comparative pilot field test for alternative drives (standard, series and parallel drives) and fuels (standard diesel, low sulfur diesel, and CNG) to test the comparative and absolute technical, economic, and environmental viability and climate advantages under typical operations in the MCMA. The testing vehicles were operated on a route that was chosen to represent the average conditions of the metropolitan area in terms of supply, demand, physical and topographic characteristics, and service providers. The buses operated under normal conditions, and their emissions were regularly measured under a scientifically designed and statistically representative test protocol (this protocol, including sample size, was designed during project preparation by STE with assistance from MIT, West Virginia University, the University of Toronto, and the Institute for Transportation Studies at the University of Berkeley).

The field test consisted of real-time measurement of the following parameters: (a) emissions (local and global) resulting from current and anticipated driving cycles; (b) real operating costs; (c) fuel efficiency per type of vehicles, and other indicators of sustainable transport with assistance from an ad hoc high-level steering committee with significant experience from institutions such as MIT. The test was aimed at:

(a) developing a scientific test protocol adapted to Mexico City's conditions that can produce significant data on emission reductions, fuel efficiency, and indicators of operating and maintenance costs;
(b) using the results of the pilot test to simulate the level of reductions in local and global pollutants that could be obtained by assuming various scenarios of adoption of these technologies; and
(c) enabling cost effectiveness and possibly cost-benefit analyses to determine the extent or rate to which the adoption of these technologies is justified compared to other air quality measures. The test was linked to other components in that it complements regulatory and institutional activities that would enable the development of corridors with the examination of alternative buses to be used in the corridors, to reduce GHG emissions in the transport system. A part of the field test this component also included the provision of an essential framework for evaluation of alternative vehicle options.

To perform the environmental evaluation, two methods to measure the emission of pollutants for the available buses were selected. One method uses a chassis dynamometer; this method is widely established in various countries for engine certification and is a basis for generating emission regulations. Because Mexico has no dynamometers for heavy vehicles, the tests were done using the West Virginia University (WVU) portable chassis dynamometer. The dynamometer was used on two driving cycles designed to replicate a typical urban area in Europe and Mexico City. The other method consists of using an on-line measurement of exhaust gases. Specifically, the Ride-Along Vehicle Emission Measurement (RAVEM) system developed and built by Engine, Fuel & Emissions Engineering (EF&EE) was selected.

The tests were performed on two types of **vehicle fleet**s. The first, consisting of vehicles that presently circulate in the MCMA, were evaluated to serve as a baseline and designated as “reference vehicles.” The second fleet consisted of test vehicles that may possibly be introduced to operate in the new Strategic Transportation Corridors system. These represent the “test vehicles.”

Table 15. Fleet of reference vehicles used in the field test

Vehicle	Type of Fuel	Number
Diesel-run Bus	350 ppm sulfur diesel azure	2
Diesel-run Bus	50 ppm sulfur diesel	1
Diesel-run Bus with Emission Control	50 ppm sulfur diesel	1
CNG-run Microbus	CNG	1
LPG-run Microbus	LPG	1
Gasoline-run Microbus	Gasoline	1
Dual-run Microbus	Gasoline/CNG	1
Total		**8**

The tests were performed on buses with alternate fuels (hybrids and Compressed Natural Gas), on modern diesel-run vehicles, and on normal diesel-run vehicles, to measure technical, economic, and environmental advantages while operating under MCMA conditions.

In all, 14 buses were evaluated, including the 3 models of articulated buses that belong to METROBUS. The vehicles were operated under normal conditions in Mexico City during the time that they remained in the country. The buses were made available through the cooperation and financial commitment of bus manufacturers and fuel suppliers, including the manufacturers of hybrid bus technologies (both series and parallel drive) and CNG (articulated and standard) buses.

Figure 16. Parallel and series drive hybrid buses participating in the field test (Allison and Eletrabus)

It was decided that articulated vehicles would use 50 ppm diesel on a daily basis during the test, because such large vehicles using this type of fuel are a viable option in the short and medium terms for introduction to the corridor system. Other diesels used had 15 ppm and 350 ppm of sulfur.

Table 16. Fleet of test vehicles

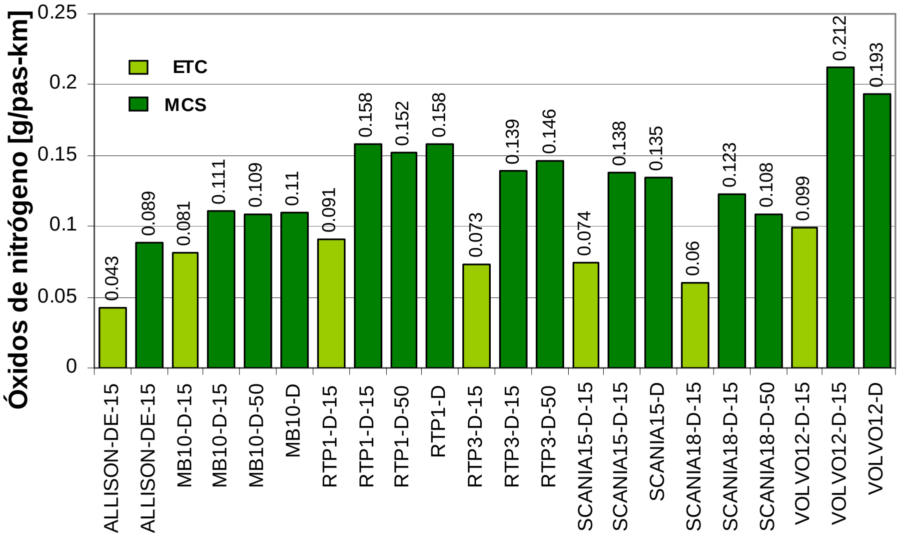
Technology	Make	Length (m)	Certification	Fuel	Number
Diesel	Mercedes	12.6	EPA 98	D 50 ppm S	1
	Mercedes	11.4	EPA 98	D 15 ppm S	1
	Mercedes	10	EPA 2004	D 15 ppm S	1
	Scania	15	EURO III	D 15 ppm S	1
	Scania	18	EURO III	D 50 ppm S	1
	Volvo	12	EURO III	D 15 ppm S	1
CNG	Ankai	11.2	EPA 2004	CNG	1
	Faw	16	EPA 2004	CNG	1
	Busscar	11.2	EPA 2004	CNG	1
Hybrid	Allison	12	EPA 2004	D 15 ppm S	1
	Electrabus	12	EURO II	D 15 ppm S	1
Metrobús	Volvo	18	EURO III	D 350 ppm S	1
	Scania	18	EURO III	D 350 ppm S	1
	Fénix	18	No control	D 350 ppm S	1

Test results

The dynamometer and online tests were conducted during 2005 and 2006 at the installations of the STE and over the actual Insurgentes Avenue, prior to construction of the Bus Rapid Transit System. The dynamometer test results are summarized below for nitrogen oxides, particulates, and CO_2 for the diesel vehicle fleet and the parallel drive hybrid vehicle. Because the test fleet consisted of only a few vehicles per type and in many cases for advanced technologies a single vehicle was tested, caution should be exercised in extrapolating the information obtained.

The results have been reported and published (West Viriginia University 2005; SMA 2006). The test results for the dynamometer clearly indicate advantages in emissions of N_2O, particulates, and CO_2 for the hybrid parallel drive vehicle (the series drive did not reach Mexico City on time for tests on the dynamometer) over the standard drive diesel vehicles.

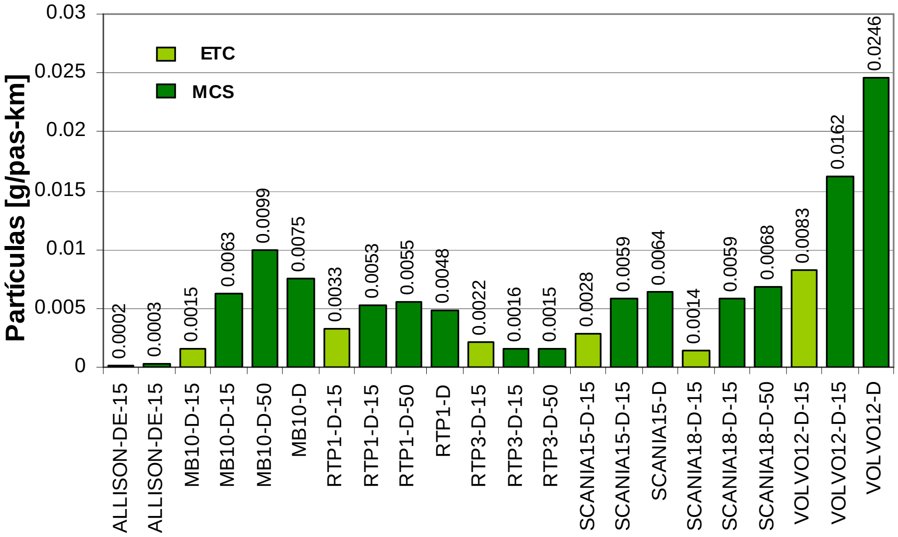
Figure 17. Emissions of N_2O in grams per passenger-kilometer for the testing fleet



Source: SMA 2006

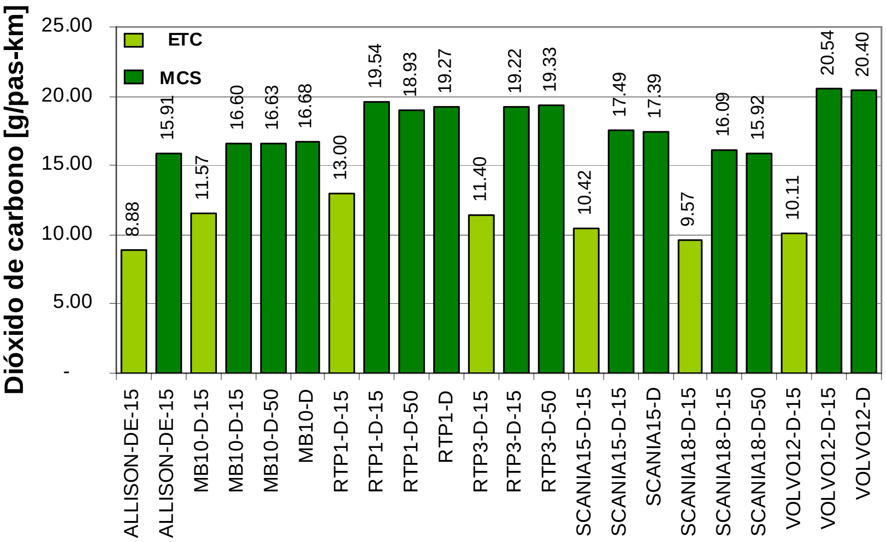
Figure 17 summarizes the results of the dynamometer test on N_2O for both cycles for standard drive and hybrid parallel diesel. The hybrid parallel drive vehicle had lower emissions than all diesels. Figure 18 likewise summarizes the corresponding results for PM_{10}. Again, the hybrid vehicle had lower emissions of particulates compared to the standard drive diesel vehicles.

Figure 18. Particle emissions in grams per passenger-kilometer for the testing diesel fleet



Source: SMA 2006

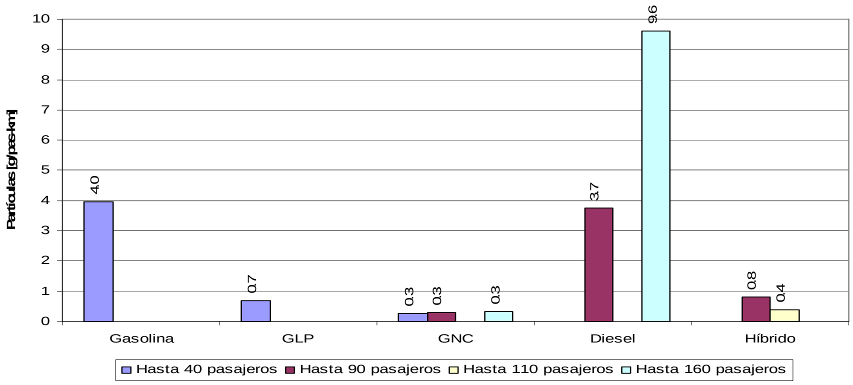
Figure 19. CO_2 emissions in grams per passenger-kilometer for the testing diesel fleet



Source: SMA 2006

During the RAVEM tests, which included CNG and hybrid vehicles, the CNG vehicles had significantly lower particle emissions than diesel vehicles. The hybrid parallel drive also presented lower particle emissions than those from a standard drive diesel. Additional tests have been scheduled for a fleet of CNG and CNG-hybrid buses in 2007.

Figure 20. Emission of particles (PM_{10}) per passenger-km



Consideration of externalities in annual cost of operation

On the basis of the test results, the Bank conducted an economic analysis on a per-passenger basis, comparing the annualized capital, maintenance, and fuel cost as well as the externalities associated with health cost and an estimate of climate damage caused by greenhouse gas emissions. The analysis included three different bus technologies: Standard Diesel, Natural Gas, and Hybrid Buses.[6] The analysis assumed a lifetime of 10 years, a traveled distance of 80,000 km per year, and a discount rate of 10 percent. The baseline scenario considers the average of five standard diesel buses. In order to quantify the health cost caused by the operation of the buses on a regular basis, the analysis only looked at the PM_{10} emissions (no ozone) and translated these into health costs based on the results of the economic valuation of air quality conducted in Mexico City. For the quantification of the climate damage, the CO_2 emissions per bus were assumed to imply costs of US$85 per t CO_2e.

The figure below summarizes the results (annualized costs include capital, fuel, operation, health, and climate) at an oil price of US$70/BBL and a carbon price of US$85 per t CO_2e. When the externalities are considered, the natural gas option has the lower annualized costs. This results primarily from the very low PM emissions. The hybrid diesel option also claims substantial credit in avoided health costs, but the higher capital costs result in smaller net gain. The hybrid option has lower climate damage. A hybrid gas option will be tested as part of the future program of activities in Mexico City.

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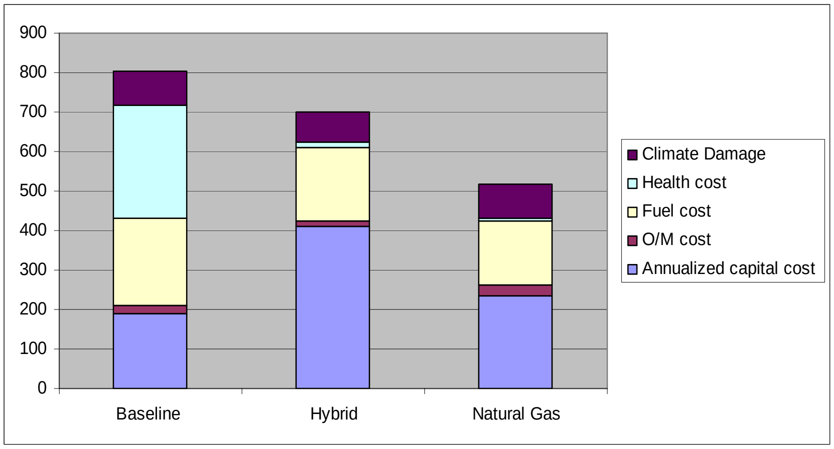
[6] The analysis used cost and emission data generated through the field test of alternative bus technologies undertaken under the project. As part of the field test, 18 buses were examined in terms of their local and global emissions and their operating cost. The buses were tested with RAVEM equipment and with a dynamometer chassis. The latter tested the buses with Mexican and European driving cycles. For purposes of this analysis, the results of the dynamometer testing were used for the Mexican driving cycle.

Figure 21. Annualized costs of operation of alternative bus technologies (US$/year)



Development of Transport Corridors under the Clean Development Mechanism

Mexico: Transport Corridors (P082656)

The concept of Bus Rapid Transit (BRT) is not new. Plans and studies for various BRT-type alternatives have been prepared for at least 70 years, although there has been a greater emphasis in recent years prompted by the success of the Transmilenio and similar systems in other cities. BRT is a high-quality bus-based transit system that delivers fast, comfortable, and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in customer service (Levinson 2002). BRT essentially emulates the performance and amenity characteristics of a modern rail-based transit system but at a fraction of the cost. A BRT system will typically cost 4 to 20 times less than a light rail transit (LRT) system and 10 to 100 times less than a metro system.

To achieve a high level of quality, BRT systems need to be executed in concert with an urban development vision that places a premium on public space. A BRT requires: exclusive right-of-way lanes, reformed business and institutional structures, rapid boarding and alighting, free transfers between routes, pre-board fare collection and fare verification, enclosed stations that are safe and comfortable, clear route maps, signage and real-time information displays, modal integration at stations and terminals, clean vehicle technologies and excellence in customer service.

BRT systems are typically in the range of US$500,000 per kilometer to US$15 million per kilometer. By comparison, at-grade LRT appears to be in the range of US$13 million to US$40 million per kilometer. Elevated systems can range from US$30 million to US$100 million per kilometer. Underground metro systems seem to range from US$45 million to as high as US$320 million per kilometer (L.Wright and L. Fulton 2005).

The objective of the Bus Rapid Transit System Carbon Finance Project in Mexico City was to contribute to reductions in local airborne pollutants and greenhouse gas emissions generated by the transport sector in the MCMA.

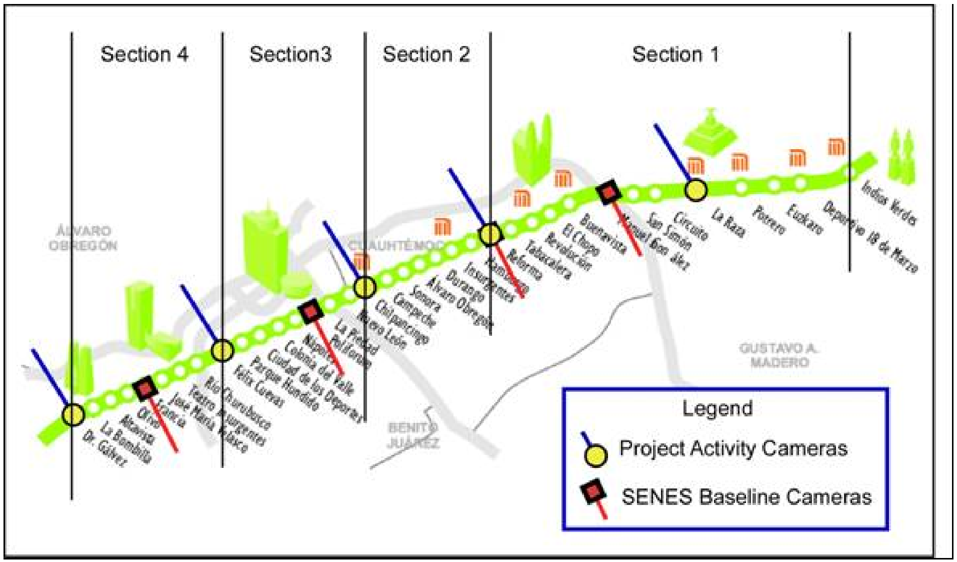
This project supported the development of the first surface mass transport corridor in Mexico City (Insurgentes Avenue) and associated traffic management measures. It represents the first transport transaction, supported through carbon finance, worldwide. The corridor was developed with the participation of existing operators and thus did not include a bid process, which may have resulted in sub-optimum prices. On the other hand, the participation of existing operators reduced the time required to reach consensus on the scope of the system.

The project was also intended to develop and demonstrate the catalytic use of the Clean Development Mechanism (CDM) to foster technology as well as regulatory and institutional changes in the public transport sector. It also supported the development and implementation of tools required to measure and monitor GHG emission reductions from the transport sector. Through the involvement of carbon finance, local funding has been leveraged, and institutions, regulations and incentives have been created to enable the development of a bus rapid transport system in Mexico City.

Development of a mass transport corridor on Insurgentes Avenue, including the development of traffic management measures and a professional management structure was supported through the purchase of resulting GHG emission reductions. The corridor includes: (a) exclusive bus lanes; (b) elevated bus stations for high-platform vehicles; (c) pedestrian facilities leading to the transport corridor's bus stations; (d) concessions of services on the corridor to a restructured company using large and low-polluting (articulated) buses; and (e) promotion of low-pollution passenger transport vehicles and scrapping of programs for old vehicles on Insurgentes.

The Insurgentes Corridor was designed along 19.3 km of the 34 km of Insurgentes Avenue to meet the demand of 251,000 daily passengers. The BRT system includes 34 stations distributed approximately 450 meters apart. Ninety-seven diesel-fueled articulated buses,[7] including 10 percent as a reserve for regulation and maintenance, replaced around 350 buses and microbuses.

Figure 22. Insurgentes Corridor: First BRT in Mexico City



METROBUS initiated operations in September 2005. It mobilizes about 220,000 passengers per day. Most METROBUS passengers have migrated from the original bus fleet on Insurgentes to that replaced by the BRT. However, an important fraction reflects a modal shift from passenger cars and other small vehicles (about 15 percent). User satisfaction is also high.

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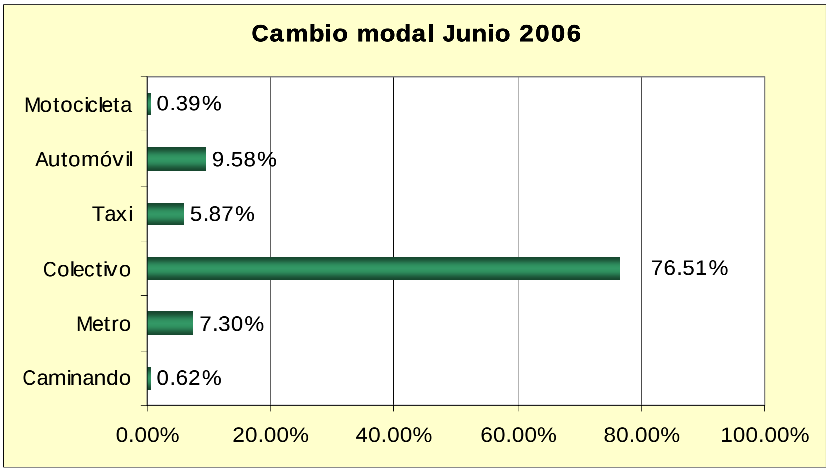
[7] The articulated buses are 18 m long; can carry 160 passengers, have low platforms and their doors on the left side. They are Euro-III certified.

The operation of METROBUS has been quite successful. A technical study conducted by SEMARNAT has documented a strong reduction of exposure to local criteria pollutants in METROBUS (23 percent for PM, 50 percent for CO). The local and global environmental benefits are at the core of the rationale for Bank support of the system. The financial analysis shows the system running a deficit caused by higher-than-expected financial costs, higher-than-anticipated bus fleet requirements, and the revenue lost to entitlements. The GDF is undertaking a review of options to meet the financial shortfall.

The modal shift observed during the first year of operation indicates that close to 16 percent of riders moved from individual vehicles (motorbikes and cars) to the Metro, while over 7 percent of passengers left the Metro for METROBUS. Although the first shift would result in greenhouse gas emission reductions, the second shift represents a net gain in emissions. Movements from the old buses to the new systems do not represent a modal shift but they do contribute to emission reductions.

Figure 23. Modal shift measured over Insurgentes Avenue in June 2006



Source: METROBUS 2007

Monitoring methodology for emission reductions

The reduction in anthropogenic emissions of GHG by sources due to the proposed CDM project activity is caused by:

- *The improvement in operating conditions for buses.* Confined, segregated bus lanes together with bus-priority traffic signals will allow buses on the route to operate more efficiently and without interference from other traffic, thus reducing journey time and congested idle, both of which will result in lower fuel consumption and lower GHG and local emissions.
- *The improvement in bus technology and capacity*. The use of 806 modern, high-capacity, 160-passenger diesel buses in place of approximately 350 old, small- and mid-sized gasoline-, gas- and diesel-powered units will also result in lower overall fuel consumption and lower GHG and local emissions.

- *The introduction of fare prepayment technology*. Fare prepayment will streamline the boarding process and reduce journey and bus-idle time, thus reducing fuel consumption and GHG and local emissions.
- *The use of centralized bus fleet control*. This will allow a coordinated scheduling of bus services that dynamically adjusts bus frequency with demand to result in fewer buses scheduled in off-peak hours. This will reduce bus fuel consumption and GHG and local emissions.
- *Traffic improvements for the other vehicles on the route*. Reduced journey time for other (non-bus) vehicles that use the route due to the elimination of multi-lane interference from buses competing for passengers, together with the flow improvement schemes, will reduce fuel consumption and GHG and local emissions.
- *The creation and demonstration of a sustainable business environment* for public transport which pioneers the adoption of organizational measures and incentives under a regulatory framework in which the GHG emissions-efficient services can be provided.
- *The introduction and demonstration of a trunk-feeder concept* that reduces the number of bus kilometers because small buses are only used to transport passengers to and from trunk stations, and high-capacity buses transport the passengers for longer distances between trunk stations.
- *The provision of a gradual alternative to the building of additional highways* that will result in better use of public space through the active promotion of increasing transit share which will enhance these benefits by further reducing congestion and travel cost, emissions, and urban degradation. These changes can only be brought about once the barriers caused by national and/or sectoral policies and circumstances have been eliminated.

The crediting period selected for the project is seven years, renewable twice for a maximum of 21 years, beginning August 22, 2005. It is proposed that the GHG reduction be verified and certified during the first period in years 1, 4, and 7 and subsequently on a three-yearly basis. The emissions totals of CO_2 equivalent (CO_2 eq) that will be reduced through this project in the first seven-year period will be in the order of 181,000 tons.

The quantification of emission reductions was proposed under a new methodology, specifically designed for METROBUS. However, the CDM did not accept the proposal and since then the project sponsors have decided to use the already approved methodology for Transmilenio.

Early results from the operation of METROBUS

From an operational and environmental perspective, the operation of METROBUS has been a resounding success. The system began operating in November 2005. During the first year of operations it was credited with the following indicators (METROBUS 2007):

- Passengers carried: 103 million

- Average weekday use: 260,000
- Average speed: 20 km/hr
- Maximum availability per hour: 8,500 passengers
- Total distance traveled: 10 million kilometers
- Waiting time between buses: 1.1–2 minutes

The efficiency of METROBUS can also be assessed by the fact that it now carries more passengers than some of the Metro lines (lines 4 and 6) and 3.5 times more than the light rail at a fraction of the cost in infrastructure.

The project has already filed a verification report in which the emission reductions have been quantified and is expected to be registered as a CDM project, using an approved methodology.

Reduction of global emissions

The estimate of emission reductions through the METROBUS operation considers the reductions caused by the replacement of 368 buses with 97 articulated buses to be a major positive impact. These have been estimated at 21,882 tons for the first year of operation. The emission reductions due to the improvement of the traffic flow for other vehicles on Insurgentes have not yet been validated by field measurements and are not accounted for in the final estimates, even though preliminary estimates indicate reductions on the order of 11,000 t CO_2 per year. Field surveys have demonstrated a 10 percent modal shift from private vehicles to METROBUS, of which 32 percent of drivers indicated the use of their vehicle by someone else. The resulting emission reductions are estimated to amount to 10,490 t CO_2e per year. The emission reduction estimates for the first year of operation also take into consideration additional emissions that would not have occurred in the absence of the project. These include: additional buses in operation as a consequence of modal shift, and thus additional passengers; removal of left turns and generation of additional trips; generation of additional travel times for vehicles crossing the corridor; emissions from scrapping old buses; and emissions from buses running empty between operating hours. Net emission reductions constitute 29,177 tons of CO_2e for the first year.

Reduction of exposure to local pollutants through the operation of METROBUS

Mexico's National Institute of Ecology, in collaboration with the Sustainable Transport Center, conducted a study to estimate the impacts of the METROBUS operation on local pollutants. Concentrations of CO, $PM_{2.5}$, PM_{10}, and benzene were measured before and after the implementation of the corridor. The results of the measurements are summarized in the following table:

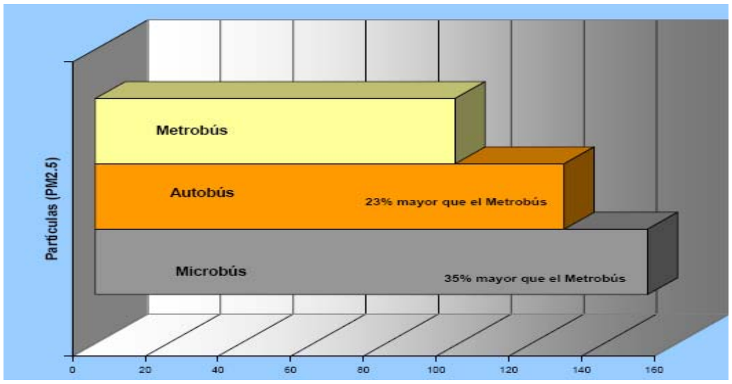
Table 17. Reduction of exposure to airborne pollutants along Insurgentes Corridor

	Transport Modes		
	Microbus	Autobus	Metrobus
Number of runs	36	37	68
Concentrations:			
Carbon monoxide (ppm)	15.8	11.4	7.5
Particulate Matter: $PM_{2.5}$ ($\mu g/m^3$)	152	129	99
Particulate Matter: PM_{10} ($\mu g/m^3$)	196	202	183
Benzene (ppbv)	10.2	8.9	4.2

Source: INE 2006

The operation of METROBUS has proved to significantly reduce $PM_{2.5}$, benzene, and CO concentrations in its area of influence. The reasons for the reductions are seen as a consequence of improved technologies that have better emission controls. METROBUS also operates with fewer stops than the previous system, thus reducing major emissions during start-ups. The METROBUS system operates on separate bus lanes and reduces the infiltration of pollutants emitted by private vehicles on parallel lanes. The study demonstrates the important, positive impact that METROBUS can have on human health.

Figure 24. Reduction of relative exposure to particulate matter by METROBUS
($PM_{2.5}$ in micrograms per cubic meter)



Source: INE, 2006

The reductions of local criteria pollutants, although important, are not sufficient to make a dent in exposures at a city level, nor does the reduction in greenhouse gas emissions constitute a major fraction of those generated by the city. However, the system works and constitutes a sound basis on which to build an expanded citywide BRT system. The city government has announced the intention to build nine additional corridors and expand the corridor along Insurgentes. The reductions in greenhouse gases are expected to be an order of magnitude higher and the exposure to local criteria pollutants should also be lower along the selected routes. The experience and investments on Insurgentes are fully justified by the prospects of an expanded system. The expansion of METROBUS has been also proposed for support under the CDM.

Lessons Learned and Recommendations for Further Work

Transport plays a critical role in efforts to achieve low carbon development. Although the intensity of carbon emissions from the transport sector in Latin America is well below the corresponding emissions in the United States and other industrial nations, there are substantial challenges and opportunities in order to maintain and improve emissions performance while providing the services that growing economies and quality of life demand from the transport sector.

Transport is also key to reducing impacts on exposure to airborne pollutants in urban areas. The health risks due to air pollution (specifically ozone and PM) are quantified by estimating the relationship between the incidence of adverse health effects and air quality. Data obtained as part of the efforts described in this document for Mexico City indicate that obtaining air quality compliance for ozone and PM_{10} and key airborne pollutants (AQS1) offers benefits of approximately US$2 billion per year, with high and low estimates of benefits of some US$4 billion and US$400 million, respectively. This is a substantial health benefit that needs to be considered when the benefits of transport sector improvements are examined.

Thus, transport management requires an integrated approach that goes hand-in-hand with urban development, air quality, and climate strategies which together respond to the combined needs of economic and environmental performance. There are substantial harmonization opportunities for both agendas in the transport field. Reductions in GHG emissions from the transport sector are associated with reductions in the use of fuels and thus have the potential to reduce emissions of volatile organic compounds, nitrous oxide, and particulate matter.

Bus rapid transit systems provide an emerging model of surface urban transport in Latin America, typified by the experiences in Bogotá, Curitiba, and other cities, and starting to take shape as well in Mexico City. This model seeks to optimize the use of public space and promote gains in efficiency, safety, and environmental performance. These systems respond to the need for cost-effective mass transport but also serve to advance the goals of low carbon footprint and reduced loads of air toxics and local criteria pollutants, and complement investments already made in subways and other mass transport systems.

The widespread adoption of bus rapid transit systems in Latin American countries and the associated reductions in emissions of local and global concern stand in contrast with increases in the energy intensity of passenger transport in industrialized North America. The experience of these systems should be of interest to urban planners and policy makers in those countries for their potential application.

Modal shift represents a strong option for the reduction of GHG emissions through the transport sector. The implementation of the Insurgentes Corridor has already resulted in significant emission reductions after only one year in operation. It has also resulted in a significant modal shift from individual passenger vehicles.

A suitable business environment for public transport is a requisite for sustainable gains in environmental efficiency and performance. The case of Mexico City has demonstrated that the creation of an enabling environment is necessary before sustainable measures can be implemented. The creation of a stable institution for the management of the corridor, the involvement of private bus operators, the new regulatory framework under which the services are being provided, and the structuring of an integrated fare represented key success factors in the development of METROBUS.

Mexico City is positioned for a citywide transport corridor approach. The successful METROBUS pilot experience has demonstrated the feasibility of the BRT concept for the city and provided important lessons learned for its replication. The programmatic approach is already among the current administration’s priorities, including its implementation with cleaner bus technologies.

BRT results in reduced local pollutants, with significant positive impacts on health. The INE study has shown that the operation of METROBUS has significantly reduced exposure to local pollutants by users of the METROBUS system. Further improvements in bus technologies and fuel types will continue to reduce this exposure.

Development of transport baseline methodologies needs to be further encouraged. To date there is only one approved transport baseline methodology. The availability of more methodologies would provide an additional incentive to move ahead faster with BRT concepts in developing countries. The case of Mexico has demonstrated how the prospect of carbon finance was key to surmounting several barriers.

Further field testing of bus technologies is needed for defining emission standards and for the decision-making process on alternative bus technologies for public transport. The field test has provided helpful data for the operation of alternative bus technologies under real conditions at Mexico City’s altitude. However, because the test fleet consisted of only a few vehicles per type and in many cases for advanced technologies a single vehicle was tested, further field testing is needed to strengthen the database for decision making on bus technologies for public transport with major emission reduction potentials.

Introduction of new bus technologies and low carbon fuels needs to be encouraged to form a larger share of the modal and fuel mix. The analysis of these systems should take into account the economic benefits of avoided health and climate impacts.

The proposed expansion of METROBUS will correspondingly increase the net reduction in greenhouse gases in Mexico City. A 10-corridor system has the potential to reduce annual emissions by between 300,000 and 500,000 tons per year, more if low carbon bus technologies (hybrid drives) are deployed. The combination of modal shift and reduced congestion with low-carbon, low air toxic vehicles will place the city at the forefront of developments in climate- and health-responsive BRTs worldwide.

References

CAM, 2002. Programa para Mejorar la Calidad del Aire de la Zona Metropolitana del Valle de México (2002–2010). Comisión Ambiental Metropolitana. Mexico, D.F.

Davies S., and Dieguel, S., 2006. Center for Transportation Analysis, Engineering Science & Technology Division. Transportation Energy Data Book. Edition 25. Oak Ridge Nacional Laboratory. Oak Ridge, Tennessee.

Dirección General de Gestión Ambiental del Aire, 2007. Informe Ejecutivo de la Calidad del Aire en la Zona Metropolitana del Valle de México. Secretaría del Medio Ambiente de la Ciudad de México. 4: 48. Diciembre 2006.

Dow, K. and T. Downing, 2007. The Atlas of Climate Change. Earthscan. NHBS. Devon, UK.

ECMT 2007. Cutting Transport CO_2 Emissions. What Progress? European Conference of Ministers of Transport 2007. OECD Publishing. Paris, France.

EIA, 2006. International Energy Outlook 2005. Energy Information Administration. U.S. Department of Energy. Washington, D.C.

Epstein, P. 2005. Climate Change and Health: a perspective. *New England Journal of Medicine*. October 6.

IEA (2004) *International Energy Annual 2002*. Washington, DC. Online at: http://www.eia.doe.gov/iea/carbon.html. (April 18, 2005).

IEA, 2006. World Energy Outlook 2006. International Energy Agency, Paris, France.

IFU, 2002. Air Modeling in Mexico City. Final Report. Fraunhofer Institute for Atmospheric Environmental Research. Garmisch-Partenkirchen, Germany

INE, 2006. Reducción de exposicion a contaminantes criterio en el corredor de Insurgentes. Mexico. DF.

Institute for Transport Policy Studies, 2004. Urban Transport and the Environment, 2004, p. 332.

IPCC, 2007, Draft Fourth Assessment Report. IPCC Secretariat. Geneva, Switzerland.

IPCC-SPM. 2007. Fourth Assessment Report. Summary for Policymakers. IPCC Secretariat. Geneva, Switzerland.

Levy, P.E. et al., 2004. Modelling the impact of future changes in climate, CO_2 concentration and land use on natural ecosystems and the terrestrial carbon sink. Global Environmental Change 14 (2004) 21–30.

Levinson, 2002. Bus Rapid Transit Systems. An Overview. *Journal of Public Transportation, Vol. 5, No. 2, 2002.*

Lloyd Wright, Bus Rapid Transit Planning Guide, Institute for Transportation & Development Policy, July 2006.

METROBUS, 2007. Supervision report to the World Bank. Mexico. D.F.

Schellnhuber et al. (eds). Avoiding Dangerous Climate Change. Cambridge University Press. 2006

SMA, 2006. Estrategia Local de Acción Climática de la Ciudad de México. Secretaría de Medio Ambiente. Mexico, D.F.

SMA, 2007. Pruebas en Campo de Autobuses de Tecnologías Alternativas en la Ciudad de México. Reporte Final. Secretaría de Medio Ambiente. Mexico, D.F.

Stacy C. Davis, Susan W. Diegel, 2006. Center for Transportation Analysis, Engineering Science & Technology Division. Transportation Energy Data Book: Edition 25.

STAPPA/ALAPCO, 1999. Reducing Greenhouse Gases and Air Pollution. A Menu of Harmonized Options. Final Report. State and Territorial Air Pollution Program Administrators and Association of Local Air Pollution Control Officials. Washington, D.C.

Vergara, W. 2004. *Responding to Climate Change. A proposed strategy for the World Bank in Latin America.* World Bank Latin America Region. Sustainable Development Series. No. 19. Washington, D.C.

Vergara, W. 2005. *Adapting to Climate Change. Lessons Learned, Work in Progress and Proposed Next Steps for the World Bank in Latin America.* World Bank Latin America Region. Sustainable Development Series. No. 25. Washington, D.C.

Vergara W. et al., 2007. Economic Consequences of Rapid Glacier Retreat in the Andes (submitted for publication, *Journal of the American Geophysical Union, EOS*).

Webster et al. 2005. Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment. *Science* September 16: 1844–1846.

West Virginia University. 2005. Final Report. Chassis Dynamometer Emissions Characterization of Buses in Mexico City. West Virginia University Center for Alternative Fuels, Engines and Emissions. Morganstown, West Virginia.

World Bank, 2000. Implementation Completion Report. Mexico: Transport Air Quality Management Project for the Mexico City Metropolitan Area. (Loan 3543-ME). Washington, D.C.

World Bank, 2002. Mexico: Introduction of Climate-Friendly Measures in Transport Project. Project Appraisal Document P059161. Washington, D.C.

World Bank, 2002b. Improving Air Quality in Metropolitan Mexico City. An Economic Valuation. Policy Research Working Paper 2785. Washington, D.C.

World Bank, 2005. Mexico City Insurgentes Bus Rapid Transit—BRT—System Carbon Finance Project. Project Appraisal Document P082656. Washington, D.C.

World Resources Institute (WRI). 2005. Navigating the Numbers. Greenhouse Gas Data and International Climate Policy. Washington, D.C.

World Resources Institute (WRI). 2007. Target: Intensity. An Analysis of Greenhouse Gas Intensity Targets. Washington, D.C.

Wright L. and L. Fulton. 2005. Climate Change Mitigation and Transport in Developing Nations. *Transport Reviews, Vol. 25, No. 6, 691–717*, November 2005

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