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PURPOSE

The Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP) is a special global technical assistance program run as part of the World Bank's Energy, Mining and Telecommunications Department. ESMAP provides advice to governments on sustainable energy development. Established with the support of UNDP and bilateral official donors in 1983, it focuses on the role of energy in the development process with the objective of contributing to poverty alleviation, improving living conditions and preserving the environment in developing countries and transition economies. ESMAP centers its interventions on three priority areas: sector reform and restructuring; access to modern energy for the poorest; and promotion of sustainable energy practices.

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Abbreviations and Acronyms

ACEA	Association des Constructeurs Européens d'Automobiles
AMIA	Asociación Mexicana de la Industria Automotriz
ANPACT	Asociación Nacional de Productores de Autobuses, Camiones y Tractocamiones
AQIRP	Air Quality Improvement Research Program
ASM	acceleration simulation mode
ASTM	American Society for Testing and Materials
BAR	(CARB's) Bureau of Automotive Repair
CAA	Clean Air Acts
CAM	Comisión Ambiental Metropolitana (Metropolitan Environmental Commission)
CARB	California Air Resources Board
CES	constant elasticity of substitution
CGE	computable general equilibrium
CFE	Comisión Federal de Electricidad
CH_4	methane
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CONCAWE	Conservation of Clean Air and Water in Europe
COP	Conference of the Parties
EER	Energy Environment Review
EPA	Environmental Protection Agency
EPEFE	European Programme on Emissions, Fuels and Engine Technologies
ESMAP	Energy Sector Management Assistance Programme
EU	European Union
EUROPIA	European Petroleum Industry Association
FCC	fluidized catalytic cracking
FCCC	(United Nations) Framework Convention on Climate Change
FTP75	Federal Test Procedure 75
GDF	Gobierno del Distrito Federal
GDP	gross domestic product
GHG	greenhouse gas
GVW	gross vehicle weight
HC	hydrocarbons
I/M	inspection and maintenance
IMF	International Monetary Fund
IMECA	Indice Metropolitano de Calidad del Aire
INE	Instituto Nacional de Ecología

INEGI	Instituto Nacional de Estadística, Geografía e Informática
ISO	International Organization for Standardization
LCO	light cycle oil
LEV	low emission vehicle
LPG	liquefied petroleum gas
MON	motor octane number
MTBE	methyl tertiary-butyl ether
NO	nitric oxide
N_2O	nitrous oxide
NO_2	nitrogen dioxide
NO_x	oxides of nitrogen
NTE	not to exceed
O_2	oxygen
OBD	on-board diagnostics
OBD II	on-board diagnostics generation two
PEMEX	Petróleos Mexicanos
PM	particulate matter
PM_{10}	particles with an aerodynamic diameter less than 10 microns
$PM_{2.5}$	particles with an aerodynamic diameter less than 2.5 microns
RFG	reformulated gasoline
RON	research octane number
RVP	Reid vapor pressure
SAE	Society of Automotive Engineers
SAM	social accounting matrix
SE	Secretaría de Energía (Energy Secretariat)
SEMARNAP	Secretaría de Medio Ambiente, Recursos Naturales y Pesca (Environment, Natural Resources and Fishery Secretariat)
SFTP	Supplementary Federal Test Procedure
SO_2	sulfur dioxide
SO_x	oxides of sulfur
SUV	sport utility vehicle
T_{50}	temperature at which 50 percent of the fuel evaporates
T_{90}	temperature at which 90 percent of the fuel evaporates
UNAM	Universidad Nacional Autónoma de México
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
US EPA	United States Environmental Protection Agency
VOC	volatile organic compound
ZMVM	Zona Metropolitana del Valle de México
US$	U.S. dollars

Units of Measurement

b/d	barrels per day
bhp	brake horsepower
kg/m^3	kilograms per cubic meter
km	kilometer
km/h	kilometers per hour
kPa	thousand pascals
l	liter
PJ	petajoule (10^{15} joules)
ppm	parts per million
psi	pounds per square inch
rpm	revolutions per minute
vol%	percent by volume
wt%	percent by weight
wt ppm	parts per million by weight

Glossary of Terms

Aromatics	Hydrocarbons that contain one or more benzene rings in their molecular structures. Aromatics have valuable anti-knock (high-octane) characteristics.
Benzene	An aromatic hydrocarbon with a single six-carbon ring and no alkyl branches. Benzene is a carcinogen.
Catalytic converter	A device built into the exhaust system of an engine containing a catalyst that converts carbon monoxide (CO) to carbon dioxide, and unburned hydrocarbons to carbon dioxide and water. If only CO and unburned hydrocarbons are converted, the converter is called a *two-way* converter. *Three-way* converters convert, in addition, oxides of nitrogen (NOx) to nitrogen and water (or oxygen or carbon dioxide).
Cetane index	An estimate of cetane number based on an empirical relationship with density and volatility parameters. The cetane index cannot reflect the addition of cetane improvement additives.
Cetane number	An empirical measure of a diesel fuel's ignition quality that indicates the readiness of the fuel to ignite spontaneously under the temperature and pressure conditions in the engine's combustion chamber. Adding cetane improvement additives can increase the cetane number.
Coking	A refinery process representing severe thermal cracking, whereby heavy residual fuel oil is converted into (1) solid coke, (2) lower boiling hydrocarbons suitable as feedstocks to other refinery units, and (3) naphtha and light gas oil.

Elasticity	Percent change in quantity caused by a one-percent change in price.
Fluidized catalytic cracking (FCC)	A refinery process for converting heavy oils into light cycle oil, gasoline and lighter products.
Hydrocarbons	Organic compounds composed of carbon and hydrogen.
Hydrotreating	A refinery process in which a stream is treated with hydrogen to reduce the amount of sulfur, nitrogen, and other heteroatoms, and to saturate double bonds (for example, in aromatics and diolefins). The terms hydrotreating, hydroprocessing and hydrodesulfurization are used rather loosely in the industry.
Hydrodesulfurization	Removal of sulfur in a fuel in the presence of hydrogen.
Light Cycle Oil (LCO)	The light portion of a catalytic cracker reactor effluent which is not converted to naphtha and lighter products.
Motor octane number (MON)	The octane value of a fuel, determined using the engine conditions that correlate with road performance during highway driving conditions.
Octane number	A measure of resistance to self-ignition (knocking) of a gasoline. The higher the octane number, the higher the anti-knock quality of the gasoline.
Olefins	A class of hydrocarbons that have one double-bond in their carbon structure.
Oxygenates	Any organic compounds containing oxygen. Specifically for the petroleum industry, oxygenates typically refer to alcohols and ethers used to boost octane and/or to reduce CO in the engine exhausts.
Ozone	A colorless gas, ozone is an allotropic form of oxygen in which the molecule is O3.
Polycyclics	Aromatic compounds with more than one six-membered ring. Polycyclics are carcinogens. The diesel fraction of FCC product is a source of polycyclics.
Reid vapor pressure (RVP)	A standardized measure of a fuel's volatility at a specified set of conditions, with a higher value indicating a more volatile fuel. RVP is usually measured in psi (pounds per square inch) or kPa (thousand pascals).
Research octane number (RON)	The octane value of a fuel, determined when vehicles are operated at low speed or under city driving conditions.
T90	The temperature at which 90 percent of fuel evaporates.

Executive Summary

1 The Mexico Energy Environment Review (EER) is one of the first such reviews supported by the joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP). Conducted jointly by specialists in the energy and environment sectors in specific countries, energy-environment reviews examine the local, regional and global impacts of energy production and consumption. Outputs of these reviews include (1) a diagnosis and analysis of issues related to the exploitation of fossil and other fuels and (2) strategies and options for addressing these issues.

2 The use of fossil fuels and their impact on the environment present two distinct but related challenges to Mexico. Mexico is a major oil producer. In the face of mounting evidence that human-induced climate change appears to be occurring as a result of a build-up of greenhouse gases (GHGs) that trap heat in the atmosphere, there is a move to try to reach an agreement on limiting the amount of fossil fuel consumption among industrial countries, and to urge developing countries to adopt similar but voluntary agreements. As an exporter of crude oil, Mexico will be affected by international agreements limiting fossil fuel consumption. It is also important for Mexico to understand how its own fossil fuel consumption is expected to evolve in the coming years, and to see if there is scope for limiting the growth of GHG emissions without having too much adverse impact on the economy.

3 Mexico also suffers from serious urban air pollution in the form of ozone and fine particulate matter, much of which is due to the combustion of fossil fuels. Adoption of cleaner technologies, proper maintenance of equipment (such as vehicles), and demand management are key instruments for tackling urban air pollution. Demand management in turn will help reduce greenhouse gas emissions.

Program Description

4 The Mexico EER has two parts. The first addresses GHG emissions and examines energy consumption patterns across key economic sectors with a view to forecasting future energy demand and supply, and associated emissions of pollutants (both local and global pollutants but focusing on GHGs). Several energy-pricing instruments for reducing GHG emissions are then examined in terms of their impact on energy consumption and resulting emissions as well as their macroeconomic and socioeconomic consequences.

5 The second part targets urban air pollution arising from transport emissions and, more specifically, gasoline-fueled vehicles. It examines vehicle fleet characteristics in terms of vehicle technology, vehicle category, age, service and engine size, and relations to emissions. It reviews the history of the vehicle inspection and maintenance (I/M) program in Mexico City to distill lessons, and analyzes the emissions data collected in the I/M program. It studies the link between fuel quality and vehicle performance, and discusses the ramifications of the proposed gasoline specifications in the context of the status of the refining sector in

Mexico, the effects of fuel quality developments in North America, and likely future vehicle emissions regulations in Mexico.

Part 1: Modeling of Energy Consumption and Emissions Under Different Scenarios

6 To determine the relationship between emissions and the level of the economy in such a way as to be able to analyze the impact of policy switches at a sector level, it was decided that the overall model strategy would require a "bottom-up" demand model to be linked to a macro-computable general equilibrium (CGE) model. The former would allow for demands for energy from all major sectors and would track the impact on emissions through a detailed linking to the technologies used to meet these demands. The aggregate of the demands would be linked to overall macroeconomic variables via a purpose-built CGE model. The models were calibrated for 1996, and three economic growth-rate scenarios were simulated: low, most-likely and high.

7 In order to estimate future energy demand in the bottom-up model, the review analyzed seven major sectors in the economy: residential, service, industrial, transport, power, refining, and gas processing. The first five sectors were further decomposed into subsectors. The results of the findings from this sector analysis were then linked to a macroeconomic model to assess the impact of different policies on gross domestic product (GDP), government budget, trade, employment, and equity (effects on different income groups). Emissions were computed for each sector separately and for Mexico as a whole.

8 The analysis involved two computer programs. One was the bottom-up model called the Brundtland scenario model, or BRUS, originally developed in Denmark. The version used for this study, BRUS-II-M, computes energy demand as a function primarily of annual growth rates of GDP and population (split into urban and rural), value added in each sector, energy efficiency gains and price elasticities. From the resulting energy-use data, the total of emissions at a country level is computed. The other program was a dynamic CGE model developed by Professor Roy Boyd of Ohio University and calibrated for Mexico. Historical data for 1996 were entered in both programs as a starting point.

9 For this study BRUS-II-M was run for three years—1996, 2004 and 2010—corresponding to two time periods: 1996–2004 and 2004–2010. Fuel substitution and energy-saving policies can be imposed, as can energy efficiency gains. Historical consumption data in different sectors are collected and regression analysis carried out to forecast future demand as a function of key economic parameters. The outputs from BRUS-II-M included demand for fuels and electricity in each sector, emissions in each sector as a function of fuels used, and supply of power in three geographical regions as a function of mode of power generation.

10 The CGE model has nine producing sectors, sixteen production goods, four household categories (income levels), seven consumption sectors, a foreign sector and a government sector. The relationships between final demand and inputs of all goods are based on the most up-to-date input output table available. The value added in each producing sector allows for substitution between labor and capital through constant elasticity of substitution (CES) functions. Output prices are determined by market clearing. Consumer demand for

goods depends on prices and incomes. Labor supply, taxes and transfers determine household incomes, while the government budget is related to tax revenues and government spending.

11 To simulate the impact of the alternative scenarios, BRUS is run to obtain the fuel outputs from different sectors. These are then fed into the CGE model as exogenous factors, allowing the model to recompute the relative prices needed to clear the markets, and the associated macroeconomic variables. For a given GDP scenario (say, 5.2 percent annual growth) used in BRUS-II-M to calculate the outputs for a given change in policy, the CGE model may show that aggregate output itself will be affected by the policy option chosen. In this study, because the impact on GDP (which is the primary driver for outcomes in BRUS-II-M) of different policy options was small, the results from the CGE model were not fed back to BRUS-II-M for further iteration. A key assumption in the running of the model is that the government budget remains balanced throughout the period (as it was approximately in 1996). This has important implications for the policies described below because, if the government collects more taxes, it is assumed then to spend the extra receipts, thus partially restoring the level of aggregate demand in the economy, albeit on different goods.

Modeling Results

12 Following are the key scenarios examined:[1]

- *Scenario 1—No new policies*. Scenario 1 represents the case whereby none of the policies adopted by the government of Mexico since 1996 are implemented. Specifically, future power plants run on fuel oil, there are no attempts to minimize gas flaring and venting during oil production, and there are no policies to promote the use of fluorescent light bulbs or natural gas in various sectors. A comparison of scenarios 1 and 2 will indicate emissions savings as a result of the implementation of the current policies.
- *Scenario 2—Baseline*. Scenario 2 defines the baseline case. It includes all the policies that are already in place or have been adopted for implementation by the government of Mexico. The policies incorporated in the model include the following:
    - (a) ILUMEX, which promotes substitution of incandescent bulbs with fluorescent bulbs in the residential sector (for example, installation of 2,400,000 fluorescent bulbs by 2004)
    - (b) Annual growth of natural gas use in the industrial and residential sectors by 13.6 percent and 4.3 percent (at 5.2 percent annual GDP growth) to 2010. This is achieved in BRUS by substituting liquefied petroleum gas (LPG) and fuel oil with natural gas
    - (c) Elimination of use of kerosene in the industrial sector
    - (d) Promotion of co-generation and auto-generation in the industrial sector

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[1] Scenarios 3 and 4 are built on Scenario 1. They need to be run in order to run Scenarios 5 and 6, but the results are not directly applicable for policy formulation.

(e) Installation of new power plants as per Comisión Federal de Electricidad's plan to 2008, with the majority being combined cycle natural gas fired plants

(f) Promotion of the use of compressed natural gas (CNG) as a transport fuel in Mexico City.

- *Scenario 5—Power subsidy elimination.* This scenario eliminates power tariff subsidies in scenario 2.
- *Scenario 6—Carbon taxes.* Scenario 6 takes scenario 2 and imposes a carbon tax of about US$10–12/ton of CO_2 (US$37-44/ton of carbon) on oil, gas and coal. The level of carbon tax is comparable to the equilibrium international permit price of US$11–12/ton of CO_2 recently computed by the Oxford Institute for Energy Studies and the Center for international Climate and Environmental Research in Oslo (Bartsch and Müller 2000). The latter study assumed that the Kyoto targets are achieved with full flexibility among the Annex B countries. A higher carbon tax case, where carbon taxes were increased by an additional 50 percent, was also examined. The scenario assumes that the same levels of carbon tax are imposed in Mexico's trading partners.
- *Scenario 7—Combined case.* This scenario takes scenario 5 and adds carbon taxes, enabling examination of the combined impact of eliminating power subsidies and imposing carbon taxes on the baseline case.

13 The results for the year 2010 are summarized in Table E.1. As mentioned above, the government of Mexico has already begun to implement the policies outlined in scenario 2. Thus, the results of the various policy alternatives are best seen in terms of their contrast to this scenario, and this is the reason for comparing differences between various scenarios and scenario 2 in Table E.1. The table shows that, as expected, an increase in the underlying rate of growth leads to a general rise in the level of consumer welfare for each consumer class, GDP, and final capital stock by 2010, as seen in scenarios 2 and 5. Emissions are a strong function of GDP growth, as these scenarios show.

Table E.1 Results for Scenarios 1, 2, 5, 6 and 7 for the Year 2010 (trillions of 1996 pesos unless indicated otherwise)

	Scenario								
Result	*1*	*2*	*2*	*2*	*5*	*5*	*5*	*6*	*7*
% GDP annual growth in BRUS	5.2	3.7	5.2	6.2	3.7	5.2	6.2	5.2	5.2
Demand for fuels in BRUS, PJ	10,746	8,311	10,442	12,265	8,068	10,096	11,877	10,281	9,911
Demand for power in BRUS, PJ	1,435	1,084	1,429	1,734	993	1,310	1,429	1,408	1,271
Emissions, million tons of CO_2	804	588	737	861	570	712	839	726	699
% Change relative to scenario 2	9.0	0.0	0.0	0.0	-3.1	-3.4	-2.6	-1.5	-5.2
GDP recomputed in CGE	5.41	4.48	5.47	6.25	4.47	5.46	6.23	5.42	5.41
% Change relative to scenario 2	-1.2	0.0	0.0	0.0	-0.2	-0.3	-0.2	-0.9	-1.2
% GDP annual growth computed	5.2	3.8	5.3	6.2	3.7	5.2	6.2	5.2	5.2
Capital stock	11.56	8.01	11.77	15.36	7.97	11.71	15.29	11.53	11.48
% Change relative to scenario 2	-1.8	0.0	0.0	0.0	-0.5	-0.5	-0.5	-2.0	-2.5
Balance of payments	0.14.	0.112	0.139	0.157	0.111	0.137	0.154	0.120	0.117
% Change relative to scenario 2	0.7	0.0	0.0	0.0	-0.9	-1.4	-1.9	-13.7	-15.8
Government expenditure	1.77	1.64	1.78	1.89	1.64	1.78	1.89	1.81	1.83
Government revenue	1.77	1.64	1.78	1.89	1.64	1.78	1.89	1.81	1.83
% Change relative to scenario 2	-0.4	0.0	0.0	0.0	0.1	0.1	0.2	2.0	2.7
Welfare									
Agent 1, lowest 20%	1.132	1.042	1.133	1.201	1.041	1.132	1.199	1.132	1.130
Agent 2, next 30%	3.381	3.114	3.386	3.587	3.110	3.382	3.583	3.382	3.377
Agent 3, next 30%	5.223	4.814	5.233	5.544	4.810	5.230	5.540	5.235	5.228
Agent 4, highest 20%	8.691	7.984	8.678	9.191	7.991	8.686	9.201	8.694	8.694
% Change relative to scenario 2									
Agent 1, lowest 20%	-0.09	0.0	0.0	0.0	-0.10	-0.09	-0.17	-0.09	-0.27
Agent 2, next 30%	-0.15	0.0	0.0	0.0	-0.13	-0.12	-0.11	-0.12	-0.27
Agent 3, next 30%	-0.19	0.0	0.0	0.0	-0.08	-0.06	-0.07	0.04	-0.10
Agent 4, highest 20%	0.15	0.0	0.0	0.0	0.09	0.09	0.11	0.18	0.18

Note: PJ ≡ petajoules. Emissions are those of CO_2, methane and N_2O computed in BRUS-II-M and are on a CO_2-equivalent basis. Scenarios 6 and 7 take the lower of the two carbon tax cases. The welfare figures are cumulative between 1996 and 2010 and discounted by the discount rate used in the CGE model.

14 Had the Mexican government decided to carry on with existing policy in 1996 and not adopted the policies evaluated in scenario 2, the situation would be distinctly different. Scenario 1 shows that GDP, the capital stock, government expenditures and the welfare of agents 2 and 3 all decline from their levels in scenario 2. Only agent 4 (the highest income class) and the balance of trade increase, with only modest gains. By 2010, fuel demand in scenarios 1 and 2 differs by 3 percent, but annual emissions in scenario 1 exceed those in scenario 2 by close to 10 percent because of the difference in fuel mix, with less carbon intensive natural gas being used much more in scenario 2 at the expense of fuel oil.

15 Scenario 5 shows the effects of a removal of all electricity subsidies. The net effect of such a policy is somewhat mixed when compared to the changes brought about by

scenario 2. Whereas government revenues increase by 0.1 percent as expected, GDP, the balance of trade and the capital stock go down slightly relative to scenario 2. The removal of power subsidies is an effective instrument for curbing emissions and demand for power.

16 The most significant macro effect of imposing a carbon tax is on the balance of trade. The trade balance declines by over 13 percent relative to scenario 2 even in the case of "low" carbon tax. This is because (1) an exportable good (i.e., crude petroleum) is now heavily taxed and (2) international demand for oil grows less rapidly in the wake of a general imposition of carbon taxes. GDP, the capital stock, and the welfare of agents 1 and 2 also decline, while the welfare of agent 4 rises along with government expenditures. All of these trends are amplified in the case of higher carbon taxes. Carbon taxes are not as effective as the removal of power subsidies for curbing emissions, so that even imposing "high" carbon taxes does not achieve the same level of reductions in emissions as the elimination of power subsidies. This is because the latter policy directly targets power tariffs, suppressing demand for power—which, in turn, is a significant consumer of fuel oil. The fall in demand for fuel oil is therefore much greater in scenario 5 than in scenario 6.

17 The impact of levying a carbon tax and removing the power subsidies seems to combine the effects seen in scenarios 5 and 6. There is a severe decline in the balance of trade and a fall in both GDP and the level of the capital stock. Overall consumer welfare fares the worst here out of all the scenarios examined. As expected, this combined policy has the largest impact on demand for fuels and power as well as emissions. The incremental benefit of introducing carbon taxes, however, is markedly smaller than that of eliminating power subsidies.

18 Table E.1 gives a clear picture of the relationship between the performance of the macroeconomy and the level of CO_2 emissions during the coming decade. The key determinant will be the growth rate: the difference in the level of emissions (and hence the cumulated total emitted) between a "low" growth rate of 3.7 percent per year and the "most likely" growth rate of 5.2 percent per year in scenario 2 (baseline case) is between 588 and 737 million tons. This difference (20 percent of the medium growth case emissions) is far larger than can be achieved by the most stringent policies considered. For example, with the imposition of a high carbon tax at about $16 a ton of CO_2 coupled with the removal of subsidies to electricity, the level of emission drops from 737 to 692 million tons of CO2.

19 The reason for the relatively small impact of these fuel-switching and energy-reducing policies lies in the assumptions built into the CGE modeling exercise. Two aspects of the model limit the reduction in energy use, and hence in emissions, that result from policy switches. First, the government is assumed to spend any extra revenue, from taxes or reduced subsidies, on the same pattern of goods and services as it did in 1996. This increment creates demand for energy inputs, and although the price of energy is now higher, leading to some substitution, this is a relatively small effect because the elasticity of substitution between energy and non-energy inputs is low. Second, the model does not permit unemployment in the short run, so that as the price of energy rises the model adjusts to keep full employment, which results in GDP not suffering a major reduction. The driving force for long-term economic growth is unaffected by changes in the price of energy, so that although there is a traverse to a slightly lower level of energy use, the model keeps the long-run growth rate at the same level,

and this keeps the growth rate of demand for energy high. Because carbon taxes are assumed to be applied both domestically and abroad there is no reason to switch production to foreign sources, while electricity is effectively non-tradable and cannot be switched to foreign suppliers.

20 The relatively small shifts in GDP resulting from alternative policies indicate that energy substitution helps reduce emissions without requiring a significant reduction in GDP. For example, comparing scenario 2 and scenario 7 with a low carbon tax, GDP falls only 1.2 percent by 2010, whereas emissions fall 5.2 percent. The changes in consumer welfare confirm this, with only small impacts on this index. The distribution of income is slightly adversely affected in these cases, but as scenario 5's 6.2 percent GDP growth illustrates, a program of compensating lower-income groups could be carried out without adverse impact on the overall level of GDP (or emissions).

21 One of the important aspects of the policy shifts analyzed is the increase in government spending. In the high-carbon-tax/electricity-subsidy-removal case, government spending rises by nearly 4 percent. This would contribute to welfare in ways that are over and above the creation of extra employment and higher wages, since the increased provision of public goods provides a stream of services in addition to the consumption of marketed goods and of leisure which enter the utility functions of the different groups. To the extent that public goods benefit the poorer groups to a relatively greater extent, this may help to offset the slightly regressive nature of the policies analyzed.

22 The changes in the welfare of the different income groups are generally small for the policies considered. As explained above, this is because the government is assumed to spend the extra receipts from reducing subsidies or increasing taxes, thus creating jobs and holding wages up to offset the declines caused by the direct impact of the policies considered. However, the effects of removing electricity subsidies and of imposing carbon taxes are both regressive, with the highest income group actually being better off as a result of the policies. Despite the higher prices for all energy items, this group is compensated by both (1) the increase in GDP resulting from the extra government spending and (2) the ownership of capital, where the higher rate of return compensates for the smaller stock of capital.

Part 2: Vehicular Emissions and Transport Fuels Policy

23 Deteriorating urban air pollution continues to be a concern in Mexico. In the Zona Metropolitana del Valle de México (ZMVM), the ambient ozone standards have historically been exceeded on more than 300 days a year, and particulate standards over 150 days. Because the transport sector is a significant source of air pollution, there has been much discussion in Mexico on tightening both vehicle emission standards and fuel specifications.

24 The second part of the Mexico EER is intended to address the above problem and consists of two components. The objectives of the first component are to analyze the available data on the vehicle population and the evolution of vehicle emission standards in Mexico, review the emissions inspection program in the Valley of Mexico, and examine the exhaust emissions data collected in the inspection program with a view to identifying those factors that affect emission levels. This component focuses primarily on gasoline vehicles for

which a large body of data exists. The amount of data available on diesel vehicles, in contrast, is limited even in ZMVM. The second component builds on the first component and examines different options for tightening transport fuel specifications in Mexico.

Vehicle Population and Characteristics

25 The official vehicle population figures in Mexico overestimate the number of vehicles in operation. Although new vehicle sales are added every year to the existing population, vehicle retirement is often not captured. In this study, mortality curves for different vehicle categories were constructed for ZMVM and the rest of Mexico to account for vehicle retirement. The total number of gasoline vehicles operating in Mexico in 1999, calculated after applying the mortality curves, was 7.4 million, of which 3.0 million were in ZMVM. This model does not, however, contemplate the atypical operation of imported used vehicles in the border zone with the United States, where large numbers of vehicles of U.S. origin operate with Mexican frontier-zone license plates, with U.S. license plates, or with no plates or registration at all. The gasoline vehicle categories consist of passenger cars, vans and wagons, pickups, class 3, class 5 and class 7.[2] The diesel population is considerably smaller. In 1999, about 253,000 diesel vehicles were operating in Mexico, 48,000 of them in ZMVM.

26 Lead, which acts as a poison for the catalysts used in catalytic converters, was eliminated from gasoline in Mexico in 1997. Three-way catalytic converters became mandatory in light vehicles in Mexico in 1993, and in heavier vehicles in 1996. In 1999, approximately 46 percent of gasoline vehicles operating in Mexico had no converter, in contrast to 78 percent in 1993. In ZMVM, the percentage of vehicles with no converter in 1999 was 42 percent.

27 The weighted average age of vehicles in Mexico in 1999 was 9.1 years, ranging from 7.0 years for vans and wagons to 15.2 years for class 5 and class 7 vehicles. As expected from higher disposable income and stricter emission standards for in-use vehicles, the average age of vehicles in ZMVM—8.9 years—is slightly lower than in the rest of the country, with the exception of vans and wagons, class 5 and class 7 vehicles. With this life expectancy, the introduction of new technology to improve emissions, though required for all new vehicle sales, will not have a substantial overall effect for several years.

28 Odometer readings are recorded when vehicles are inspected. The data were filtered (to eliminate suspect recordings) to estimate the annual kilometers traveled as a function of vehicle usage, model year and catalytic converter type in ZMVM. Consistent with international experience, new vehicles are driven more than old vehicles. Because vehicles equipped with catalytic converters are newer than those without, they are driven more. Taxis are driven the most, whereas trucks (for local delivery) and private vehicles are driven the least. Comparing the most and least intensively used, taxis are driven 45 percent more than gasoline-powered trucks. On average, therefore, there does not seem to be a dramatic difference in the annual kilometers traveled by vehicle type or usage. Vehicles with no

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[2] Class 3 vehicles have a gross vehicle weight of 4,545 kg to 6,364 kg; class 5 and 7 vehicles have a gross vehicle weight of 7,273 kg to 11,818 kg.

converters contribute to 32 percent of total kilometers traveled. Those with three-way converters account for two-thirds of all travel.

Emissions Standards

29 Mandatory testing for vehicle emissions in Mexico City was first introduced in 1988. The emissions standards, which initially applied to the levels of hydrocarbons (HC) and carbon monoxide (CO), were tightened progressively in 1994 and 1996, with further changes introduced in 1999. In 2000 limits for nitric oxide (NO) were established.

30 The initial limits permitted substantially higher emissions from vehicles of earlier model years. However, not only have the general levels of emissions for all vehicles been progressively lowered, but the levels for most for the earlier model years have also been reduced by greater amounts, so that the differences between levels for different model years are now relatively small. A slight allowance is made for the weight of the vehicle with respect to the emissions of HC.

31 A key feature of the Mexico City program to reduce emissions is the use of special certificates for vehicles with low emission levels. These vehicles are exempted from the day-without-a car program that applies to all other vehicles, in which the vehicle cannot be operated on one preassigned day a week.

Emissions Monitoring and Compliance

32 The emissions testing program in ZMVM has evolved through several phases since its inception. Initially tests were carried out in government test-only centers and in privately owned test-and-repair garages. By 1992 all vehicles circulating in ZMVM had to display a certificate showing that they had passed the annual emissions test, or else they would be liable to a fine imposed by traffic police.

33 The use of test-and-repair garages in the absence of a strong enforcement program allowed many garages to profitably issue false pass certificates. Estimates suggested that as many as 50 percent of vehicles obtained passes incorrectly. This led to the closing of all test-and-repair centers in 1996 and the establishment of "verificenters" with much improved protocols for ensuring that testers would find it difficult to issue false pass certificates. In 1997, 22.5 percent of vehicles failed the emissions test at their first submission.

34 Subsequent developments have led to a situation where some of the most polluting vehicles appear to be managing to continue driving in ZMVM. These developments include weaker enforcement—by allowing only the "Ecological" police officers (of whom there are relatively few) to issue fines for failure to display a certificate—and the extension of choice as to where to take a test to centers outside the Federal District (observance of protocols has been more strict in the Federal District than in the rest of ZMVM).

Emissions Characteristics

35 The review analyzed 3.5 million emissions data from 14 semester periods between 1993 and 1999 to (1) identify parameters that affect emission levels and (2) assess future emission trends. Data interpretation was made difficult by the fact that the rigor with

which the inspection program was carried out in ZMVM has varied from year to year as well as by location, with the most rigorous inspection occurring in 1997 in the Federal District (in terms of both the percentage of vehicles that reported for inspection and of inspectors carrying out the tests according to the established protocols and failing vehicles accordingly). For this reason, the improvement in the performance of the same model year vehicles since the first semester of 1997 should be treated with caution.

36 The following is a summary of findings:

- *Model year:* Emission levels were correlated most strongly with the vehicle model year, with generally decreasing emissions with increasing model year. This reflects advancing vehicle technology for controlling exhaust emissions.
- *Total distance traveled:* For a given model year, emissions were not correlated with the total distance traveled to any significant extent. More specifically, there was no monotonic increase in emissions with increasing distance traveled. This may be in part due to engine overhauls and other major repairs carried out on intensively used vehicles.
- *Private versus commercial vehicles:* Over certain model years, commercial vehicles had much higher emissions of CO than privately owned vehicles. There was no trend in the case of NO.
- *Vehicle weight:* Heavier vehicles tended to have higher emissions than lighter vehicles.
- *Catalytic converter type:* Although vehicles equipped with three-way converters came on the market in Mexico in the 1980s, pre-1991 vehicles had the same emission levels irrespective of the status of converter. Two-way converters installed in the 1991 and 1992 model years had no positive impact on emissions in 1999, and in fact increased the emissions of NO compared to vehicles with no converters. Three-way open- and closed-loop converters in vehicles from the 1993 model year and later appeared to be functioning reasonably in 1999.
- *Catalyst deactivation:* A set of criteria established by the California Air Resources Board (CARB) was used to evaluate the percentage of vehicles with "defective" catalytic converters. A significant fraction of pre-1993 vehicles were found to have deactivated catalysts in 1997. This percentage steadily declined such that, by 1999, three-way closed-loop converters were defective in less than 5 percent of vehicles from any model year after 1990, and three-way open-loop converters were defective in less than 3 percent of vehicles after 1992. The corresponding figures for two-way converters from the model years 1991 and 1992 were 12 percent and 22 percent, respectively.

Lessons from Mexico City

37 The emissions test results confirmed that technology is important, in that cars with converters generally emitted less than those without. For model years 1994 and 1995, only three percent of the catalytic converters fitted appeared to be seriously deactivated, so

that the effectiveness of the program of wholesale mandatory converter replacement for these model years, implemented in 2000, is questionable.

38 Given technically efficient testing procedures and an effective enforcement mechanism, the experience in ZMVM shows that it is possible to use a discriminating set of compliance rules. Not only can the pass-level of emissions be tailored to the relevant characteristics of the vehicle population (including age, weight and installed technology), but limits on driving the vehicle can be set so as to reduce the use of the higher-polluting (albeit legal) vehicles on those days when the ambient pollutant concentrations are especially high. By contrast, the purpose of a "day-without-a-car" program—in which the permission to drive a car originally depended only on the last digit showing on number plates—was easily circumvented by many families by the purchase of a second vehicle, thus increasing the total vehicle population which could be used on those days when there was no ban in force.

39 One of the key aspects of any emissions testing program is the relationship between testing and enforcement. The experience in Mexico City shows that for a testing program to be effective, a number of conditions must be met:

- The testing stations should provide accurate evaluations of the emissions levels and should not issue false pass certificates ("false passes") to vehicles exceeding the legal limits.
- A legal framework has to be established that allows sanctions to be applied for failure to carry out the testing protocols correctly. The testing stations must be subject to monitoring by independent bodies, and in cases of noncompliance, sanctions must be applied.
- The certificate for passing the test must be easy to monitor, and there should be sufficient monitors (for example, traffic police) to ensure a high probability of catching vehicles that do not display such a certificate.
- The fine for not displaying or not having a legal emissions test certificate must be high enough to act as an incentive to pass the test.
- The testing technology has to be able to prevent the use of temporary "tuning," which enables a vehicle to pass the test but cannot be sustained for regular driving. In the absence of such a technology, motorists and garages become adept at circumventing the purpose of the testing procedure, which is to identify high-polluting vehicles.
- All testing centers must be subject to equally rigorous implementation of protocols and inspection of their procedures. Otherwise, owners of the highest-polluting vehicles easily identify the "softest" centers for passing the test.
- The private sector in Mexico was able to provide a competitive supply of testing centers. However, as always with such an arrangement, the government had to regulate the sector to prevent profit-seeking activities that were against the public interest (for example, supplying false pass certificates to motorists, thus saving them money but increasing pollution levels).

- The optimal number of centers, relative to the volume of traffic to be tested, has to be licensed. If there are too many small centers, the rigor of the tests tends to be watered down as each garage tries to increase market share.
- The use of garages permitted to both test and repair resulted in very poor implementation, leading to a high level of false pass certificates and, ultimately, the closure of all test-and-repair garages. This conflict of interest needs to be resolved.

Transport Fuel Specifications

40 There has been a growing recognition worldwide that vehicles and fuels should be considered together because of close interactions between fuels, vehicle technology, test driving cycles and reference fuels used in testing emissions. This approach, adopted in North America, has had a significant impact on Mexico, in part because vehicle manufacture in Mexico is closely linked to the North American market, and the severity of air pollution in Mexico City is comparable to what has been experienced in some metropolitan areas of the United States.

41 In the United States new standards, called "Tier 2," will be phased in beginning in the 2004 model year (autumn 2003). Tier 2 is a comprehensive national control program that regulates the vehicle and its fuel as a single system. Under Tier 2, sulfur in gasoline will be reduced from the current national average of about 300 wt ppm to 30 wt ppm, and sulfur in diesel will be lowered by 97 percent from the current limit of 500 wt ppm (which is also currently the limit in Mexico) to 15 wt ppm.

42 Mexico is only now completing the implementation of Tier 1 emission standards, which were introduced in the United States in the 1994 model year (autumn 1993). The auto manufacturers have recently agreed in principle to start phasing in durability requirements[3] for Tier 1 in 2001 and reach full compliance by 2005.[4] Mexico has not adopted supplementary driving cycles introduced in the United States to control emissions under more realistic driving conditions. Historically in Mexico, vehicle emission standards have lagged considerably behind fuel specifications, which are broadly in line with current U.S. transport fuel quality (with the exception of sulfur in gasoline, which is more than double the U.S. average).

43 Against this backdrop, the auto manufacturers in Mexico have recently offered to (1) introduce Tier 2-compliant, light-duty gasoline vehicles with a two-year lag, starting in 2006, and (2) supply only Tier 2-compliant vehicles by 2009. The current proposal is to lower the limit on sulfur in gasoline to 300 wt ppm by 2005, and to the level needed to meet Tier 2 emission standards for gasoline vehicles (30 wt ppm on average) by 2009. Because the discussion in Mexico has focused on gasoline, these proposed measures address ozone concerns more than the issue of fine particulate matter. Because a large body of evidence

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[3] These requirements mandate that vehicles manufactured continue to meet specified emission standards for the "useful life" of the vehicle, currently set at 160,000 km in the United States.

[4] For 80,000 km rather than 160,000 km.

exists linking fine particulate matter to premature mortality and morbidity, Mexico should not lose sight of the need to mitigate particulate emissions from vehicles at the same time.

44 PEMEX, Mexico's state-owned oil company and the country's only refiner, is currently undergoing a multi-billion dollar investment program to be able to process much more Maya crude—which is high in sulfur and heavy residual oil—and to produce higher octane gasoline blending components. The investment program is expected to be completed by 2004. PEMEX faces the formidable task of lowering sulfur content in gasoline (and eventually in diesel) just as it has decided to increase the amount of Maya crude processed. PEMEX has a corporate policy of purchasing only commercially proven refining processes. It would be quite costly to upgrade gasoline in Mexico to meet the new sulfur specifications needed for Tier 2 using only conventional (i.e., commercially proven) refining processes. Enormous savings may be realized for reducing sulfur to 300 wt ppm by using emerging technologies that are beginning to be tested in the United States and that are expected to come onstream by late 2003 at a number of U.S. refineries.

45 There are several considerations in implementing the above-proposed strategy for mitigating transport emissions:

- Fuels and vehicles should be treated as a single system. Introducing Tier 2-compliant gasoline vehicles years ahead of the requisite gasoline sulfur reduction would be costly to consumers who might not benefit from the higher price paid for these vehicles. More specifically, if there is a delay in the gasoline sulfur reduction program, the advanced aftertreatment devices found in Tier 2–compliant vehicles may become deactivated. There are no comprehensive data on the long-term impact of driving tens or even hundreds of thousands of kilometers on high-sulfur gasoline on Tier 2 vehicles; however, in a recent U.S. study, even after 1,400 km, catalytic converter activity did not recover completely after switching back to low-sulfur gasoline
- The auto/oil industry needs to be given sufficient lead time. In the United States, for example, the authorities are required to give four years of lead time to the industry. There is an urgent need in Mexico to reach a consensus and issue final regulatory rulings on vehicle emission and fuel quality standards if 2005 is to be one of the deadlines (for durability requirements and reducing sulfur in gasoline to 300 wt ppm).
- The refinery investment at PEMEX is influenced not only by financial considerations and the need to obtain approval from the Finance Ministry and Congress, but also by the timing of the introduction of Tier 2 standards in the United States. Engineering and construction firms that are candidates for revamping PEMEX refineries to bring sulfur in gasoline down to 300 wt ppm will also be involved in revamping a large number of U.S. refineries to meet the Tier 2 gasoline sulfur standard between 2003 and 2006 and the diesel sulfur standard by 2007; in addition, the next sulfur rulings in the European Union for gasoline and diesel come into effect in 2005. Engineering and construction firms expect to be fully occupied until January 2007. To have the PEMEX

sulfur reduction program in place by 2005, PEMEX will likely need to sign up with a contractor in the next year or two, so as not to suffer the delays caused by being the last one in line. It is widely acknowledged in the oil industry that, by 2005, costs for all refinery projects will have escalated because of shortages in construction personnel and equipment. Another consideration is that if PEMEX wants to take advantage of superior and considerably cheaper emerging refining technologies to reduce sulfur in gasoline, they may have to wait until mid-2004 if "commercially proven" is conservatively defined. Waiting until then would most certainly be too late to meet the deadline of 2005. Lastly, if Congress and the finance ministry want to see the completion of the current investment program before any new investment programs are considered, again it would not be possible to meet the deadline of 2005.

- It would make sense to coordinate the two stages of the gasoline sulfur reduction program so that the necessary infrastructure can be planned in advance during the first stage (300 wt ppm) for the second investment program (average of 30 wt ppm). This would enable rapid implementation of the second sulfur reduction program when the time comes, reducing the cycle time from engineering design to startup.
- In ZMVM, undoubtedly the most polluted region in Mexico, the level of sulfur in gasoline is limited to 500 wt ppm. Lowering sulfur in gasoline from 500 to 300 wt ppm is unlikely to significantly improve air quality. An alternative strategy may merit consideration: introducing Tier 2 emission standards in ZMVM first—possibly before reducing the level of sulfur throughout the country from the current 700 wt ppm to 300 wt ppm—by revamping the one or two refineries that supply gasoline to ZMVM and supplementing the supply with gasoline imports. This move is likely to be opposed by the auto industry, however.

46 These considerations highlight the urgent need for Mexico to recognize the importance of (1) synchronizing the schedule for fuel and vehicle emission standards and (2) allowing considerable lead time to meet the schedule for sulfur reduction. The next two years will be crucial in determining whether the oil industry in Mexico will be in a position to support the auto industry has taken to move towards the gradual phase-in of Tier 1 and Tier 2 emission standards for gasoline vehicles.

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Background

1.1 The Mexico Energy Environment Review (EER) is one of the first "energy-environment reviews" supported by the joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP). Conducted jointly by specialists in the energy and environment sectors in specific countries, these reviews examine the local, regional and global impacts of energy production and consumption. Outputs of these reviews would include diagnosis and analysis of issues related to the exploitation of fossil and other fuels, as well as the development of strategies and the articulation of options to address these issues.

1.2 The use of fossil fuels and their impact on the environment present two distinct but related challenges to Mexico. Mexico is a major oil producer. In the face of mounting evidence that human-induced climate change appears to be occurring as a result of build-up of greenhouse gases (GHGs) that trap heat in the atmosphere, there is a move to try to reach an agreement on limiting the amount of fossil fuel consumption among industrial countries, and to urge developing countries to adopt similar but voluntary agreements. Mexico as an exporter of crude oil will be affected by international agreements limiting fossil fuel consumption.

1.3 It is also important for Mexico to understand how its own fossil fuel consumption is expected to evolve in the coming years, and to see if there is scope for limiting the growth of energy consumption without having too much adverse impact on the economy. According to Mexico's Instituto Nacional de Ecología (INE), carbon dioxide (CO_2) emissions amounted to 0.44 gigatons and methane to 0.0036 gigatons in 1990 in Mexico, corresponding to approximately 2 percent and 1 percent of global emissions, respectively. According to the Carbon Dioxide Information Analysis Center, fossil-fuel CO_2 emissions from Mexico grew at an annual rate of 7.3 percent from 1981 to 1982. From 1983 to 1989, fossil-fuel CO_2 emissions were relatively level. Between 1989 and 1996 total emissions rose 24.8 percent, reaching an all-time high of 95 million metric tons of carbon (equivalent to 0.35 gigatons of carbon dioxide) in 1996. Emissions growth resulted chiefly from increasing oil production; even in 1996, close to three-quarters of emissions were from petroleum products, the highest fraction of any of the major CO_2-emitting countries. Per-capita emissions peaked in 1982. The impact of the oil price dislocations of the late 1970s and early 1980s is also reflected in a 79 percent decrease in emissions from gas flaring after 1982. Consumption of natural gas has become increasingly important in Mexico and now accounts for one-fifth of fossil-fuel CO_2 emissions (Marland and others 2000).

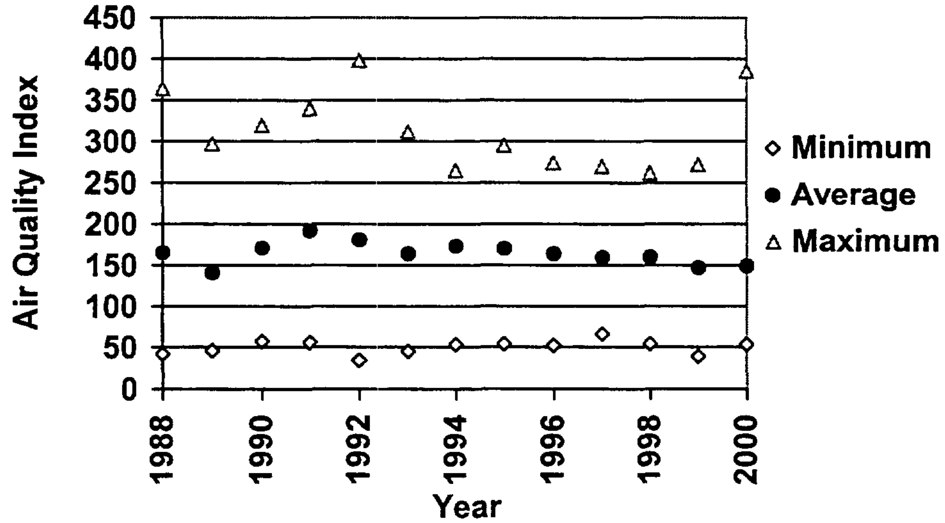
1.4 Mexico also suffers from serious urban air pollution in the form of ozone and fine particulate matter, much of which is due to the combustion of fossil fuels. The ambient concentrations of particles smaller than 10 microns (PM_{10}) and ozone have historically exceeded the air quality standards for a large number of days every year, as shown in Table 1.1. An air quality index called IMECA (Indice Metropolitano de Calidad del Aire) has been defined and computed in Mexico City. The historical trend of IMECA is shown in Figure 1.1. The index of 100 is considered to represent acceptable air quality for public health. There has been some improvement of air quality since the mid-1990s, but the index is still 50 points above what is considered acceptable. Adoption of cleaner technologies, proper maintenance of equipment (such as vehicles), and demand management are key instruments for tackling urban air pollution. Demand management in turn will help reduce GHG emissions.

Table 1.1 Number of Days per Year that Ozone and PM_{10} Concentrations in Mexico City Satisfied Air Quality Standards

Pollutant	*1995*	*1996*	*1997*	*1998*	*1999*
Ozone	41	39	43	45	65
PM_{10}	273	186	212	176	345

Source: GDF (2000)

Figure 1.1 Air Quality Index in Mexico City



1.5 The Mexico EER has two parts. The first addresses GHG emissions and examines energy consumption patterns across the key sectors of the economy with a view to forecasting future energy demand and supply, and associated emissions of pollutants (both local and global pollutants but focusing on GHGs). Several energy-pricing instruments for reducing GHG emissions are then examined in terms of their impact on energy consumption and resulting emissions as well as their macroeconomic and socioeconomic consequences.

1.6 The second part of the EER targets urban air pollution arising from transport emissions and, more specifically, gasoline-fueled vehicles. It examines vehicle fleet characteristics in terms of vehicle technology, age and engine size, and their relations to emissions. It reviews the history of the vehicle inspection and maintenance (I/M) program in Mexico City to distill lessons, and analyzes the emissions data collected in the I/M program. It studies the link between fuel quality and vehicle performance, and discusses the ramifications of the proposed gasoline specifications in the context of the status of the refining sector in Mexico, the effects of fuel quality developments in North America, and likely future vehicle emissions regulations in Mexico.

Introduction to Part 1: Modeling of Energy Consumption and Emissions Under Different Scenarios

1.7 Forecasting demand for energy and calculating associated emissions forms an important component of policy formulation in energy and environment ministries. Both fuels and electricity (generated mostly by burning fuels) are necessary for a host of economic activities. But whereas fuels raise significant tax revenues for the government in Mexico, electricity—which is currently subsidized—is a source of fiscal deficit, making it difficult to expand supply capacity to meet future growth in demand. On the climate change front, the combustion of fossil fuels is the largest contributor to GHG emissions, and the fact that future emissions levels will be closely linked to demand for fuels underscores the importance of demand management in government policy.

1.8 The study team examined energy consumption by using two models to assess the impact of different policy options on energy demand, on emissions, and on Mexico's macroeconomy. The first model, called BRUS-II-M, was developed by the Energy Secretariat (Secretaría de Energía, or SE) by modifying a prototype model provided by Risø National Laboratory in Denmark. It calculated future demand for different fuels and power based on an assumed annual rate of growth of gross domestic product (GDP) and population, price elasticities, and other parameters. BRUS-II-M also calculated emissions of various pollutants associated with energy consumption.

1.9 The team fed these results into a dynamic computable general equilibrium (CGE) model that computed long-run equilibrium levels of GDP, domestic consumption, imports, exports, government revenue, investment, market clearing prices, and welfare for different income groups. Several scenarios were examined, including the impact of not having adopted any of the policies introduced since 1996, eliminating power subsidies, and imposing carbon taxes at two different levels.

Introduction to Part 2: Vehicular Emissions and Transport Fuels Policy

1.10 Deteriorating urban air pollution continues to be a concern in Mexico. In the Zona Metropolitana del Valle de México (ZMVM, or Mexico City Metropolitan Area), the ambient ozone standards have historically been exceeded on more than 300 days a year, and particulate standards on more than 150 days. Because one of the significant sources of air pollution is the transport sector, there has been much discussion in Mexico on tightening both vehicle emission standards and fuel specifications.

Link Between Transport, Fuel, and the Environment

1.11 The pollutants of special concern in Mexico are fine particulate matter and ozone. Transport contributes to high ambient levels of both pollutants. Fine particles are emitted directly from vehicles, and in addition are formed as a result of secondary formation from oxides of nitrogen (NO_x) and of sulfur (SO_x). Oxides of nitrogen are emitted both by gasoline- and diesel-fueled vehicles. In the case of gasoline, NO_x emissions can be reduced by means of three-way catalytic converters. The amount of SO_x emitted is directly proportional to the amount of sulfur in the fuel and is reduced by treating the fuel itself (for example, hydrotreating diesel and gasoline). In general, the largest contributor to fine particulate formation is incomplete combustion of fossil fuels and biomass. Poor fuel quality, inefficient combustion processes, and poor vehicle and equipment maintenance all contribute to fine particulate emissions. Vehicle emissions, which occur near ground level, cause much greater human exposure to harmful pollutants than do emissions from sources at elevated levels, such as power plants.

1.12 Ozone is responsible for photochemical smog and has been associated with transient effects on the human respiratory system. Of the documented health effects, the most significant is decrements in the pulmonary function of individuals engaging in light to heavy exercise. Ozone is formed by photochemical reactions between volatile organic compounds (VOCs) and NO_x in the atmosphere. Ozone abatement is complicated by nonlinear interactions among ozone precursors. Photochemically reactive VOCs include aldehydes, olefins, and aromatics with two or more alkyl groups.

1.13 Gasoline-fueled vehicles are a significant source of photochemically reactive organic compounds, and both gasoline and diesel contribute to NO_x emissions. Although three-way catalytic converters—installed in the majority of gasoline vehicles in Mexico beginning in 1993 and mandated for all vehicles in 1996[5]—have substantially reduced NO_x emissions by converting NO_x to nitrogen, there is no exhaust control for NO_x in in-use diesel vehicles. Therefore, diesel vehicles are expected to make increasing contributions to NO_x emissions from the transport sector in the future.

1.14 As for particulate matter, a series of extensive studies, mainly in the United States, has demonstrated small changes in a wide range of health indicators—mortality, hospital admissions, emergency room visits, time off school or work, respiratory symptoms, exacerbation of asthma, and changes in lung function—that show clear associations with particulate concentrations. Of the various health indicators, the measurement of mortality has been particularly well studied. In terms of health impact, small particles are much more damaging than coarse particles. Their small average size means that the particles are able deeply to penetrate the body's respiratory tracts, especially the alveolar regions of the lung. Particles

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[5] Catalytic converters became mandatory for vehicles weighing less than 2,722 kilograms in 1993, and for heavier vehicles in 1996.

smaller than 2.5 microns ($PM_{2.5}$) are especially responsible for high incidences of respiratory infections. Although particulate matter can vary widely from area to area and over time, the size of the estimated effects, particularly those on mortality, does not vary greatly with location.

1.15 Recent studies have indicated that the number of particles to which the individual is exposed could be more important than the particles' mass. Although air quality standards for particulate matter are based on mass throughout the world today, standards based on number are expected to be increasingly introduced in the medium-term future. Measures that reduce the mass of particles emitted do not necessarily reduce the number of fine particles. For example, a recent study showed that at highway speeds the numbers of particles were similar among three gasoline and four diesel vehicle types tested and remained unaffected by the quality of the fuels (*Automotive Environment Analyst* 1998).

1.16 Traffic is a large contributor to fine particulate emissions. On a mass basis, diesel vehicles generally emit much more fine particulate matter than do gasoline vehicles. In terms of the number of particles, the difference between light-duty gasoline and light-duty diesel vehicle emissions in one study was found to vary from a factor of more than 2,000 at 50 kilometers per hour (km/h) to 3 at 120 km/h. In terms of size, a higher proportion of gasoline particulate emissions may be of smaller size (less than 1 micron) than diesel emissions (CONCAWE 1998). There is a growing view that diesel exhaust poses a serious cancer risk, suggesting that diesel particulate emissions may be especially harmful to public health.

1.17 Another concern is airborne toxics, of which only limited data on ambient concentrations are available. Toxic emissions from vehicles include benzene, polycyclic aromatics, 1,3-butadiene and aldehydes. 1,3-butadiene is a potent carcinogen. Benzene, another carcinogen, is increasingly targeted for reduction in gasoline.

1.18 The drive in North America and elsewhere to limit sulfur in gasoline and diesel stems from the fact that sulfur acts as a poison for the precious metals that are the active components in conventional catalytic converters (although the effects may be reversible) as well as from the incompatibility of high levels of sulfur with emerging exhaust control technologies (such as continuously regenerating traps for diesel powered vehicles).

Mexico City Metropolitan Area

1.19 The ZMVM consists of two jurisdictions: the Federal District and the State of Mexico. The evolution of the vehicle I/M system offers many lessons including those on the advantages and disadvantages of (1) test-and-repair centers versus high-volume, test-only centers and (2) public versus privately managed inspection centers; and the impact of (1) the number of test centers relative to the size of the vehicle fleet and (2) the fact that two different government entities (in this case the Federal District and the State of Mexico) are administering the same emission standards and monitoring compliance.

1.20 Because the I/M system in ZMVM has existed for a number of years, there is a large database of emissions measurements. This provides a valuable tool for understanding the impact of various parameters—vehicle age, vehicle technology, vehicle engine size, vehicle usage, odometer readings—on emission levels, as well as the impact of emission standards and the rigor with which they are enforced. This study has tried to examine some of these relationships.

Fuel Quality

1.21 There are complex interactions between fuels, vehicle technology, test driving cycles and reference fuels with regard to their relative influences on vehicle emissions. A given vehicle will show different emission levels depending on the test driving cycle. As an illustration, Mexico effectively relaxed emission standards for gasoline vehicles recently by modifying the test driving cycles to reduce the failure rate of in-use gasoline vehicles for nitric oxide (NO) emission limits at vehicle inspection centers (exhaust emission limits were unchanged).

1.22 A number of fuel parameters affect vehicle emissions. For gasoline, they include volatility, distillation temperature profile, and the amount of lead, sulfur, benzene, total aromatics, olefins, and oxygen-containing compounds commonly referred to as *oxygenates*. For diesel, they include distillation temperature profile, density, cetane, and the amount of sulfur and aromatic—particularly polycyclic aromatic—compounds. Mexico phased lead out of gasoline in 1997, so lead emissions from vehicles no longer pose a threat to public health.

1.23 As mentioned in the previous section, sulfur in gasoline acts as a (temporary) poison for catalytic converters. Vehicle manufacturers recommend that the level of sulfur in gasoline be kept below 500 parts per million by weight (wt ppm), and preferably below 100 wt ppm. The impact of reducing sulfur on catalytic converter performance follows a non-linear relationship, with emissions decreasing more rapidly below 100 to 150 wt ppm.

1.24 Benzene is a carcinogen and is emitted from gasoline both as a result of evaporation and as unconverted benzene from the exhaust pipe. Alkyl-aromatics (i.e., all aromatics other than benzene) also dealkylate during combustion, and a fraction is emitted as benzene. Benzene in gasoline contributes much more to the overall benzene emissions than non-benzene aromatics—it takes roughly an order of magnitude more alkyl aromatics than benzene itself in gasoline to result in the same amount of benzene emissions from the tailpipe, and only benzene itself can contribute to evaporative emissions.

1.25 Aromatics with two or more alkyl groups are photochemically reactive and contribute to ozone formation. Therefore, the photochemical reactivity of aromatics and their decomposition to benzene are the two primary environmental concerns leading to limits on the amount of aromatics in gasoline. For vehicles equipped with catalytic converters, the U.S. Auto/Oil Air Quality Improvement Research Program (AQIRP) found that decreasing total aromatics from 45 percent to 20 percent had no significant impact on ozone formation (Auto/Oil AQIRP 1997). For vehicles not equipped with catalytic converters, increasing aromatics in gasoline increases NO_x emissions. As described earlier, NO_x is a precursor for both ozone and secondary fine particulate formation.

1.26 Olefins are photochemically reactive and are ozone precursors. This is the primary concern. In addition, at elevated levels olefins increase the emissions of NO_x. In the U.S. Auto/Oil AQIRP, reducing olefins in gasoline from 20 percent to 5 percent led to a marked decrease in predicted ozone. Because VOCs contain photochemically reactive hydrocarbons (HC), reductions in VOC emissions will reduce the amount of ozone precursors in the atmosphere. One effective way to prevent this is to reduce gasoline volatility. In the U.S. Auto/Oil AQIRP, lowering Reid vapor pressure (RVP)[6] from 9 pounds per square inch (psi) to 8 psi led to a marked decrease in predicted ozone as a result of lower light olefins.

1.27 Oxygenates such as ethers and alcohols have high blending octane and facilitate combustion in vehicles not equipped with oxygen sensors. They also dilute gasoline, thereby decreasing the amount of undesirable gasoline components such as benzene and olefins. Oxygenates are more miscible (mixable) with water than gasoline, however, and contamination of ground and drinking water with methyl tertiary-butyl ether (MTBE), the most extensively used oxygenate, is a growing concern in the United States.

1.28 Sulfur in diesel was reduced to 500 wt ppm in 1993 in the United States and 1996 in Mexico and the European Union (EU) to control particulate emissions. In the future converter technology will most probably be used to control emissions from diesel vehicles, and the impact of sulfur on catalysts (as in the case of gasoline) will become an equally important consideration.

1.29 The European Programme on Emissions, Fuels and Engine Technologies (EPEFE), as part of the European Auto/Oil Programme, examined the impact of varying polycyclic aromatics (aromatics with more than one ring) on vehicular emissions and found that decreasing polycyclic aromatics from 8 percent to 1 percent decreased both particulate and NO_x emissions from light-duty and heavy-duty diesel vehicles. The impact of reducing total aromatics on vehicular emissions is less clear. A cooperative program between Esso and Statoil found, for example, that reducing total aromatics from 32 percent to 10 percent had no marked effect on particulate emissions (Betts and others 1992).

Fuel Quality Trend in Industrial Countries and Implications for Mexico

1.30 In North America, the EU and Japan, there is a move towards "sulfur-free" fuels. The United States Environmental Protection Agency (US EPA) has set future gasoline and diesel sulfur limits at 30 and 15 ppm, respectively. The EU is targeting 50 ppm for both fuels, although there is talk of lowering the diesel sulfur limit to 10 ppm. These moves represent the "best available technology" and, although costly to implement, are intended to enable adoption of the state-of-the-art exhaust emission control systems.

1.31 Mexico's vehicle manufacturing industry is closely integrated into the North American market. Mexico will probably adopt similar standards and technologies eventually, but the immediate question is how to phase in appropriate measures cost-effectively. In answering this question, the following factors need to be taken into account:

- Air quality in different cities in Mexico;
- Vehicle fleet characteristics, including the level of vehicle maintenance, age and technology;

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[6] Reid vapor pressure (RVP) is a measure of gasoline volatility.

- The structure of the refining sector in Mexico and the crude slate;
- The relative costs of adopting state-of-the-art vehicle and fuel technologies compared to those for addressing other issues such as water quality, health service and education.

Structure of the Report

1.32 This report is divided into two parts. Chapters 2 and 3 make up Part I, which deals with the modeling of energy consumption and resulting emissions as a function of several policy scenarios. Chapter 2 reviews the methodology underlining the analysis, and describes in some detail the two computer programs used in this study. Chapter 3 presents the results of the modeling and discusses the likely impact of several energy policy options on the macroeconomy as well as demand for energy and GHG emissions from the combustion of fossil fuels and biomass.

1.33 Chapters 4 and 5 form Part II. Chapter 4 deals with vehicle emissions, with a focus on gasoline-fueled vehicles in the Valley of Mexico. The chapter begins by reviewing emissions standards, monitoring and compliance policies. It next deals with the characteristics of the vehicle population, vehicle production and sales. It then takes 3.5 million emissions measurements from the I/M program in the Valley of Mexico and examines the parameters that are expected to affect emissions levels.

1.34 Chapter 5 turns to fuel quality improvement, and discusses the potential impact of gasoline sulfur reduction—the most important question facing Mexico today in the area of transport fuel quality—on the refining sector, as well as the readiness of the refining sector for sulfur reduction. The characteristics of the vehicle fleet described in Chapter 4 are also considered in examining the suitability of fuel sulfur reduction as a strategy for mitigating transport emissions in Mexico.

2

Modeling of Energy Demand Forecast

2.1 Energy use is crucial to economic development and improving the welfare of society. Optimal supply and consumption of energy, however, requires careful consideration of various aspects of energy production and use, including energy supply to final consumers, energy pricing, and emissions from the production and consumption of energy. Fossil fuels—oil, gas and coal—are by far the greatest contributor to emissions from energy use, although biomass is another source of emissions. The emissions include the so-called local and regional pollutants (such as carbon monoxide, particulate matter, SO_x, NO_x and ozone), and those greenhouse gases (GHGs) with global warming potential. There is little controversy over the fact that the concentrations of GHGs have risen in recent years. There is also a growing body of evidence that increasing GHG emissions from human activity are contributing to a rise in the earth's surface temperature.

2.2 The international community's response to increasing emissions of GHGs centers on the U.N. Framework Convention on Climate Change (FCCC) agreed at the Earth Summit in Rio de Janeiro in 1992. This was supplemented in December 1997 by the Kyoto Protocol, under which the developed countries made legally binding commitments to reduce their emissions of six GHGs by an overall total of 5.2 percent below 1990 levels between 2008 and 2012. However, the protocol will become legally binding only when it has been ratified by at least 55 parties to FCCC, including Annex B developed countries accounting for at least 55 percent of global CO_2 emissions in 1990, and this has not yet happened. In particular, the prospect is slim of the United States ratifying the protocol in either the short or the medium term, and without its participation the protocol's implementation is unlikely to be successful.

2.3 If the Kyoto Protocol were ratified and implemented, such a course of events would affect Mexico, a significant oil and gas producer. The official position of the government of Mexico on the Kyoto Protocol is that of no voluntary agreement. The government has nonetheless taken a number of steps to reduce emissions from the combustion of fossil fuels in general, and of GHG emissions in particular. The amount of gas flared or vented during production will be curtailed significantly in the future. In the power sector, nearly all future power plants commissioned by Comisión Federal de Electricidad (CFE) will use natural gas in combined cycle gas turbine power plants. The *Prospectiva del mercado de gas natural* issued each year by SE sets ambitious targets for expanding the use of natural gas in various sectors. Natural gas is a clean fuel with virtually no particulate or other harmful emissions, and in addition it reduces greenhouse gas emissions relative to other fossil fuels, particularly coal.

2.4 The purpose of Part I of the Mexico EER is to assess the impact of policies to reduce GHG emissions on energy consumption, emissions, the macroeconomy and social welfare in Mexico. The study was undertaken jointly by SE and the Environment, Natural Resources and Fishery Secretariat (Secretaria de Medio Ambiente, Recursos Naturales y Pesca, or SEMARNAP). The objective of the study was to forecast energy demand and supply to the year 2010 under different scenarios, and assess the impact of the introduction of several policies on GHG emissions, key macroeconomic parameters, and equity.

2.5 Some of the key energy policy issues facing SE include (1) the amount of oil and gas to be produced in the future and how to finance the capital outlays required; (2) the amount and type of oil to be exported versus refined for domestic consumption; and (3) how to meet rapidly growing demand for power given generation capacity shortfalls and burgeoning power tariff subsidies (which amounted to US$3.4 billion in 1998). One of the first steps in addressing these issues is to estimate demand for power and various fuels in the next 10 years and how that demand may be affected by various economic parameters and government policies. From the viewpoint of SEMARNAP, the question is how to support economic development with increasing energy consumption while protecting the environment. Examination of measures to reduce emissions of harmful pollutants is a principal concern of SEMARNAP. The ministry is also engaged in dialogue with the international community on emission reduction targets for GHGs at conferences of the parties (COP) of the FCCC and elsewhere, including COP-6 in the Hague in November 2000.

Approach

2.6 To determine the relationship between emissions and the level of the economy in such a way as to be able to analyze the impact of policy switches at a sector level, the study team decided that the overall model strategy would require a "bottom-up" demand model to be linked to a macro-CGE model. The former would allow for demands for energy from all major sectors and would track the impact on emissions through a detailed linking to the technologies used to meet these demands. The aggregate of the demands would be linked to overall macroeconomic variables via a purpose-built CGE model.

2.7 To estimate future energy demand in the bottom-up model, the team analyzed seven major sectors in the economy : residential, service, industrial, transport, power, refining, and gas processing. The first five sectors were further decomposed into subsectors. The results of the findings from this sector analysis were then linked to a macroeconomic model to assess the impact of different policies on GDP, government budget, trade, employment and equity (effects on different income groups). Emissions were computed for each sector separately and for Mexico as a whole.

2.8 Two computer programs were used to carry out analysis in this study. One was the bottom-up model, called BRUS-II-M; this was used to compute energy demand as a function primarily of annual GDP, population, value added in each sector, energy efficiency gains and price elasticities. From energy-use data, the total of emissions at a country level was computed. Because the BRUS-II-M model does not distinguish demands and activities by locations, it cannot isolate urban emission levels from the total. The other model was a CGE model developed by Professor Roy Boyd of Ohio University and calibrated for Mexico. Historical data for 1996 were entered in both programs as a starting point.

2.9 BRUS-II-M was run for two time periods (in this study, 1996–2004 and 2004–2010) and accepted annual GDP growth rates, discount rates and prices for these time periods as inputs. Fuel substitution and energy saving policies could be imposed, as could energy efficiency gains. Historical consumption data in different sectors were collected and regression analysis carried out to forecast future demand as a function of key economic parameters. The outputs from BRUS-II-M included demand for fuels and electricity in each sector, emissions in each sector as a function of fuel used, and supply of power in three geographical regions as a function of mode of power generation.

2.10 The CGE model had nine producing sectors, sixteen production goods, four household categories (income levels), seven consumption sectors, a foreign sector and a government sector. The relationships between final demand and inputs of all goods were based on the most up-to-date input-output table available. The value added in each producing sector allowed for substitution between labor and capital through constant elasticity of substitution (CES) functions. Output prices were determined by market clearing. Consumer demand for goods depended on prices and incomes. Labor supply, taxes and transfers determined household incomes, while the government budget was related to tax revenues and government spending.

2.11 The CGE model was first benchmarked from 1996 using an assumption about the growth of the economy which was also to be used in the later scenarios; cases of low (3.7 percent), most likely (5.2 percent) and high growth (6.2 percent) rates were simulated. In this case all sectors are assumed to have grown at the same rate over the horizon of the model (because there are no changes in relative prices). All other scenarios can be compared to each other via their comparisons to this benchmark case.

2.12 To simulate the impact of the alternative scenarios, the team ran BRUS-II-M (if necessary) to obtain the fuel outputs from different sectors. Since these were now different from the levels taken in the benchmark case, they were fed into the CGE model as exogenous factors; the model recomputed the relative prices needed to clear the markets, and the associated macroeconomic variables. For a given GDP scenario (say 5.2 percent annual growth) used in BRUS-II-M to calculate the outputs for a given change in policy, the CGE model may show that aggregate output itself will be affected by the policy option chosen. In this study, the impact of GDP (which is the primary driver for outcomes in BRUS-II-M) of different policy options was small, so that the results from the CGE model were not fed back to BRUS-II-M for further iteration.

Description of the Models

2.13 The study team modeled the years 1996–2010, basing all calculations on 1996 Mexican pesos. BRUS-II-M—run for 1996, 2004 and 2010—computed total fuel consumption in the economy based on pre-determined annual GDP growth rates (3.7 percent, 5.2 percent and 6.2 percent, taken from the *prospectivas* prepared by SE for 1999–2009). The period from 1996 to 2010 was selected based on interest expressed by SE to assist in the preparation of future *prospectivas*. The three GHGs considered in this study were CO_2, methane (CH_4) and nitrous oxide (N_2O).[7] The consumption figures by fuel type were fed into the CGE model to target the same fuel consumption levels. The CGE model was run for every year between 1996 and 2011. The outputs from CGE included changes to GDP growth, relative prices, and impacts on expenditures in different income groups.

BRUS-II-M

2.14 BRUS-II-M is a Microsoft Excel–based computer model originally developed by Risø National Laboratory Systems Analysis Department in Denmark. SE and the World Bank modified the program extensively. The final version of the program used in this study consisted of the following sectors:

- *Residential*: The residential sector was divided into urban and rural households. The model considered 17 electrical appliances (air conditioning, air washers, computers, dishwashers, dryers, fans, fluorescent light bulbs, incandescent light bulbs, irons, microwave ovens, ovens, refrigerators, television sets, washing machines, water pumping, video cam recorders, and "other") as well as different fuel options for hot water heating, cooking and space heating. In each case, the team used the percentage of houses using the particular appliance or fuel and energy consumption per year per household to compute overall energy use. Future projections (in terms of percentages of households using the appliances, the number of appliances per household, and so on) were provided by Universidad Nacional Autónoma de México (UNAM) on the basis of their research.
- *Service:* For the service sector, the model considered energy consumption in the use of electronics, pumps, air compressors, ventilation, air conditioning, cooking, water heating, lighting and process heat. Fuel substitution was considered in the service sector. Projections of future energy use were based on regression analysis of past data as a function of population and value added, which is assumed to grow at the same rate as GDP.
- *Industry:* For the industrial sector, the model considered 17 sub-sectors: agriculture, aluminum, beer, cement, ceramics and glass, chemicals, construction, fertilizers, iron and steel, mining, paper, petrochemicals, rubber,

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[7] In addition, some data were entered to compute emissions of carbon monoxide (CO), sulfur dioxide (SO_2), NO_x, non-methane hydrocarbons and particulate matter. However, because this section of BRUS-II-M is not fully complete, these results will not be presented in this report.

sugar, tobacco, vehicle manufacture and "other." Auto-generation and co-generation, as well as fuel substitution, were considered.

- *Transport:* For the transport sector, the model considered passenger cars, delivery vans, trucks, urban and inter-urban buses, trains and metros, ferries and ships. Annual vehicle kilometers traveled, total number of vehicles in each vehicle category, and fuel economy are used to compute fuel consumption. The projected number of vehicles is based on regression analysis of past data (as a function of GDP and population), while the annual number of kilometers traveled grows in proportion to per capita GDP. Fuel switching was considered. Gasoline vehicles were subdivided into those with and without three-way catalytic converters, because aged three-way converters have been found to increase N_2O emissions.
- *Power:* For the power sector, the model considered thermal, hydroelectric, geothermal, nuclear, wind and solar power plants. CFE furnished all the data, including future plant construction to the year 2008. Power generation was divided into three geographical regions, in accordance with CFE's database. Each type of power plant (for example, hydroelectric, coal, or combined cycle) was given a priority assignment and a load duration curve, which, together with the priority ranking, was used to determine the order in which different plants were run and for how many hours. In the case of power supply shortage, more plants were built.
- *Refining:* PEMEX provided the data for the purpose of computing fuel consumption. The model used a single set of numbers irrespective of scenarios considered.
- *Gas plants and oil & gas exploration and production:* PEMEX provided the data for the purpose of computing emissions. The model used a single set of numbers, except for the amount of gas flared or vented with and without the recently introduced government policy to limit flared and vented gas.

2.15 Although it is a comprehensive program, BRUS-II-M is amenable to future refinements by virtue of the fact that it is written in Excel. SE and SEMARNAP will continue to collect data and modify the program as new information and data become available.

2.16 Data on the energy contents of different fuels and emission factors were taken from the Reference Manual of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*[8] whenever the figures were available. The most extensive documentation was found for CO_2 (which is largely a function of the carbon content of each fuel aside from combustion efficiency) and methane. SO_2 emission factors were based on the sulfur content of each fuel, unless flue gas desulfurization units were installed. It was difficult to estimate emission factors for the other pollutants in some cases.

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[8] Intergovernmental Panel on Climate Change (1996).

2.17 The study team encountered some difficulties in obtaining data needed as inputs to the program. Where requisite data were not available, simplifying assumptions had to be made. For example, if price elasticity was available for one fuel type but not another, the same elasticity was assumed as long as fuels were "similar" (for example, diesel and fuel oil). It was particularly difficult to estimate capital costs for (1) technologies designed to increase energy efficiency and (2) emerging, commercially unproven technologies. Although BRUS-II-M was designed to calculate capital cost requirements in principle, the team was not able to obtain much of the needed information. Therefore, incremental capital cost requirements for implementing different policy options will not be presented in this report.

2.18 In developed countries with extensive data availability, a bottom-up model can be used to evaluate different technology improvement options and their cost-effectiveness. Unfortunately, in this case, because of the above shortcomings concerning cost data, it was not possible to assess the dynamic effects on energy efficiency in response to higher carbon taxes and other energy saving policies.

Computable General Equilibrium Model

2.19 The Computable General Equilibrium (CGE) model is designed to focus primarily on the workings of the energy sector in Mexico and to show that sector's linkages to the economy at large. Hence, it contains a number of special features not commonly found in country-wide CGE models. For example, the outputs from refining and petrochemicals are broken down into seven different categories rather than being treated as a single output. More specifically, the output of the refinery/petrochemicals sector is broken down into liquefied petroleum gas (LPG), gasoline, diesel, kerosene, fuel oil, coke, and petrochemicals. To allow for output transformation in the refining and petrochemicals processes, an elasticity of transformation between fuels is also included. These seven outputs in turn are used as inputs for the nine production sectors as well as the seven consumption sectors, and are traded on international markets. A more detailed description of this model is given in Annex 1.

2.20 At the same time, output in the oil and gas extraction is also broken down into its constituent parts, namely, crude oil production and natural gas production. Again, as with refining, these two outputs do not necessarily occur in fixed proportions and can be altered according to an elasticity of transformation. Finally, as with the refinery sector, the oil and gas outputs are used as inputs in other production and consumption sectors, and sold to foreign consumers.

Production

2.21 The production portion of the CGE model is built on information from a balanced data set that is flexible as regards the substitution between the primary factor inputs (capital and labor). The input-output table used is an updated version of the 1990 table; the update was performed with information provided by SEMARNAP. Technologies are represented by production functions, which exhibit constant elasticities of substitution. Technological progress is taken as exogenous to the model. Production in each sector for every time period is represented as a CES value added function of capital and labor inputs, where the elasticity of substitution can vary between zero and infinity.

2.22 Producers maximize profits in a competitive market environment in each time period. Output and input prices are treated as parameters. Profit maximization, based on the described production technology, yields output supply and factor demands for each production sector and factor market in the model. One central modification to the model is made. The modification consists of introducing nested functions in the production side of the economy as well as in the production of final consumption goods and services. These nests allow for different degrees of substitution for the inputs considered. In the particular case of production, it allows substitution between labor, capital, energy, and non-energy inputs; and in the case of the production of consumption goods, between food and housing, transport, and household energy use.

2.23 The equilibrium in the labor market is endogenous. Demand for labor is determined by the firms as a result of their profit maximization process. Sixty hours per week is the limit of time that can be either supplied as labor or enjoyed as leisure. This leisure/labor choice is made by individuals (in this case by the income groups) depending on the marginal tax rate on income. The higher this marginal tax rate, the less labor supplied and the more leisure consumed. The rate of growth of population is exogenous.

Consumption

2.24 On the demand side, the CGE model reflects the behavior of domestic consumers and foreigners (who can also invest) as well as the government. Domestic consumers are grouped according to income and a demand equation is specified for each group. The four income groups in this model are termed *agent 1* (bottom 20 percent), *agent 2* (next 30 percent), *agent 3* (next 30 percent) and *agent 4* (top 20 percent). Each group has a different consumption bundle depending on its income. All four groups are endowed with labor; the two better-off groups are also endowed with capital, which they sell to finance (1) the purchase of domestic or foreign goods and services, (2) savings or (3) the payment of taxes to the government. Maximizing the nested utility function with respect to the expenditure constraint simultaneously determines the consumption level of the seven consumer goods and services, the amount of labor supply, and the consumers' level of saving and investment in each of the time periods.

Government

2.25 The government sector is treated as a separate agent. The government agent is modeled with an expenditure function similar to the household expenditure functions (based on a CES utility function). Revenues derived from all taxes and tariffs are spent according to an expenditure function. Government revenues and expenditures are equal as a result. The government also redistributes income through subsidies and transfer payments. Taxes in the model are expressed *ad valorem* and include personal income taxes, labor taxes, capital taxes, property taxes, revenue taxes, value added taxes, sales taxes, and import tariffs. When applicable, taxation is based on marginal tax rates. To capture the incentive effect of the tax system, the highest marginal rate is levied on the relevant revenue base. Since this procedure results in over-taxation, the difference between the revenue generated by the highest marginal tax rate and the average tax rate is rebated to consumers as a lump-sum transfer.

Trade

2.26 International trade within the model is handled by means of a foreign agent. Output in each of the producing sectors is exported to the foreign agent in exchange for foreign-produced imports. Price-dependent import supply schedules are derived from elasticity estimates found in the literature (See, for example, Serra-Pache 1984, Romero 1994 and Fernández 1997).

2.27 In specifying the substitutability between foreign and domestically produced goods, we replace the classic Hecksher-Ohlin assumptions and rely instead on the Armington assumptions. Under there assumptions, foreign imports and domestically produced goods are considered to be imperfectly substitutable goods (as opposed to Hecksher-Ohlin case where foreign and domestically produced goods are perfect substitutes). Armington postulates that domestic and foreign goods are both inputs in a CES production process, the output of which is a combination of the two, and it is this combined good that is consumed domestically. The benefit of such a setup is that a country can both import and export goods from the same industry sector. Thus, for each time period, the value of total imports is equal to the total value of exports plus foreign transfers. Since these transfers are used to finance domestic investment, this relation provides the closure rule, namely, that investment is equated to domestic savings minus net exports. This, of course, includes balanced trade as a special case.[9]

Prices

2.28 In the CGE model prices are normalized to levels in 1996, so that movements thereafter serve to indicate relative changes. The model does not allow for any inflation, and a discount factor is used to convert values of output in later years to constant 1996 terms. Finally, it is important to emphasize that the model is constantly in equilibrium and that prices, rather than being sticky, move so that each market is cleared each period. As a result, there are no short-run unemployment effects arising from the failure of any market to clear. This feature of the dynamic model means that the simulation results reported in the next chapter represent medium- to long-run effects, rather than the short-run effects of any policy changes.

Labor Growth and Capital Formation

2.29 Growth within the dynamic CGE model is brought about by the changes over time in both the labor force and the capital stock. In keeping with the theoretical underpinning of the Ramsey model, changes in the population are taken as exogenous and constant over the time period considered. In the absence of any perturbation, the Ramsey model predicts that the economy will grow at the labor growth rate in the steady state. Labor growth itself is the sum of the growth in the number of workers and the growth in efficiency of each worker.

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[9] Capital flows are the remainder of the exports minus imports, or net exports, since the deficit in the current account must be made up for by the capital account. Mexican investment abroad is considered here since in 1994 Mexico was a net exporter.

2.30 The capital growth rate is modeled in accordance with capital theory and is represented by a system of three equations. For each time period the following conditions hold:

- The opportunity cost of acquiring a unit of capital next year is a unit of consumption in the present period.
- The price of capital in this period must be equal to the present period's rental value of capital plus next period's price of capital.
- The capital stock in the next period must be equal to this year's capital stock plus net investment.

Taken together, these relations ensure that economic growth will be consistent with profit-maximizing behavior on the part of investors.

Calibration and Data

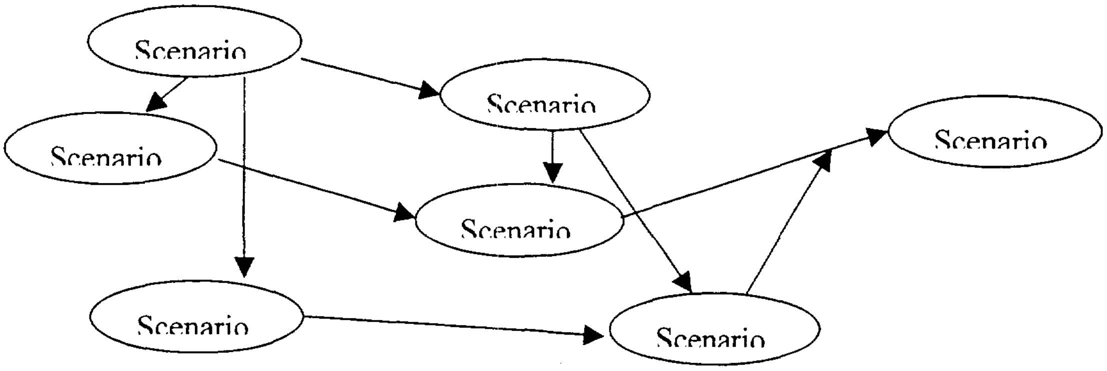
2.31 The model is calibrated to a 1996 data set, with these data coming from a variety of sources. The team obtained 1996 data for income and expenditure for each of the income categories. Data on consumer expenditures on final goods by income category are from the *Encuesta Nacional de Ingresos y Gastos de los Hogares 1996* published by the Instituto Nacional de Estadística, Geografía e Informática (INEGI). Data on imports and exports are from *International Financial Statistics*, various editions, published by the International Monetary Fund (IMF), *The Mexican Economy 1995* published by the Banco de México, and the *Anuario Estadístico de los Estados Unidos Mexicanos 1996* published by INEGI. Data on inputs, outputs, and use of labor and capital by production sector comes from data compiled by INEGI and supplied by SEMARNAP. This same source, along with the *Anuario Estadístico de los Estados Unidos Mexicanos,* was used to calculate the transformation matrix as well as to find investment levels by sector. All results on fossil fuel consumption (both aggregate and sectoral), fuel prices, fuel imports and exports, and government consumption of various fuels were provided by SE, PEMEX, and INEGI.

2.32 The team calculated tax levels and rates from the input-output tables as well as from *El Ingreso y el Gasto Público en México 1996* by INEGI. The latter documents, along with *The Mexican Economy 1995* and *Encuesta Nacional de Ingresos y Gastos de los Hogares 1996,* were also used to obtain data on government expenditures and transfer payments. Finally, data on interest rates, capital earnings, and depreciation were obtained from *The Mexican Economy 1995*, as well as from Barro and Sala-i-Martin (1995). Substitution elasticities between capital and labor were taken from Heuter (1997) and Skuta (1997) and import demand elasticities were taken from Wylie (1995) who obtained estimates on various imported items.

Scenarios Examined

2.33 This study examined the impacts of not implementing the policies recently adopted by the government of Mexico, of eliminating power tariff subsidies, and of imposing carbon taxes. Each scenario is described in detail below. The relationships among different scenarios are shown in Figure 2.1.

Figure 2.1 Linkages Among Different Scenarios



Scenario 0—Benchmark

2.34 This is a calibration run for the CGE model whereby every economic parameter is made to grow at a pre-determined rate every year. All other results from CGE are defined in terms of percentage changes relative to scenario 0. BRUS-II-M is not run for this scenario. There is a calibration run for each of the three growth rates simulated. The size of the government budget balances year by year in scenario 0 are the reference points for policies that are "revenue neutral"—that is, such policies produce the same total government spending for each year as are calculated in scenario 0.

Scenario 1—No New Policies

2.35 Scenario 1 represents the case whereby none of the energy related policies adopted by the government of Mexico since 1996 is implemented. Specifically, future power plants run on fuel oil, there are no attempts to minimize gas flaring and venting during oil production, and there are no policies to promote the use of fluorescent light bulbs or natural gas in various sectors. A comparison of scenarios 1 and 2 will indicate emissions savings as a result of the implementation of the current policies.

Scenario 2—Baseline

2.36 Scenario 2 defines the current situation, or the baseline. It includes all the policies that are already in place or have been adopted for implementation by the government of Mexico. The policies incorporated in the model include the following:

(a) ILUMEX, which promotes substitution of incandescent bulbs with fluorescent bulbs in the residential sector (for example, installation of 2.4 million fluorescent bulbs by 2004).

(b) Annual growth of natural gas use in the industrial and residential sectors by 13.6 percent and 4.3 percent (at 5.2 percent annual GDP growth) to 2010. This is achieved in BRUS-II-M by substituting LPG and fuel oil with natural gas.

(c) Elimination of use of kerosene in the industrial sector.

(d) Promotion of co-generation and auto-generation in the industrial sector.

(e) Installation of new power plants as per CFE's plan to 2008, with the majority being combined cycle natural gas fired plants.

(f) Promotion of the use of compressed natural gas (CNG) as a transport fuel in Mexico City, resulting in the numbers of CNG vehicles shown in Table 2.1.

Table 2.1 Number of CNG Vehicles Operating in Mexico City: Data Entry in BRUS-II-M

Vehicle type	*2004*	*2010*
Passenger cars	9,764	48,177
Urban buses	6,183	24,754
Delivery vans	9,864	75,872

Scenario 3—Elimination of Power Tariff Subsidies

2.37 This scenario eliminates power tariff subsidies in scenario 0. CGE requires that all cases be run relative to scenario 0 first before adding conditions contained in scenario 2. Two cases were run. In the first case, power tariff subsidies were eliminated without safeguard policies introduced to assist those lesser-off households who are now having to pay more for electricity. In the second case, the government surplus arising from subsidy removal was used to make two lump-sum transfers to raise consumer incomes of agents 1 and 2 to the same level as in scenario 0.

Scenario 4—Carbon Taxes

2.38 Scenario 4 takes scenario 2 and imposes a carbon tax of about US\$10–12/ton of CO_2 (US\$37–44/ton of carbon) on oil, gas and coal. The level of carbon tax is comparable to the equilibrium international permit price of US\$11–12/ton of CO_2 recently computed by the Oxford Institute for Energy Studies and the Center for International Climate and Environmental Research in Oslo (Bartsch and Müller 2000). The latter study assumed that the Kyoto targets are achieved with full flexibility among the Annex B countries. This base case is referred to as the *low carbon tax case* hereafter. A higher carbon tax case (referred to as the *high carbon tax case*), where carbon taxes were increased by an additional 50 percent, was also examined.

Scenario 5—Power Subsidy Elimination on Scenario 2

2.39 Scenario 5 takes scenario 3 and adds to it the conditions contained in scenario 2. This enables examination of the impact of power subsidy elimination on the baseline case. With respect to safeguard policies, the government surplus arising from subsidy removal was used to make two lump-sum transfers to raise consumer incomes of agents 1 and 2 to the same level as in scenario 2.

Scenario 6—Carbon Taxes

2.40 Scenario 6 takes scenario 4 and adds to it the conditions contained in scenario 2. This enables examination of the impact of imposing carbon taxes on the baseline case.

Scenario 7—Combined Case

2.41 This scenario takes scenario 5 and adds carbon taxes, enabling examination of the combined impact of eliminating power subsidies and imposing carbon taxes on the baseline case.

3

Modeling Results

3.1 The team ran BRUS-II-M for scenarios 1, 2, 5, 6 and 7 for each of the three GDP growth rates, computing fuel demand as well as GHG emissions. The CGE model was first run in what is termed "Benchmark" using a 1996 Mexican social accounting matrix. In this scenario—scenario 0 as described in Chapter 2—imports, exports, government expenditures, production and consumption in all sectors rise steadily by the initial rate of growth and all prices expressed in 1996 units decline each period by the rate of discount. Specifically, the values of all future outputs in today's terms decline by the social discount rate; in this model this was accomplished by letting the current prices decline in each period after the initial period. In addition, income and household welfare, the capital stock, government spending and imports all grow by this same rate. There are three benchmark cases, each corresponding to a different assumption with respect to overall economic growth: 3.7 percent, 5.2 percent and 6.2 percent per year. The different growth rates are introduced by allowing the "technical progress augmented" labor force to grow at these different rates—that is to say, although the actual growth in labor force might not be different, labor force was effectively considered to grow at different rates as a result of differences in productivity increase—and allowing capital and all sectors to adjust to this new rate.

3.2 To see the effects of policies, the study team ran the CGE model using inputs from BRUS-II-M. In each of the years that BRUS-M solves for (2004 and 2010), the quantities of fuels and energy sources differ from the quantities implied by constant growth. Hence, the quantities for those years are translated into a format compatible with the CGE format[10] and entered directly into the CGE program as an exogenous change. In other words, the quantities calculated by BRUS-II-M are first translated into percentage changes (since all quantities in the CGE model are calculated on a percentage basis). They are then entered into the CGE model as shifters to the model's calculated production of those fuels in each of the years solved for by BRUS-II-M. The CGE model solves for a new equilibrium based on these

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[10] In CGE there are no quantity variable units as such. A *quantity unit* is described as the quantity that could be purchased by 1 peso in 1996. Hence, the prices of individual fuels are used to translate their quantities into CGE units.

shifts for each of the fuels in the energy sector. The incremental results of this policy are then obtained by contrasting the results of the new model run with that of the steady state. In each scenario, the models were calibrated so that the level of each variable matched the actual level observed in 1996.

Energy Demand and Emissions from BRUS-II-M

3.3 As mentioned earlier, there was no iteration between CGE and BRUS-II-M, and the results obtained using the CGE model were not fed back to BRUS-II-M. Therefore, the results presented here represent the leading order estimates. In particular, the impact of both the removal of power subsidies in scenario 5 and 7 and the imposition of carbon taxes depends only on price elasticities of demand entered into BRUS-II-M and not on resulting incremental changes in GDP. This was considered acceptable since the incremental changes in GDP compared to the starting assumptions were negligibly small on an annualized basis, as Table 3.7 and Table 3.8 show.

3.4 Table 3.1 shows projected fuel and power demands in 2004 and 2010. By 2010, demand for fuels is about double that in 1996 in all cases at an annual GDP growth rate of 5.2 percent, and the increase in demand for power is even greater. Comparison of scenarios 1 and 2 shows that the impact of implementing current energy policies compared to the counterfactual of not adopting any of them is modest, resulting in a 3 percent drop in demand for fuels and a 0.4 percent drop in demand for power at an annual GDP growth rate of 5.2 percent by 2010. The impact of eliminating power subsidies is greater on demand for power than on demand for fuels as a whole, as expected. Relative to scenario 2, scenario 5 shows about a 3 percent drop in demand for fuel by 2010, but a considerably greater drop in demand for power—as much as 21 percent in the high GDP growth case. Imposing carbon taxes does not greatly affect fuel and power demand, resulting in a fall on the order of 2 percent compared with scenario 2. As expected, combining carbon taxes with power subsidy elimination results in the largest fall in demand, with fuel demand falling by about 6 percent and demand for power by close to 15 percent in the high carbon tax case compared to scenario 2.

3.5 The resulting emissions are shown in Table 3.2 to Table 3.6. The emissions are computed on a CO_2-equivalent basis, using the numerical estimates of global warming potentials given by the Intergovernmental Panel on Climate Change over a time scale of 100 years. The panel estimates that the global warming potential of methane is 21 times and that of N_2O is 310 times that of CO_2.

Table 3.1 Fuel and Power Demand in 2004 and 2010 (petajoules)

Scenario	*1*	*2*	*2*	*2*	*5*	*5*	*5*
% GDP growth	5.2	3.7	5.2	6.2	3.7	5.2	6.2
Fuel demand in 2004	7,477	6,399	7,212	7,841	6,231	6,993	7,598
% Increase relative to 1996	46	25	41	53	22	37	48
Power demand in 2004	953	814	941	1,038	747	864	941
% Increase relative to 1996	61	38	59	75	26	46	59
Fuel demand in 2010	10,746	8,311	10,442	12,265	8,068	10,096	11,877
% Increase relative to 1996	110	62	104	139	58	97	132
Power demand in 2010	1,435	1,084	1,429	1,734	993	1,310	1,429
% Increase relative to 1996	142	83	141	193	68	121	141

Scenario	*6*	*6*	*7*	*7*
% GDP growth	5.2	5.2	5.2	5.2
Carbon tax	Low	High	Low	High
Fuel demand in 2004	7,089	7,028	6,839	6,763
% Increase relative to 1996	38	37	34	32
Power demand in 2004	920	910	832	817
% Increase relative to 1996	55	54	41	38
Fuel demand in 2010	10,281	10,207	9,911	9,818
% Increase relative to 1996	101	99	93	92
Power demand in 2010	1,408	1,396	1,271	1,251
% Increase relative to 1996	138	136	115	111

Note: Fuel demand includes fuels needed in power generation. Power demand is shown separately on account of the importance of the power sector, and includes power generated from all sources including renewables.

Table 3.2 Emissions in Scenarios 1 and 2 (million tons of CO_2 equivalent)

		Scenario 1, 5.2% GDP growth			*Scenario 2, 5.2% GDP growth*		
Fuel type	*1996*	*2004*	*2010*	*% growth 1996–2010*	*2004*	*2010*	*% growth 1996–2010*
Fuel oil	82	144	261	8.6	72	74	-0.7
Diesel	38	56	88	6.1	54	85	5.8
Kerosene	0.7	0.6	0.8	0.8	0.2	0.2	-8.7
LPG	26	32	40	3.1	34	45	4.0
Gasoline	71	113	179	6.8	113	175	6.6
Jet fuel	6.9	8.9	14	5.2	8.9	14	5.2
Natural gas	80	113	132	3.7	147	243	8.3
Coal	16	31	31	4.8	31	31	4.8
Biomass	37	39	40	0.5	39	41	0.7
Coke	11	15	18	3.4	16	19	4.0
Petroleum coke	0.2	0.3	0.4	3.8	4.5	9.1	29.6
Total fuels	371	554	804	5.7	520	737	5.0

Note: *Percent growth* refers to the annualized rate of growth in emissions between 1996 and 2010.

Table 3.3 Emissions in Scenarios 2 and 5 (million tons of CO_2 equivalent)

	Scenario 2, 3.7% GDP growth			*Scenario 2, 6.2% GDP growth*			*Scenario 5, 5.2% GDP growth*		
Fuel type	*2004*	*2010*	*% growth 1996–2010*	*2004*	*2010*	*% growth 1996–2010*	*2004*	*2010*	*% growth 1996–2010*
Fuel oil	47	55	-2.9	83	75	-0.6	58	54	-2.9
Diesel	46	60	3.3	62	106	7.5	54	83	5.7
Kerosene	0.2	0.1	-12.0	0.3	0.3	-6.8	0.2	0.2	-8.7
LPG	33	43	3.7	35	47	4.3	34	45	4.0
Gasoline	95	130	4.4	126	213	8.1	113	175	6.6
Jet fuel	7.1	9.4	2.2	10	18	7.1	8.9	13.9	5.2
Natural gas	141	194	6.6	157	297	9.8	145	239	8.2
Coal	31	31	4.8	31	31	4.8	31	31	4.8
Biomass	38	39	0.4	40	43	0.9	39	41	0.7
Coke	15	17	3.1	17	21	4.5	16	19	4.0
Petroleum coke	4.5	8.4	28.8	4.5	9.6	30.1	4.5	9.1	29.6
Total fuels	458	588	3.4	566	861	6.2	504	712	4.8

Note: *Percent growth* refers to the annualized rate of growth in emissions between 1996 and 2010.

Table 3.4 Emissions in Scenario 5 (million tons of CO_2 equivalent)

	Scenario 5, 3.7% GDP growth			*Scenario 5, 6.2% GDP growth*		
Fuel type	*2004*	*2010*	*% growth 1996–2010*	*2004*	*2010*	*% growth 1996–2010*
Fuel oil	37	40	-5.1	77	76	-0.6
Diesel	46	60	3.3	61	106	7.5
Kerosene	0.2	0.1	-11.8	0.3	0.3	-6.8
LPG	33	43	3.7	35	47	4.3
Gasoline	95	130	4.4	126	213	8.1
Jet fuel	7.1	9	2.2	10.4	18	7.1
Natural gas	139	192	6.5	149	275	9.2
Coal	31	31	4.8	31	31	4.8
Biomass	38	39	0.4	40	43	0.9
Coke	15	17	3.1	17	21	4.5
Petroleum coke	4.5	8.4	28.9	4.5	9.6	30.2
Total fuels	446	570	3.1	551	839	6.0

Note: *Percent growth* refers to the annualized rate of growth in emissions between 1996 and 2010.

Table 3.5 Emissions in Scenario 6 (million tons of CO_2 equivalent)

	Scenario 6, 5.2% GDP growth, low tax			*Scenario 6, 5.2% GDP growth, high tax*		
Fuel type	*2004*	*2010*	*% growth 1996–2010*	*2004*	*2010*	*% growth 1996–2010*
Fuel oil	68	72	5.7	66	70	-1.2
Diesel	54	83	-8.7	54	83	5.6
Kerosene	0.2	0.2	3.9	0.2	0.2	-8.7
LPG	33	44	6.6	33	44	3.8
Gasoline	112	174	5.2	112	173	6.5
Jet fuel	8.9	14	8.2	8.9	14	5.2
Natural gas	144	239	4.8	143	238	8.1
Coal	31	31	0.7	31	31	4.8
Biomass	39	41	3.8	39	41	0.6
Coke	16	19	29.5	15	18	3.7
Petroleum coke	4.5	9.0	4.9	4.5	9.0	29.5
Total fuels	511	726	5.4	507	721	4.9

Note: *Percent growth* refers to the annualized rate of growth in emissions between 1996 and 2010.

Table 3.6 Emissions in Scenario 7 (million tons of CO_2 equivalent)

	Scenario 7, 5.2% GDP growth, low tax			*Scenario 7, 5.2% GDP growth, high tax*		
Fuel type	*2004*	*2010*	*% growth 1996–2010*	*2004*	*2010*	*% growth 1996–2010*
Fuel oil	52	47	-3.8	49	44	-4.4
Diesel	54	83	5.6	53	83	5.6
Kerosene	0.2	0.2	-8.7	0.2	0.2	-8.7
LPG	33	44	3.9	33	44	3.8
Gasoline	112	174	6.6	112	173	6.5
Jet fuel	8.9	13.9	5.2	8.9	14	5.2
Natural gas	142	236	8.1	141	234	8.0
Coal	31	31	4.8	31	31	4.8
Biomass	39	41	0.7	39	41	0.6
Coke	16	19	3.8	15	18	3.7
Petroleum coke	4.5	9.0	29.6	4.5	9.0	29.6
Total fuels	493	699	4.6	487	692	4.6

Note: *Percent growth* refers to the annualized rate of growth in emissions between 1996 and 2010.

3.6 Table 3.2 shows that in 1996, fuel oil and natural gas were the largest contributors to GHG emissions in Mexico. Had the government carried on with the policies that were in force in 1996, the amount of GHG emissions from fuel oil would have more than tripled by 2010. As a result of the government's policy to expand the use of natural gas at the expense of fuel oil, GHG emissions from fuel oil actually decline in scenario 2 for all the three GDP growth rates. Overall, 67 million tons of CO_2-equivalent emissions are saved in scenario 2 compared to scenario 1 in 2010.

3.7 Examination of scenario 2 in Table 3.2 and Table 3.3 shows that GHG emissions grow at or slightly below the rate of GDP growth in scenario 2: the annual rates of growth of GHG emissions between 1996 and 2010 are 3.4 percent, 5.0 percent and 6.2 percent for the corresponding GDP growth rates of 3.7, 5.2 and 6.2 percent, respectively. The consumption of coal is independent of GDP growth (and of policy options considered in this study) because it is used at power plants that have no access to gas, and hence fuel switching is not an option.

3.8 The removal of power subsidies reduces emissions, so that the rate of growth in emissions is lower than that of GDP in scenario 5. Imposing carbon taxes does not have as much effect. Even at the high carbon tax rate of US\$15–18 per ton of CO_2 (equivalent to US\$55–66 per ton of carbon), the reduction in emissions is comparable to (and slightly less than) that when power subsidies are eliminated.

3.9 As one might expect, combining carbon taxes with the removal of power subsidies has the greatest impact on controlling emissions. There was little incremental benefit of imposing the higher of the carbon tax rates, with emissions reaching about 700 million tons of CO_2 equivalent by the year 2010 at the annual GDP growth rate of 5.2 percent. Additional results are given in Annex 2.

CGE Outputs

3.10 Detailed results from the CGE model outputs are tabulated in Annex 2. A discussion of the key results is given below. Because prices calculated in the CGE model are market clearing prices and are not necessarily informative for policymakers (because each market is cleared in each period, as described in Chapter 2), their values are not reported separately. Prices are discussed in the following sections, however, to explain other results.

Scenario 0, Benchmark

3.11 Scenario 0, called the *benchmark case*, assumes that there is no change in energy policy over the 1996–2011 time horizon and that, consequently, there is no change in the relative prices of the various fuels. The results are shown in Table 3.7. It is important to note that the function of the benchmark case is to provide a framework against which all other policies will be contrasted. Scenario 0 shows what would happen if all sectors the Mexican economy were to continue to grow at a specified rate throughout the period of the model simulation.

3.12 Furthermore, scenario 0 assumes that the balance of trade, government revenue and expenditure, the amount of savings in this economy, and the effective labor supply in hours worked all grow by this exogenously specified rate of growth. Accordingly, since all components of income and the amount of leisure[11] grow at the same rate, the distribution of income remains constant while welfare for each group grows at a common rate. Welfare per individual grows at the rate of technical progress (the common growth rate less the population growth rate). Scenario 0 might then be thought of as a "balanced growth" scenario starting in 1996.

Scenario 1: No New Policies

3.13 1996 was an important year for policymakers. At that time they had the option of continuing on with past policy (corresponding to scenario 1 in this study, the "no new policy" scenario) or pursuing a different set of policies (the policies outlined in scenario 2). The government chose the latter path. Nonetheless, because it is a matter of some interest to see what would have happened under previous policy and, both scenarios are contrasted to the benchmark case.

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[11] This does not refer to *leisure per household*, which is generally constant, but rather about the value of *aggregate leisure*, which grows as the population and income increases. Leisure per household can, however, change in response to changes in the income tax rate, and this, of course, changes the aggregate levels of labor and leisure as well.

Table 3.7 CGE Results in Scenarios 0, 1 and 2 for the Year 2010 (trillions of 1996 pesos unless indicated otherwise)

Scenario	*0*	*0*	*0*	*1*	*2*	*2*	*2*
% GDP annual growth in BRUS	3.7	5.2	6.2	5.2	3.7	5.2	6.2
Emissions, million tons of CO_2				804	588	737	892
% Change relative to scenario 2				9.0	0.0	0.0	0.0
GDP calculated in CGE	4.44	5.43	6.20	5.41	4.48	5.47	6.25
% Change relative to scenario 2	-0.77	-0.75	-0.69	-1.18	0.0	0.0	0.0
% GDP annual growth computed	3.7	5.2	6.2	5.2	3.8	5.3	6.2
Capital stock	7.91	11.62	15.16	11.56	8.01	11.77	15.36
% Change relative to scenario 2	-1.23	-1.26	-1.28	-1.79	0.0	0.0	0.0
Balance of payments	0.11	0.14	0.16	0.14	0.11	0.14	0.16
% Change relative to scenario 2	0.88	0.00	0.63	0.71	0.0	0.0	0.0
Government expenditure	1.63	1.78	1.88	1.77	1.64	1.78	1.89
Government revenue	1.63	1.78	1.88	1.77	1.64	1.78	1.89
% Change relative to scenario 2	-0.25	-0.23	-0.27	-0.45	0.0	0.0	0.0
Welfare							
Agent 1, lowest 20%	1.041	1.132	1.200	1.132	1.042	1.133	1.201
Agent 2, next 30%	3.111	3.383	3.584	3.381	3.114	3.386	3.587
Agent 3, next 30%	4.814	5.234	5.546	5.223	4.814	5.233	5.544
Agent 4, highest 20%	7.992	8.690	9.207	8.691	7.984	8.678	9.191
% Change relative to scenario 2							
Agent 1, lowest 20%	-0.10	-0.09	-0.08	-0.09	0.00	0.00	0.00
Agent 2, next 30%	-0.10	-0.09	-0.08	-0.15	0.00	0.00	0.00
Agent 3, next 30%	0.00	0.02	0.04	-0.19	0.00	0.00	0.00
Agent 4, highest 20%	0.10	0.14	0.17	0.15	0.00	0.00	0.00

Note: Emissions are those of CO_2, methane and N_2O computed in BRUS-II-M and are on a CO_2-equivalent basis. The welfare figures are cumulative, discounted between 1996 and 2010 by the discount rate used in the CGE model.

3.14 Scenario 1 involves pursuing the same energy policies after 1996 that were pursued before 1996. This is quite a bit different from the energy policies followed in the benchmark case. In scenario 0 it was assumed, among other things, that gas fields, oil power stations, and fuel transportation networks grow at the same constant rate of growth. The policies actually considered by the government earlier were characterized by very little development of domestic gas fields, by the construction of oil fired electrical power plants, by little effort to curb the use of gasoline, and by continued usage of kerosene and diesel in rural areas. These policies in the energy sectors have the effect of temporarily altering the growth rate in all sectors until they return to their initial steady state growth paths in the year 2010, and will also leave the economy at a different level in 2010 than it would have attained in scenario 0, as shown in Table 3.7. Sectoral results are given in Table A2.19 to Table A2.21 in Annex 2.

3.15 Production output shows little or no change from scenario 0. There is, however, a marked decrease in the production of natural gas and an increase in the use of coal, petroleum and fuel oil. This is just as would be expected because domestic natural gas fields are not being utilized as much relative to scenario 0, while fuel oil and coal are in higher demand for electricity and manufacturing production processes. Manufacturing and chemical use declines somewhat because of higher fuel costs and sluggish investment. Interestingly, electricity use falls relative to scenario 0 because a lack of natural gas drilling causes electricity production costs to remain high, and demand low, in spite of continuing subsidies.

3.16 Consumption patterns under scenario 1 vary little from the benchmark case. In fact, with the exception of energy use (which includes electricity), gasoline and food consumption, all of which experience slight declines, there is barely any change. Import changes here are closely tied to the changes in production goods noted above. Imports of natural gas, to take one example, rise relative to a steady growth case to compensate for the lack of natural gas production within Mexico. Similarly, fuel oil imports decline as their domestic production increases.

3.17 Total government revenues, and hence spending, decline slightly. The level of the capital stock is 0.5 percent smaller than in scenario 0. This is because these energy policies have brought about a modest decline in the level of overall economic investment. The welfare of the poorest agent class remains unchanged, that of agents 2 and 3 declines slightly, and that of the high income consumers rises a very small amount.

Scenario 2—Baseline

3.18 Scenario 2 simulates the economy-wide impact of a host of energy policies that are either planned or have recently been put into place. In keeping with the simulation procedure outlined above, these new policies are first entered into BRUS-II-M, and the changes in relative fuel quantities are calculated as outputs to the simulation. These outputs in turn are entered into the dynamic CGE model; the results are given in Table 3.7. All projected changes are phased into the model over the eight-year period beginning in 2000. Such a procedure is much more realistic, and much more in keeping with actual policy guidelines, than an immediate jump in either supply or demand in energy markets.

3.19 The impacts of the policy changes in scenario 2 are relatively very large. In the case of natural gas, for example, the output in scenario 2 is almost twice that in the benchmark case, as shown in Table A2.22. The results show that as the deliverability of natural gas increases, its price drops and its production rises relative to the steady growth case. The lower price of natural gas, in turn, leads to an increase in the production of electricity. The success of other policy objectives, however, is not as clear-cut. Because of the high overall growth rate spurred by new investment, the demand for diesel increases somewhat and its production rises in spite of significant conservation initiatives by policymakers.

3.20 An examination of the input-output data reveals that, because the production of electricity is highly dependent on natural gas, a decline in the natural gas price serves to boost potential electricity supply nationwide. Demand for electricity remains fairly stable during the period examined, and this stability, combined with the supply increase, leads to a fall in electricity's price.

3.21 By encouraging the use of natural gas, the demand for its chief substitute, fuel oil, declines relative to scenario 1. The use of coke, gasoline and diesel rises as expected. However, contrary to expectations, the use of LPG and kerosene also rises. This is because the greater demand in the manufacturing and transport sectors increases the need for these fuels, and their use increases in spite of the efforts of policymakers to curb their supply.

3.22 One of the chief reasons for using a CGE model in an exercise such as this is to quantify the impacts of energy sector changes on production and consumption sectors throughout the economy. One thing that happens following these changes is that production in the oil and gas extraction sector decreases relative to both scenarios 0 and 1. This occurs because the decrease in fossil fuel demand more than compensates for the increase in domestic natural gas production. It should be pointed out, however, that there are substantial sources of foreign natural gas that may be substituted for domestic supplies. Furthermore, the extent to which this result holds depends critically on the elasticity of transformation between natural gas and crude oil in the extraction process. Natural gas and crude oil are often extracted together as a joint output in Mexico, and the more they must be extracted together (a low elasticity of transformation), the more extraction of crude oil will have to increase for a given increase in natural gas production. As far as the other production sectors are concerned, there is less change from scenario 0. Manufacturing, services, chemicals, and agriculture production all increase between one and five percent with reference to the benchmark case, and slightly more with respect to scenario 1. Finally, the level of overall investment and GDP increase as the new policy takes shape.

3.23 In contrast to the model's production sectors, the use of consumer goods is quite close to the benchmark case. The most significant change occurs in the energy sector: spurred by lower natural gas and electricity prices, consumer use of energy services increases several percent. Interestingly, the actual consumption of gasoline declines a little. This is because the price of refined gasoline and services (which account for almost all of the value-added of the actual gasoline consumed at the pump) increases relative to other production goods, and consumers substitute away from it. The production of gasoline increases slightly while its consumption goes down. This apparent contradiction is explained by the fact that "consumption" here refers to final consumption, and some gasoline goes to intermediate consumers and foreign consumers. As with scenario 1, import changes largely act as a counterweight to mitigate the severity of domestic production and price changes somewhat. Hence, imports of natural gas, fuel oil and coke decline by one-half. In spite of higher natural gas production, the increase in electricity production requires more of all existing imports, and this includes relatively low-price fuel oil from abroad. LPG imports decline relative to benchmark, whereas most other sectors experience a fairly small change in import levels. The overall balance of trade declines because of an aggregate increase in the demand for foreign goods brought about by the increase in GDP.

3.24 The welfare effects are markedly different from those in scenario 1. As noted above, investment is spurred by energy policy, leading to a generally higher level of economic growth than in the benchmark case. As a consequence, the final value of the capital stock increases by over 1 percent relative to the benchmark case. This policy seems to be fairly progressive, reflecting the importance of lower energy prices to the poor. Only the top-20-percent group experiences some loss of welfare, whereas agents 1 to 3 all benefit, with relative gains increasing with increasing income. The higher capital stock results in higher unearned income for the top income groups; however, in the case of the highest income group, increases in cost means that the net effect is to reduce income relative to scenario 1.

Scenario 3—Power Subsidy Elimination Relative to Scenario 0

3.25 In scenario 3, the rather substantial subsidies on electricity prices in Mexico are eliminated economy-wide. If subsidies had been applied uniformly across all sectors and income groups, then the results would be quite straightforward, and indeed a CGE analysis would provide little information that a simple partial equilibrium model would not provide. Subsidies in Mexico, however, vary considerably by sector: the agricultural sector receives a subsidy of 70 percent, the industrial sector receives an overall subsidy of only 10 percent, residential users get a subsidy of 57 percent, the public sector has subsidies of 5 percent, and the transportation sector receives subsidies of 50 percent. Removing such a system of subsidies then should produce a wide range of results that vary by production and consumption sector.

3.26 Turning to the results of this simulation, the most important of which are given in Table 3.8, the removal of electricity subsidies initially leads to a marked decline in the demand for and production of electricity. Following this decline, however, electricity production again increases at the steady state rate. Other production sectors experiencing negative shocks include agriculture, chemicals, petroleum and manufacturing. The decline in agriculture is due to the fact that its price increases relatively because of the large increase in costs following the subsidy removal. Manufacturing and chemical production, on the other hand, decrease because of their strong connection to investment supply and the fact that investment initially falls. Put another way, as GDP falls, investment falls and the rate of return to capital rises, and the supply from the manufacturing and chemical industries falls. By and large, all other production sectors are not affected by the subsidy removal. The level of GDP declines relative to the benchmark case.

Table 3.8 CGE Results in Scenarios 3–7 for the Year 2010 (trillions of 1996 pesos unless indicated otherwise)

Scenario	*3*	*4 low tax*	*5*	*5*	*5*	*6 low tax*	*6 high tax*	*7 low tax*	*7 high tax*
% GDP annual growth in BRUS	5.2	5.2	3.7	5.2	6.2	5.2	5.2	5.2	5.2
Emissions, million tons CO_2			570	712	839	726	721	699	692
% Change relative to scenario 2			-3.1	-3.4	-2.6	-1.5	-2.2	-5.2	-6.1
GDP	5.42	5.39	4.47	5.46	6.23	5.42	5.35	5.41	5.33
% Change relative to scenario 0/2	-0.24	-0.84	-0.22	-0.29	-0.21	-0.92	-2.36	-1.18	-2.62
% GDP annual growth computed	5.2	5.1	3.7	5.2	6.2	5.2	5.1	5.2	5.1
Capital stock	11.58	11.39	7.97	11.71	15.29	11.53	11.18	11.48	11.13
% Change relative to scenario 0/2	-0.35	-2.06	-0.46	-0.48	-0.48	-2.09	-5.27	-2.54	-5.72

Balance of payments	0.14	0.12	0.11	0.14	0.15	0.12	0.11	0.12	0.11
% Change relative to scenario 0/2	-1.46	-14.9	-0.90	-1.46	-1.95	-15.8	-26.4	-18.8	-31.1
Government expenditure	1.79	1.81	1.64	1.78	1.89	1.81	1.83	1.83	1.85
Government revenue	1.79	1.81	1.64	1.78	1.89	1.81	1.83	1.83	1.85
% Change relative to scenario 0/2	0.67	1.66	0.12	0.11	0.16	1.93	3.00	2.63	3.63
Welfare									
Agent 1, lowest 20%	1.130	1.131	1.041	1.132	1.199	1.132	1.131	1.130	1.129
Agent 2, next 30%	3.376	3.38	3.110	3.382	3.583	3.382	3.379	3.377	3.373
Agent 3, next 30%	5.225	5.235	4.810	5.230	5.540	5.235	5.238	5.228	5.232
Agent 4, highest 20%	8.688	8.705	7.991	8.686	9.201	8.694	8.721	8.694	8.721
% Change relative to scenario 0/2									
Agent 1, lowest 20%	-0.18	-0.09	-0.10	-0.09	-0.17	-0.09	-0.18	-0.27	-0.35
Agent 2, next 30%	-0.21	-0.09	-0.13	-0.12	-0.11	-0.12	-0.21	-0.27	-0.39
Agent 3, next 30%	-0.17	0.02	-0.08	-0.06	-0.07	0.04	0.10	-0.10	-0.02
Agent 4, highest 20%	-0.02	0.17	0.09	0.09	0.11	0.18	0.49	0.18	0.49

Note: Emissions are those of CO_2, methane and N_2O computed in BRUS-II-M and are on a CO_2-equivalent basis. Percent changes are relative to scenario 0 for scenarios 3 and 4, and to scenario 2 for scenarios 5, 6 and 7. The welfare figures are cumulative, discounted between 1996 and 2010 by the discount rate used in the CGE model.

3.27 There is a significant decrease in the consumption of energy. This is to be expected since this sector includes electricity consumption. Food consumption also decreases somewhat because of the rising costs of agricultural production. Services and housing then increase as consumption switches to sectors whose prices have risen relatively the least. In contrast to scenarios 1 and 2, the level of imports hardly changes in any of the model's import sectors. The balance of trade, however, does decline somewhat.

3.28 Subsidies on electricity were first installed to protect various sectors and to improve the lot of the lowest income groups. Hence it is not surprising that their removal would have a negative impact on income distribution. Table 3.8 show that welfare decreases for all consumers, but that the percentage decrease for the lower groups is higher than for the upper groups. Furthermore, the capital stock and final period investment decline a little since overall investment is slightly discouraged by the removal of power subsidies. Government revenue is increased significantly and the additional revenue is assumed to be spent in the same proportions as in the case of the 1996 revenue. To examine the impact of a more pro-poor policy, Table 3.9 shows the results of making a different assumption about the pattern of government spending. The additional government revenues were used to make two lump-sum transfers from the government to low-income agents 1 and 2, increasing consumer incomes to their benchmark level. The results show that although consumer agents 1 and 2 have no loss of welfare, the total government budget has still increased in size and there is little change in investment or the capital stock. These results illustrate that the pattern of government spending has little effect on the macroeconomy.

Table 3.9 Impact of Lump-Sum Transfers in Scenario 3

Party/item	*Income range*	*Trillions of pesos*	*% Change relative to scenario 0*
Agent 1	Lowest 20%	1.132	0.000
Agent 2	Next 30%	3.383	0.000
Agent 3	Next 30%	5.225	-0.172
Agent 4	Highest 20%	8.688	-0.023
Government		1.783	-0.449
Capital Stock		11.576	-0.406

Scenario 4—Imposition of Carbon Taxes Relative to Scenario 0

3.29 In this scenario, taxes on fossil fuels are gradually increased over the period 2000–2007 in an attempt to address increasing concern about the impact of greenhouse gas emissions from anthropogenic sources. The carbon taxes imposed are equivalent to about US$10–20 per ton of CO_2, or $37–44 per ton of carbon. As a percentage of net-of-tax prices, the tax on coal reaches a level of 45 percent by the year 2007. The tax on petroleum rises to 8.5 percent by 2007, while the tax on natural gas increases by 10 percent by 2007. The simulation is also run under the assumption of higher rates (all taxes are increased by an additional 50 percent). This translates to the tax on coal rising to 67.5 percent, the tax on petroleum rising to 12.75 percent, and the tax on natural gas rising to 15 percent.

3.30 Some of the key findings for the low carbon tax case are shown in Table 3.8. Following the imposition of a carbon tax, there is a general decline in output. The level of GDP declines by 0.8 percent by 2010 relative to the benchmark case as less fuel is available for use in manufacturing and transportation. As expected, the largest single decline comes in the production of coal, which decreases by 44 percent in the year 2010. Crude petroleum production declines by 8.7 percent and natural gas production by 5 percent by 2010.

3.31 The decline in fossil fuel production causes ripple effects across the economy. Because of its heavy reliance on fuel, production in the electricity sector declines somewhat. Other sectors such as chemicals, agriculture and various petroleum products also experience modest losses, and the level of aggregate investment declines by almost 4 percent compared to the benchmark case.

3.32 In contrast to the production sectors, the consumption sectors in this model deviate very little from the benchmark case. Food consumption declines some, but housing and consumer services actually increase by a small amount. Otherwise there is little change.

3.33 Similarly, import levels change little relative to the benchmark case, largely because of the way the simulation was run. In running this scenario, imported oil, natural gas, and coal are taxed by the same amount as their domestic counterparts to prevent a flood of cheap foreign products, and hence little change in most import levels is seen. The balance of trade, however, changes substantially since the export levels of petroleum decline substantially as a result of the worldwide decrease in demand for petroleum following its general increase in taxation in all countries. The scenario assumes implicitly that Mexico will impose a carbon tax only if there is substantial agreement elsewhere to do the same, thus leading to a global reduction in the demand for carbon-based fuels.

3.34 The welfare figures in Table 3.8 show that the effect of a carbon tax is slightly regressive. This is because of the relatively larger consumption of energy and electricity by the lower classes. Interestingly, agents 3 and 4 experience welfare increases despite the reduction in the level of capital, which affects their incomes. The decline in the relative prices of the service items they tend to consume more heavily raises welfare more than the impact of the reduction in the level of the capital they own.

Scenario 5—Power Subsidy Elimination Relative to Scenario 2

3.35 Scenario 5 combines the assumptions in scenarios 2 and 3. In essence scenario 5, compared to scenario 2, shows the incremental impact of the removal of power subsidies relative to a situation that continues with current 2000 policies. Table 3.8 shows the results of this exercise; Table A2.25 to Table A2.27 show more details.

3.36 The results in the production sectors are generally qualitatively similar to those in scenario 2. In a few cases, however, the effect of electricity subsidy removal outweighs the effect of the policies modeled in scenario 2. In scenario 5, production in all sectors other than agriculture, petroleum and transportation increases as in scenario 2. The rise in the manufacturing, chemical, electricity and gasoline sectors is significantly less than it was when the scenario 2 policies were implemented by themselves, because of the resulting reduction in the level of GDP. Petroleum and transportation decline more than in scenario 2. The agricultural output actually declines rather than increases as it did in scenario 2. Overall investment and GDP rise in scenario 5, but this rise is smaller than in scenario 2 when there was no removal of power subsidies.

3.37 The differences between scenarios 2 and 5 are even more pronounced in the consumption sectors. Following a removal of the subsidies that consumers receive for electricity, they have less money available to spend on all goods. Hence, it should come as no surprise that consumer spending on food, autos, housing and energy declines relative to scenario 2.

3.38 Because the current subsidies on electricity are primarily directed to consumers and electricity itself is a non-traded good, little difference is expected in the balance of payments between scenarios 2 and 5, and a comparison of Table 3.7 and Table 3.8 shows that this is indeed the case (as a comparison with scenario 6 will show below). It should be noted, however, that the decrease in the production of exportable goods such chemicals, autos and petroleum leads to a slight deterioration in the balance of trade relative to scenario 2.

3.39 The welfare results presented in Table 3.8 show that the welfare of the bottom three agents declines, and that of the top agent increases, relative to scenario 2. The government revenue is higher (as the government no longer has to pay subsidies), and the capital stock, although bigger than benchmark, is lower than in scenario 2.

3.40 Finally, two lump-sum transfers are made to agents 1 and 2 to bring their welfare levels back to those in scenario 2. The results are shown in Table 3.10. The policies introduced in scenario 2 compensate for the impact of power subsidy removal on the bottom half of income groups. As a result, the total amount of lump-sum transfers is considerably smaller than that in scenario 4, bringing the welfare levels of these agents back to where they were in scenario 0. The impact of lump-sum transfers is, as expected, small as a result. The capital stock hardly changes, and there is only a slight decrease in government revenue/expenditure.

Table 3.10 Impact of Lump-Sum Transfers in Scenario 5

Party/item	*Income range*	*Trillions of pesos*	*% Change relative to scenario 2*
Agent 1	Lowest 20%	1.133	0.000
Agent 2	Next 30%	3.386	0.000
Agent 3	Next 30%	5.23	-0.057
Agent 4	Highest 20%	8.686	0.092
Government		1.777	-0.113
Capital Stock		11.712	-0.487

Scenario 6—Carbon Taxes Relative to Scenario 2

3.41 Scenario 6 combines the assumptions in scenarios 2 and 4: it explores the incremental impact of introducing carbon taxes in scenario 2. The results are shown in Table 3.8 as well as in Table A2.28 to Table A2.30 found in Annex 2. The production figures differ substantially between scenarios 2 and 6, indicating that the imposition of a carbon tax would modify the outcome of present energy policy in Mexico. As might be expected, the carbon tax reduces petroleum and coal production significantly, so that the output in these two sectors is much lower than in scenario 2. As a matter of fact, the production of all fuels, except for kerosene, decreases. Manufacturing decreases relative to both scenario 2 and the benchmark case, and the level of investment and of GDP show losses relative to scenario 2 as well.

3.42 In contrast to production, the results in the consumption sectors are not markedly different from those in scenario 2. Again, the consumption of gasoline falls with respect to benchmark while the consumption of energy rises with respect to the benchmark. Autos and transport experience little change. Whereas services rise somewhat with respect to benchmark, the consumption of food declines.

3.43 The level of imports is comparable to that in scenario 2. The only variable that differs significantly is the trade balance. As noted above, a carbon tax causes the trade balance to deteriorate precisely because it is targeting petroleum and refined petroleum products, which are Mexico's most exportable goods. This effect is compounded by the fact that government revenue increases and pumps demand back into the economy. This, in turn, causes the imports of goods other than petroleum to rise.

3.44 A comparison of scenarios 2 and 6 shows that the imposition of a carbon tax tends to be slightly regressive. Agents 1 and 2 have lower welfare numbers than in scenario 2. Agents 3 and 4, however, have higher welfare numbers. There are several reasons for this. First, the lower income groups tend to consume energy as a higher proportion of their total budget. Second, the government tends to consume goods (such as government labor) with the extra revenues that primarily benefit the higher income classes.

3.45 As expected, government revenue rises relative to scenario 2 and the capital stock is smaller than it was when there was no carbon tax. Investment depends heavily on manufacturing supply and manufacturing levels decrease as fossil fuels are taxed.

3.46 For purposes of sensitivity analysis, scenario 6 was run using the higher carbon tax rates (all taxes increased by an additional 50 percent). The results are quite revealing. All sectors experience substantial losses when compared to either scenario 2 or the low carbon tax case in scenario 6. Indeed, GDP declines 2 percent from the lower tax case and investment declines by over 8.5 percent. Consumption is not affected greatly by these higher carbon tax rates, but the balance of payments falls almost twice as much with higher carbon taxes. Finally, when carbon taxes are increased, both the regressive nature of this tax and the capital stock losses it causes are much more apparent than they are in the low carbon tax case.

Scenario 7—Combined Effect of Power Subsidy Elimination and Carbon Taxes Relative to Scenario 2

3.47 Scenario 7 combines the assumptions in scenarios 2, 3 and 4, enabling examination of the changes that would be brought about in the Mexican economy following a removal of power subsidies, the imposition of a carbon tax, and all of the policies included in scenario 2. The results are reported in Table 3.8 as well as in Table A2.31 to Table A2.33.

3.48 The results of this simulation reflect the interaction between the three sets of policies, and any given result or results should be viewed in that context. In production sectors, everything (with the exception of services) declines or remains the same relative to scenario 2 owing to the combined effect of carbon taxation and subsidy removal. Natural gas, coke and liquid fuels rise relative to scenarios 3 and 4 because of the policies implemented in scenario 2. Of special interest here is the effect of all of these policies on the production of petroleum and electricity. Petroleum production declines relative to benchmark, reflecting the greater impact of carbon taxes and subsidy removal on this sector. Interestingly, however, electricity production eventually rises because of the powerful effect of all the policies carried out in scenario 2. Investment and GDP fall with respect to scenario 2.

3.49 Turning now to the consumption sectors, the results show that the combination of carbon taxes, subsidy removal and policies introduced in scenario 2 leads to a slowdown in the consumption of energy and food. Consumption in the housing and consumer services sector rises, however, as their relative prices fall.

3.50 In general, the reaction of the foreign sectors mirrors that of the production sectors. The imports of natural gas, coke and manufactured goods decrease. Overall, the balance of trade declines following the taxes on importable goods as described earlier in scenarios 4 and 6.

3.51 With the exception of the highest income individuals (agent 4), there is a modest decline in consumer welfare in this final scenario. Government revenues show considerable gains of almost 3 percent as subsidies are reduced and taxes are increased. These actions do have a cost, as indicated by the 1.2 percent drop in the level of the capital stock.

Synthesis of BRUS-II-M and CGE Model Results

3.52 Policy analysts are concerned with the influence of alternative policies on variables in the macroeconomy as well as on emissions. This final section of Chapter 3 (1) evaluates the effects of the various policy choices on the Mexican economy as a whole and (2) contrasts their impacts on energy demand, emissions, GDP, consumer welfare, the balance of payments, and the level of the capital stock.

3.53 As mentioned above, the government of Mexico has already begun to implement the policies outlined in scenario 2. Thus, the results of the various policies alternatives outlined above are best seen in terms of their contrast to this second scenario, and this is the reason for comparing differences between various scenarios and scenario 2 in Table 3.7 and Table 3.8, which show all the macro results of the different scenarios.

3.54 These tables show that, as expected, an increase in the underlying rate of growth leads to a general rise in the level of consumer welfare for each consumer class, GDP, and in final capital stock by 2010 in all the scenarios where the three growth rates were considered (scenarios 0, 2 and 5). Emissions are a strong function of GDP growth, as scenarios 2 and 5 show.

3.55 Had the Mexican government decided to carry on with existing policy in 1996 and not adopted the policies evaluated in scenario 2, the situation would be distinctly different. Scenario 1 shows that GDP, the capital stock, government expenditures and the welfare of agents 1, 2 and 3 all decline from their scenario 2 levels. Only agent 4 (the highest income class) and the balance of trade increase, with only modest gains. By 2010, despite the fact that total energy demand between scenarios 1 and 2 is comparable, annual emissions in scenario 1 exceed those in scenario 2 by close to 10 percent because of the difference in fuel mix, with less-carbon-intensive natural gas being used much more in scenario 2 at the expense of fuel oil.

3.56 Scenario 5 shows the macro effects of a removal of all electricity subsidies. The net effect of such a policy is somewhat mixed when compared to the changes brought about by scenario 2. Whereas government revenues increase by 0.1–0.2 percent as expected, GDP, the balance of trade, and the capital stock go down relative to scenario 2 for reasons discussed earlier. The removal of power subsidies is an effective instrument for curbing emissions and demand for power.

3.57 The most significant macro effect of imposing a carbon tax is on the balance of trade. The trade balance declines by over 16 percent relative to scenario 2 even in the case of “low” carbon tax. This is because (1) an exportable good (i.e., crude petroleum) is now heavily taxed and (2) international demand for oil grows less rapidly in the wake of a general imposition of carbon taxes. GDP, the capital stock, and the welfare of agents 1 and 2 also decline, while the welfare of agents 3 and 4 rises along with government expenditures. All of these trends are amplified in the case of high carbon taxes. Carbon taxes are not as effective as the removal of power subsidies for curbing emissions, so that even imposing “high” carbon taxes does not achieve the same level of reductions in emissions as the elimination of power subsidies.

3.58 The effects of imposing a carbon tax and removing the power subsidies appears to be additive. As in the case of scenario 6, there is a severe decline in the balance of trade and a fall in both GDP and the level of the capital stock. Overall consumer welfare declines particularly in the bottom half of income groups, whereas the richest 20 percent benefit the most of all the scenarios studied. As expected, this combined policy has the largest impact on demand for fuels and power as well as on emissions. The incremental benefit of introducing carbon taxes, however, is markedly smaller than that of eliminating power subsidies.

3.59 Table 3.7 and Table 3.8 give a very clear picture of the relationship between the performance of the macroeconomy and the level of CO_2 emissions during the next decade. The key determinant will be the growth rate: the difference in the level of emissions (and hence the cumulative total emitted) between a "low" growth rate of 3.7 percent per year and the "most likely" growth rate of 5.2 percent per year in scenario 2 (the baseline case) is between 588 and 737 million tons. This difference (20 percent of the medium growth case emissions) is far larger than can be achieved by the most stringent policies considered. For example, with the imposition of a high carbon tax at about $16 a ton of CO_2 coupled with the removal of electricity subsidies, the level of emission drops from 737 to 692 million tons of CO_2.

3.60 The reason for the relatively small impact of these fuel-switching and energy-reducing policies lies in the assumptions built into the CGE modeling exercise. Two aspects of the model limit the reduction in energy use, and hence in emissions, that result from policy switches. First, the government is assumed to spend any extra revenue, from taxes or reduced subsidies, on the same pattern of goods and services as it did in 1996. This increment creates demand for energy inputs, and—although the price of energy is now higher, leading to some substitution—this is a relatively small effect because the elasticity of substitution between energy and non-energy inputs is low. Second, the model does not permit unemployment in the short run, so that as the price of energy rises the model adjusts to keep full employment, which results in GDP not suffering a major reduction. The driving force for long-term economic growth is unaffected by changes in the price of energy, so that although there is a traverse to a slightly lower level of energy use, the model keeps the long-run growth rate at the same level, and this keeps the growth rate of demand for energy high. Because carbon taxes are assumed to be applied both domestically and abroad there is no reason to switch production to foreign sources, while electricity is effectively non-tradable and cannot be switched to foreign suppliers.

3.61 The relatively small shifts in GDP resulting from the alternative policies indicate that energy substitution makes a contribution to reducing emissions without needing to reduce GDP very much. For example, comparing scenario 2 and scenario 7 with a low carbon tax, GDP falls only 1.2 percent by 2010, whereas emissions fall 5.2 percent. The changes in consumer welfare confirm this, with only small impacts on this index. The distribution of income is slightly adversely affected in these cases; however, as scenario 5 illustrates (at 6.2 percent GDP growth), a program of compensating lower-income groups could be carried out without adverse impact on the overall level of GDP (or emissions).

3.62 The impact on the capital stock of different economic policies is greater than on GDP, reflecting the interaction with the rate of return. A reduction in output requires a bigger proportionate change in the use of capital since the growth in labor supply (but not hours offered) is exogenous and must be accommodated by an increase in the labor/capital ratio. This does have some impacts on the distribution of income, since only the better off groups own capital, although the fall in the stock of capital is partly offset by the increase in the rate of return.

3.63 The balance of payments is very sensitive to the introduction of a carbon tax. The removal of electricity subsidies, which decreases the demand for electricity, has little direct effect on the balance of trade, since electricity is non-tradable. By contrast, the imposition of a carbon tax, although this is assumed to be matched by carbon taxes imposed elsewhere in the world, has a very large impact since Mexico depends heavily on oil exports—which decline sharply when global carbon taxes are imposed. The model assumes a fixed exchange rate, whereas in reality part of the adjustment to a fall in export demand would be via an exchange rate adjustment.

3.64 One of the important aspect of the policy shifts analyzed is the increase in government spending. In the high-carbon-tax/electricity-subsidy-removal case, government spending is up by nearly 4 percent. This would contribute to welfare in ways that are over and above the creation of extra employment and higher wages, since the increased provision of public goods provides a stream of services in addition to the consumption of marketed goods and of leisure which enter the utility functions of the different groups. To the extent that public goods benefit the poorer groups to a relatively greater extent, this may help to offset the slightly regressive nature of the policies analyzed.

3.65 The changes in the welfare of the different income groups are generally small for the policies considered. This is, as explained earlier, because the government is assumed to spend the extra receipts from reducing subsidies or increasing taxes, thus creating jobs and holding wages up to offset the declines caused by the direct impact of the policies considered. However, the effects both of removing electricity subsidies and of imposing carbon taxes are both regressive, with the highest income group actually being better off as a result of the policies. Despite the higher prices for all energy items, this group is compensated both by the increase in GDP resulting from the extra government spending, and by the ownership of capital, where the higher rate of return compensates for the smaller stock of capital.

4

Mitigating Vehicular Emissions

4.1 Mexico City is one of the world's most polluted cities. The ambient concentrations of ozone exceed Mexico's air quality standards on most days. Airborne concentrations of fine particulate matter, which has been linked to premature death and illnesses, are also high. A significant source of both types of air pollution, in Mexico City as well as in the other major cities, is the transport sector.

4.2 The government of Mexico, at both national and regional levels, has in recent years taken a number of policy measures to try to control and limit the growth of harmful emissions from vehicles. These measures have included

- the improvement of the quality of automotive fuels;
- the mandating of vehicle technologies designed to reduce harmful emissions;
- the specification of reduced emissions standards for vehicles;
- the testing, certification, monitoring and enforcement of these emissions standards; and
- the introduction of restrictions on the use of vehicles, particularly at times of excessive pollution.

4.3 This chapter begins by reviewing the development of the emissions testing program as it has evolved in ZMVM, including methods used for certification, monitoring and enforcing compliance. Most of the chapter is concerned with the testing for gasoline-fueled vehicles because, until now, the government's primary emphasis has been on this class of vehicles, diesel vehicles being far fewer in number.

4.4 The next section begins by presenting estimates of the vehicle population in ZMVM based on sales data, inspection data and an estimated mortality adjustment for vehicles that have been scrapped. Vehicles are categorized—by type of vehicle, by type of catalytic converter installed (if any), by service function, by age (model year), and by total distance traveled prior to testing—so that large variations in emissions between these different classifications can be weighted by their relative importance in the total population.

4.5 The third section of the chapter analyzes emissions for gasoline vehicles classified by the above-mentioned categories. On the basis of these results, the section evaluates the policy decisions that have been made recently to combat overall emissions. The chapter's concluding section highlights lessons from the Mexican experience, both for future policies in that country and for application in other countries with similar problems.

Vehicle Inspection and Maintenance Program in Mexico City

4.6 Mexico City's Inspection and Maintenance (I/M) Program has been one of its main policy instruments for controlling urban pollution. The city's emissions standards have gradually tightened over time, reflecting the improved technology of newer cars and the increasing importance of combating pollution. Current standards differentiate vehicles by type and by the year of manufacture. To ensure that such a policy instrument is effective, the testing of emissions by individual vehicles has to be reliable, and there has to be a mechanism for ensuring compliance. Many of the changes in the program have been introduced to better achieve these goals.

Gasoline Vehicle Program

4.7 For vehicles equipped with gasoline engines, the I/M program targets three types of pollutant: hydrocarbons (HC), oxides of nitrogen (NO_x) and carbon monoxide (CO). CO inhibits the blood's ability to transport oxygen around the body, whereas hydrocarbons and NO_x contribute to the formation of ozone, which is an important component of urban smog and a lung irritant.

4.8 The vehicle emissions inspection program requires the measurement of the vehicle's tailpipe emissions, together with various visual checks of the vehicle's principal emission control components. Originally carried out on an annual basis, inspection has been required twice a year since 1996. Vehicles whose exhaust emissions levels are above predetermined levels are deemed to have failed the test, and must be repaired and re-tested until their emissions fall below the standards. Once the vehicle has passed the test, a sticker indicating compliance is issued. Vehicles that fail to display the sticker on the rear window are subject to a fine (of approximately US$50–100) by police; even casual visitors to ZMVM must display such a sticker.

4.9 The levels established for each pollutant are based on two main criteria: (1) the technical feasibility of achieving the desired level of emissions from the different vehicle specifications found in the population and (2) the reduction required to reach and maintain an acceptable standard of air quality within the city.

4.10 Because the emissions control technology found in newer vehicles is more effective than that specified for older vehicles when they were originally manufactured, tighter standards are applied to the newer vehicles without inflicting hardship on their owners. If these tighter standards were applied to all vehicles, some of the owners of older vehicles would be forced to remove their vehicle from the active population or to obtain the pass certificate fraudulently.

Diesel Vehicle Program

4.11 Diesel fuel has not been readily available at filling stations within ZMVM. It has been designated exclusively for heavy-duty vehicles, of which most are for long haul or inter-city usage and are covered by the rules of the Communications Secretariat (Secretaría de Comunicaciones y Transporte, or SCT). Thus, the permanent population of diesel-engine-equipped vehicles within ZMVM with local license plates (State of Mexico or the Federal District) is small—fewer than 50,000 in 1999. The impact of heavy-duty, long-haul vehicles entering ZMVM has not been fully evaluated, and no serious development of the diesel inspection program has taken place.

4.12 In Mexico City and at the Federal level, the diesel inspection program consists of a series of free-acceleration smoke tests in which the diesel engine speed is increased from a raised idle to its maximum-rated engine speed under no-load conditions. The visible smoke is measured at the exhaust pipe and its maximum reading is compared against the predetermined standard. Vehicles whose exhaust smoke emissions levels are above the predetermined cut-points are deemed to have failed the test and must be repaired to bring their smoke emissions to below the standard. This test, although consistent with international practices, fails to evaluate the principal pollutants generated under real high-altitude operating conditions, and does not fully evaluate the engine's state of repair.

Development of the Inspection and Maintenance Program in Mexico City

4.13 The vehicle I/M program has undergone a number of changes since its introduction as a voluntary exercise in 1982. The changes have been made to ensure both that more reliable and stricter testing procedures be introduced and to reduce the number of vehicles obtaining a pass certificate incorrectly (a "false pass"). The various steps are summarized in Table 4.1.

4.14 In 1982 Mexico City initiated a voluntary inspection program, operated by the Mexico City government's own test centers, to measure HC and CO. Being a voluntary program, it did not require certification or enforcement. In 1988 the city passed a law requiring an annual emissions check for all vehicles of 1982 and previous model years. These tests were initially conducted in the test-only centers operated by the city government, but soon afterwards independent test-and-repair garages were authorized. The equipment and static test procedures used met standards set in 1984 by the California Air Resources Board's Bureau of Automotive Repair ("BAR84")[12] for hydrocarbons, CO and CO_2. All motorists with cars in this age group in Mexico City, whose cars were registered in either the State of Mexico or the Federal District of ZMVM as shown on the license plates, had to display a sticker showing that they had passed the emissions test. Police had the power to fine motorists not displaying such a sticker.

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[12] "BAR84" is the name of both the Smog Check program implemented in 1984 and the test used in that program. "BAR90," mentioned later in this section, refers to the program and test of 1990.

Table 4.1 Development of the Emissions Inspection Program in ZMVM

Year	*Program*
1982	Voluntary inspection program is initiated, operated by the Mexico City government.
1988	Obligatory annual emissions inspection for 1982 and earlier model years with BAR84 (three-gas) equipment and procedures. Test-and-repair centers authorized.
1992	Obligatory test for all vehicles. Changed to BAR90 (four-gas) equipment and static test procedure.
1993	Test-only centers operated by the Mexico City government are closed and multi-lane "macro-centers" are opened. Dynamometer test introduced for "intensive usage" vehicles (all vehicles other than those privately owned).
1996	Test-and-repair centers closed. New "verificenters" authorized. "Day-without-a-car" program started.
1997	"Clean" cars exempted from "day-without-a-car" program. More verificenters authorized.
July 1997	Hybrid test protocol of CAM '97 started (acceleration simulation mode test procedure).
1999	CAM '97 test procedure fully adopted. Obligatory catalytic converter replacement for 1993-model-year vehicles.

Note: BAR = Bureau of Automotive Repair (California Air Resources Board); CAM = *Comisión Ambiental Metropolitana*.

4.15 The BAR90 specification was adopted in Mexico City in 1992 when a static test procedure measuring four gases (HC, CO, CO_2 and oxygen) was implemented to check the emissions from all the vehicles circulating in the city on an annual basis.

4.16 Concurrently, a bid proposal was generated in 1991 to create independent, multi-lane, test-only "macro-centers" in which some of the lanes would be equipped with dynamometers. These devices allow dynamic loaded-mode testing to inspect the emissions from the "intensive usage" vehicles (all vehicles other than those privately owned), which were believed to contribute more to the emissions inventory. Other lanes in the macro-centers were equipped with BAR90 static test equipment to cover the remaining vehicles. By 1993 there were 500 private test-and-repair centers, and some 24 privately owned macro-centers, in full-time operation, each of the latter having five or more test lanes. At the same time, strong lobbying by the independent garages forced the city government to close their own test-only centers. This side-by-side operation allowed a direct comparison to be made between the test-and-repair garages and the test-only macro-centers.

Test-and-Repair versus Test-Only Centers

4.17 The test-and-repair garages were by far the most convenient for vehicle owners in that they eliminated the "ping-pong" effect. Most vehicle owners took their vehicles to the garage for a tune-up and to get through the emissions test, allowing a one-stop solution to this requirement. They were not caught between a garage that argued that they had correctly repaired and tuned up the vehicle, and the macro-center that reported the vehicle out of limits. Because of this, most private vehicles went to the test-and-repair garages, whereas all vehicles that were not privately owned had to go to the macro-centers for the dynamometer test, which was unavailable at the test-and-repair garages.

4.18 On the other hand, the test-only macro-centers were far easier for the government inspectors to supervise, and allowed better technical and administrative control to be enforced. The ownership of these centers was concentrated in few industrial groups specializing in emissions inspection, facilitating the adoption of new technology and generated more uniform results among centers.

4.19 Over time, the quality of testing from the test-and-repair centers degenerated. The garages soon found that they could offer a lower price by cutting back on the cost of the repair services performed if they cheated on the emissions testing. In a market with surplus capacity, the desire to increase profits by increasing the volume of business was strong, and the chances of being caught were small. Hence, although the test-and-repair garages were convenient to the end-user, their impact on reducing emissions was considerably less than that of the test-only centers. It finally reached the stage where an estimated 50 percent of the vehicles that went through the test-and-repair centers obtained their approval certificate fraudulently. Public opinion was that it was a highly faulted emissions control program, and indeed it was very close to being shut down permanently.

Test-Only "Verificenters"

4.20 These problems led to the program being completely restructured during 1995, with major changes being enforced as of January 1996. Despite the political implications, the licenses were withdrawn from all the 600 test-and-repair centers, while the number of test-only macro-centers was increased from 26 to 33, for a total of 180 test lanes. A series of stringent quality assurance controls and technical changes were added to the multi-lane center operation and a new public identity was generated, repositioning them as test-only "verificenters."

4.21 In addition to making some technical adjustments to the testing procedures, the verificenters introduced elaborate precautions to prevent individual testers giving "false passes." These included the use of "blind" test lanes where the tester did not see the results of the test, which were available only at the exit from the station; central computer and video monitoring of testing; and technical audits of centers by government inspectors. Because of these actions, the proportions of failing tests increased substantially: whereas during the second semester of 1995 the test-and-repair centers had reported a reject rate of 5.8 percent and the macro-centers a reject rate of 10.3 percent, during the first semester of 1996, under these new operating rules, the rejection percentage from the verificenters in Mexico City was 22.5 percent.

Day Without a Car

4.22 During the first semester of 1996 major changes were made in the program, affecting the type of certificates that were issued to the vehicles. Mexico City initiated a "day-without-a-car" program that had originally been designed to limit vehicle emissions during the winter months only. ZMVM suffers from severe thermal inversions during the winter months, when the highest concentrations of ozone are measured at street level. Data available at that time showed the highest ozone levels to occur between October and March each year, and transport emissions were believed to be contributing to a significant amount of ambient concentrations of two principal ozone precursors, HC and NO_x.

4.23 Consequently, it was decided to limit the operation of all the vehicles in ZMVM during the winter months by one day a week. During an emissions contingency (defined as a situation when the air quality index was greater than three times the internationally accepted standard) only the cleanest class of vehicles would be allowed to operate. Hence, on the basis of technology fitted and emissions recorded, different certificates were issued to the vehicles, each with a different and highly visible windscreen sticker:

- *Certificate One* was issued to vehicles that met stricter emissions levels, had fuel injection, and had license plates from the Federal District or from the state of Mexico. This limited the vehicle's operation by one day per week according to its license plate termination.
- *Certificate Two* was issued to vehicles that met the normal emissions limits but did not meet the conditions for Certificate One. These vehicles were also subject to the weekly day-without-a-car rule but, in addition, were not able to operate on days declared "ambient contingency days."

4.24 All vehicles had to pass the normal emissions tests. The program did not contemplate any waiver where vehicles failed their emissions tests or where the cost of repair was above a certain figure (as in some parts of the United States); hence the only options that the vehicle owner had were either to pass the test, or not to use the vehicle in ZMVM. The windshield stickers were very effective because they were readily visible to any police officer on duty, and the fine imposed for operating a vehicle without an emissions sticker was sufficiently high to maintain the police force's interest in looking out for offenders. All traffic police were empowered to stop vehicles lacking stickers.

4.25 During the winter months of 1996 there was a high level of acceptance amongst the public for this measure to control vehicle emissions. Before the winter season was over, however, the mayor of Mexico City decreed the program as permanent, causing the general level of acceptance to take a nosedive. Twenty-four percent of journeys within ZMVM were by private car, and although most people were willing to make an extra effort to live without their vehicle one day a week during the winter months, they were not so willing to do it on a permanent basis, partly because the public transport system in the city was crowded, insufficient and in many ways deficient. The solution that many families adopted was to buy an additional older vehicle, ensuring that the license plate's termination on each of their vehicles restricted their movement on different days of the week. Hence, this measure to restrict the use of vehicles resulted in an increase in the number of vehicles in the city. In addition, the substitution of an older vehicle, on those days when the newer vehicle was not permitted to operate, raised the average emission per family. The policy also modified traffic patterns, particularly on weekends when all vehicles were allowed to circulate, providing that an emissions contingency was not being enforced, so that Saturdays became one of the most intense traffic days of the week. Vehicle emissions may even have increased as a result of this policy designed to reduce their level.

4.26 In response, a third type of certificate was added beginning in the first semester of 1997. *Certificate Zero* was issued to vehicles that met the most stringent emissions limits, were of model year 1993 or later, were fitted with an original equipment manufacturer's catalytic converter, had fuel injection, had a gross vehicle weight (GVW) of less than 2,727 kilograms (kg), and had license plates from the Federal District or from the state of Mexico. Vehicles that obtained Certificate Zero were allowed to operate on all the days of the week. This measure allowed passenger cars to be used every day of the week, and effectively limited the "day-without-a-car" program to cars of pre-1993 model years, plus vehicles of higher gross vehicle weights (particularly sport utility vehicles and pickups). The measure also restricted the newer-model-year cars that did not obtain the zero certificates because of their emissions levels or, more important, because they had out-of-state plates. Since the introduction of Certificate Zero, the difference between the Certificate One and Certificate Two has gradually declined because there have been fewer and fewer emissions contingency days. During the first semester of 1997, for cars that passed the tests, 24 percent of private cars obtained the Zero certificate, 20 percent obtained the One and 56 percent obtained the Two. The percentages were very similar for non-privately owned vehicles. In 1999, a fourth category was added, called *Certificate Double Zero*. These are vehicles manufactured in 1999 or later to meet the U.S. Tier 1 emission standards (emission standards that came into effect in the United States beginning in the model year 1994 and will remain in force until the model year 2004), and have the same privileges as Certificate Zero, but in addition are exempt from inspection for the first two years.

Quality Control

4.27 It was estimated that, during the first semester of 1997, although 73 percent of all vehicles obtained their emissions certificates correctly, eight percent of vehicles obtained a false approval because of incorrect practices in the test process in the verificenter, and an additional 19 percent of vehicles obtained their certificate through incorrect practices by the garage that tuned the vehicle prior to the test. Here, tuning the vehicle "late and lean," with late ignition timing and lean fuel/air mixture, became a common practice, as did disconnecting air hoses from the inlet manifold. Once the test had been passed, the vehicle would be re-tuned. These techniques sometimes reduced the engine power during testing to an undrivable level and increased NO emissions. However, they effectively, but temporarily, reduced hydrocarbon and CO emissions, and could not be detected by the test procedures in place. Although these percentages are high, they compare very favorably with the more than 50 percent figure of "false passes" estimated to have emanated from the test-and-repair centers.

4.28 Thus, although great strides had been made in improving the quality of the emissions control program, several areas still needed to be addressed:

(a) The elimination of the test-and-repair centers caused a major bottleneck in the remaining verificenter test lanes. This was particularly evident at the end of each month, when extremely long queues were formed by irate vehicle owners looking to get a test during the last few days of their assigned time-slot.

(b) The test protocol applied a road load to the vehicle via the dynamometer at 40 km/h for 30 seconds and then a second stage of no-load at low idle for 30 seconds. This was not sufficient to warm up and ignite the catalytic converter on many vehicles, and as such could not detect if the catalytic converter was working.

(c) It was easy to circumvent the test by tuning "lean and late" and/or by other methods. Since NO was not being measured, there was no element of control to restrict this practice.

(d) The test protocol neither generated sufficiently stable or repetitive test results, nor produced sufficiently low measurement uncertainties, to allow its use with the new lower limits that were to be enforced.

4.29 The inadequacy of the installed capacity was solved by a new bid proposal that increased the total number of verificenters to 76 with an authorization to operate 337 test lanes. These started operating during 1997 and brought the installed capacity to approximately three times that required by the total vehicle population. This number of test lanes provided a balance between the quality of service to the end-user (such as waiting time) and center profitability. If there were too many centers then the waiting time would be negligible, but so would the return on investment for the center. This would put strong pressure on each center to behave unethically if it could improve its profitability by doing so. Indeed, some centers did modify their operational procedures so as to attract more clients—by not charging for failure to pass, turning a blind eye to visual inspection failures and, in some cases, getting vehicles falsely through the test procedure.

4.30 When there were fewer centers, the companies were so highly profitable that they were willing to police themselves to ensure that they did not lose the opportunity of remaining in this excellent business. With the increase in the number of centers, the quality of service to the vehicle owners increased dramatically, but so did the requirement for government supervision.

4.31 Before 1997, vehicles with Federal District license plates had to be inspected in the Federal District. This restriction was lifted in 1997, allowing the vehicle owner to choose whether to test in the State of Mexico or in the Federal District. Because of the lack of centralized operational control of the two programs, this added flexibility caused control to be lost.

4.32 Two other changes are worth noting, and probably led to higher emissions than otherwise would have been the case. First, in 1998 the State of Mexico authorized additional verificenters and test lanes, many of which surrounded the Federal District. By 1999, the two federal entities had between them 154 verificenters operating a total of 572 test lanes. However, the two entities involved did not share a common balanced determination to maintain high standards in the emissions inspection program, causing an important number of vehicles to seek out those testing centers in the State of Mexico that would issue a pass more easily. The most polluting vehicles in particular were likely to have made this choice. As will be shown later, between the first semester of 1997 and the second semester of 1999 approximately 500,000 vehicles that would formerly have been tested in the Federal District either switched to testing in the State of Mexico or were not tested at all.

4.33 Second, at the same time (during 1998 and 1999), in a move to reduce the public's perception of corruption among the police force, traffic police were forbidden from detaining vehicles because of inspection sticker violations—this being an exclusive faculty of the Ecological Police, of which there were few. As a result, it became feasible to drive around the city without a sticker on the windshield without being stopped.

4.34 To address technical problems of the testing procedures, considerable work was done by the Mexico City government during 1995–96 to define a new protocol from which a hybrid version went into effect for the second semester of 1997. The new protocol consisted of an acceleration simulation mode (ASM) test, known as CAM '97, the objectives of which were to generate more-reproduceable test results, reduce measurement uncertainties, permit the use of stricter test limits, and reduce false approvals.

4.35 The change in test procedures and equipment mandated by the CAM '97 specification substantially reduced the uncertainties involved in the gas measurement: at the strictest levels of emissions of 100 ppm for HC, from 39 percent to less than 13 percent; while for CO the reduction, at a measurement of 1 percent, from 10 percent to less than 7 percent. For NO, which was to be measured for the first time in 1999, the measurement error at 1,200 ppm attributable to the equipment was less than 8 percent, to which had to be added an uncertainty of 13 percent from setting the load and speed correctly in the dynamometer. This protocol was finally fully adopted with its corresponding new emissions limits in the first semester of 1999. At this time, the NO emissions were not used as a cause of rejection. This was later introduced in the first semester of 2000.

4.36 An important feature of the revised testing procedure was that the new extended test protocol was benign for the majority of vehicles, resulting in lower emissions readings from the same vehicle versus the previous procedure. As an example, for vehicles of a model year not later than 1986 and with a gross vehicle weight of less than 2,727 kg, the previous test procedure had a limit of 350 ppm HC and 3.5 percent CO. With the CAM '97 test procedure, those same vehicles would give lower emissions readings and the reject rate would be lower unless the emissions standards were altered. In fact, limits of the order of 270 ppm HC, 3.0 percent CO, and 1,500 ppm NO would have been required under the new test protocol to achieve similar reject rates as before.

New Emission Limits

4.37 Partly to take account of these changes, in the first semester of 1999 new emissions limits were published simplifying the model year range and reducing the maximum values. Table 4.2 and Table 4.3 illustrate how the limits evolved over the years. Because of the change in the test protocol, the limits —other than for vehicles weighing over 2,727 kg from pre-1986 model years—were in effect relaxed some in 1999, particularly for HC.

Table 4.2 Evolution of Emission Standards for Vehicles with Gross Vehicle Weight of Less than 2,727 kg

	Hydrocarbon (ppm)s				Carbon monoxide (%)			
Year	*1994*	*1996*	*July 1996*	*1999*	*1994*	*1996*	*July 1996*	*1999*
up to 1979	700	450	350	300	6.0	4.0	3.5	3.0
1980–86	500	350	350	300	4.0	3.5	3.5	3.0
1987–1990	400	300	300	300	3.0	2.5	3.0	3.0
1991–93	400	300	200	200	3.0	2.5	2.0	2.0
1994+	200	100	100	200	2.0	1.0	1.0	2.0
"One"	—	200	200	200	—	2.0	2.0	2.0
"Zero"	—	—	100	100	—	—	1.0	1.0

Table 4.3 Evolution of Emission Standards for Vehicles with Gross Vehicle Weight of More Than 2,727 kg

	Hydrocarbons (ppm)			Carbon monoxide (%)		
Year	*1994*	*1996*	*1999*	*1994*	*1996*	*1999*
up to 1979	700	600	350	6.0	5.0	3.0
1980–85	600	500	350	5.0	4.0	3.0
1986–91	500	400	350	4.0	3.5	3.0
1992–93	400	350	350	3.0	3.0	3.0
1994+	200	200	200	2.0	2.0	2.0
"One"	—	200	200	—	2.0	2.0
"Zero"	—	—	100	—	—	1.0

4.38 Over time the emissions limits had been made gradually more stringent, but this effect was most marked for the earlier model years. In 1994 vehicles of model year up to 1979 had an allowable emissions limit of up to 700 ppm for HC, whereas model years of 1994 or later had a limit of 200 ppm. By 1999 the limits (excluding the higher standards required for a One or Zero certificate) were 300 or 350 ppm for the pre-1979 vehicles, but were still at 200 ppm for the post-1994 vehicles. This differential tightening of standards had the effect of bearing most heavily on vehicles whose emissions were generally higher.

4.39 As an incentive to remove older and more polluting vehicles from the population in Mexico city, the emission limits established in 1999 were set at a level that would not have been met by many of older vehicles even when they were new. This tended to push these vehicles out of ZMVM into the rest of the country.

4.40 During the first semester of 1999, a voluntary program was established to replace the catalytic converters on the 1993-model-year vehicles. The change in catalytic converters was obligatory only for vehicles that had NO emissions greater than 800 ppm. During the course of this program it was seen that the 800-ppm level was unrealistically low, and this figure was increased to 1,200 ppm.

4.41 During the second semester of 1999, owners of all 1993-model-year vehicles were required to replace the catalytic converters irrespective of the emissions reading obtained in the test. During the first semester of 2000, this program was made obligatory for 1994-model-year cars and, in the second semester of 2000, for 1995 model year as well.

4.42 During the first semester of 2000, NO limits were established. The limits were the same for all vehicle weight categories and were set at 1,200 ppm for Certificate Zero, 1,500 ppm for Certificate One, and 2,500 ppm for Certificate Two. Having established these limits, it was found that they were causing unnecessary hardship to a number of vehicles, not allowing them to obtain the desired certificate, and as a result, the government decided to reduce the dynamometer load that is applied to the vehicle during the 24 km/h stage of the test on 481 different vehicle types. This move allowed the emissions limits to remain the same, while allowing more vehicles to pass the test. This illustrates the interdependence between test conditions and emission levels, and how exhaust emission limits can be effectively changed by altering either the limits on pollutant concentration levels or test conditions.

Vehicle Fleet Population

4.43 The official vehicle population figures in Mexico overestimate the number of vehicles in operation. Although new vehicle sales are added every year to the existing population, vehicle retirement is often not captured. As a result, differences of up to 42 percent have been measured when the official figures are compared to data obtained from extensive field surveys. The vehicle population figures in this study were developed from a detailed analysis of the vehicles circulating in ZMVM. The analysis used an extensive sample of more than 1.7 million vehicles to develop a mortality model[13] that, in combination with vehicle retail sales data from 1951 to date, painted a more accurate picture of the characteristics of the vehicle fleet operating in Mexico's largest metropolitan area. This model was later extended to include the rest of the country by incorporating the vehicle sales data for this extended area, resulting in a modified vehicle mortality model that reflects the longer vehicle life found outside of ZMVM. This model does not, however, contemplate the atypical operation of imported used vehicles in the border zone with the United States, where large numbers of vehicles of U.S. origin operate with Mexican frontier-zone license plates, with U.S. license plates, or with no plates or registration at all. Without developing a vehicle fleet model for this border region and for those states with a significant migrant workforce (which was outside the scope of this study), the model lacks the data to include such vehicles.

4.44 The total number of gasoline vehicles in Mexico in 1999, calculated after applying the mortality curves, was 7.4 million, of which 3.0 million were in ZMVM. The vehicle categories consist of passenger cars, vans and wagons, pickups, class 3 (GVW of

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[13] This model was based on sales data, vehicles tested in emissions inspection during the first semester of 1997 (the semester when the greatest percentage of vehicles were tested) and other factors.

4,545 kg to 6,364 kg), and classes 5 and 7 (GVW of 7,273 kg to 11,818 kg). The breakdown in Mexico as well as ZMVM is given in Table 4.4.

4.45 The weighted average age of vehicles in Mexico in 1999 was 9.1 years, ranging from 7.0 years for vans and wagons to 15.2 years for class 5/7 vehicles. As expected, because of higher disposable income and stricter emission standards for in-use vehicles, the average age of vehicles in ZMVM—8.9 years—was slightly lower than in the rest of the country. However, in the vans/wagons and class 5/7 categories, the average age of vehicles in ZMVM was greater than in the rest of the country. The findings are shown in Table 4.4. The average age of class 5/7 gasoline vehicles is markedly different from that of diesel vehicles in the same vehicle weight class, where the average age is approximately one-half.

Table 4.4 Gasoline Vehicle Population and Age in 1999, by Vehicle Type

Vehicle type	*Number ZMVM*	*Number Outside ZMVM*	*Age in years ZMVM*	*Age in years Outside ZMVM*
Cars	2,180,000	4,620,000	8.6	9.2
Vans and wagons	250,000	640,000	7.6	6.7
Pickups	370,000	1,560,000	10.1	10.1
Class 3	150,000	480,000	9.6	9.7
Class 5 and 7	40,000	90,000	15.8	14.7
Total	2,990,000	7,380,000	8.9	9.3

4.46 The age distribution of vehicles in Mexico as well as in ZMVM is shown in Table 4.5. About two-thirds of vehicles are from the 1991 model year or later.

Table 4.5 Breakdown of Vehicles in 1999, by Model Year

Location	*to 1960*	*1961-65*	*1966-70*	*1971-75*	*1976-80*	*1981-85*	*1986-90*	*1991-95*	*1996-99*
Mexico	0.5%	0.6%	1.4%	3.5%	7.1%	11.1%	15.6%	31.2%	29.1%
ZMVM	0.2%	0.4%	1.1%	3.4%	6.5%	10.6%	15.4%	33.3%	29.1%

4.47 Lead was eliminated from gasoline in Mexico in 1997. Because lead acts as a permanent poison for the catalysts used in converters, three-way catalytic converters were not mandated in vehicles weighing less than 2,727 kg until 1993; in heavier vehicles, not until 1996. A limited number of heavy vehicles have been authorized to be sold without converters for use with LPG or natural gas. In 1999, approximately 46 percent of gasoline vehicles in Mexico had no catalytic converter, in contrast to 78 percent in 1993, when three-way converters were first installed in the majority of new vehicles. The breakdown of the vehicle fleet by converter type in 1999 and 1993 is shown in Table 4.6. In ZMVM, the percentage of gasoline vehicles equipped with catalytic converters is slightly higher than in the rest of the country. Between 1993 and 1999 the percentage of vehicles with no converter declined from 75 percent to 42 percent.

Table 4.6 Gasoline Vehicle Population, by Converter Type

Converter type	*Mexico 1999*	*Mexico 1993*	*ZMVM 1999*	*ZMVM 1993*
No converter	46%	78%	42%	75%
Two-way converter	2%	3%	2%	3%
Three-way open-loop	2%	4%	3%	4%
Three-way closed-loop	50%	16%	53%	18%

4.48 Table 4.7 illustrates a breakdown of gasoline vehicles in ZMVM according to their usage. As expected, most passenger cars are for private use, whereas the majority of class 3 and class 5/7 are commercial vehicles.

Table 4.7 Gasoline Vehicle Population in ZMVM, by Service

Vehicle type	*Private*	*Taxi*	*Commercial*	*Bus*	*Truck*	*Government*
Cars	80.8%	4.6%	14.0%	0.0%	0.0%	0.7%
Pickups	65.5%	2.4%	28.4%	0.4%	0.6%	2.5%
Vans and wagons	55.9%	0.0%	29.7%	0.1%	10.7%	3.6%
Class 3	2.4%	21.0%	35.3%	2.0%	37.2%	2.1%
Class 5 and 7	1.5%	0.1%	44.4%	3.2%	36.9%	13.9%

Note: Based on 1998–1999 data collected in I/M.

4.49 The diesel vehicle population in Mexico is considerably smaller than that of gasoline vehicles. In 1999, about 253,000 diesel vehicles were operating in Mexico, 48,000 in ZMVM. The number of vehicles in each vehicle category in 1999 is shown in Table 4.8. Whereas the total number of diesel vehicles is only 3.5 percent of the number of gasoline vehicles, the consumption of diesel by vehicles is nearly one-half the consumption of gasoline. For example, in 1999, 510,900 barrels per day (b/d) of gasoline was consumed in Mexico, compared to 224,900 b/d of automotive diesel. In ZMVM, the amount of automotive diesel purchased has been about one-fourth to one-fifth that of gasoline in recent years. This suggests that emissions from diesel vehicles, none of which are controlled for NO_x emissions, are likely to be considerably higher than their absolute numbers would indicate. As an increasing percentage of gasoline vehicles become equipped with three-way converters, the relative contribution of diesel vehicles to total emissions will increase further. No reliable data have been generated on how much time is spent or distance covered by long-haul trucks and buses in metropolitan areas. For the purpose of estimating the contribution of diesel emissions to urban air pollution, collecting such information would be useful.

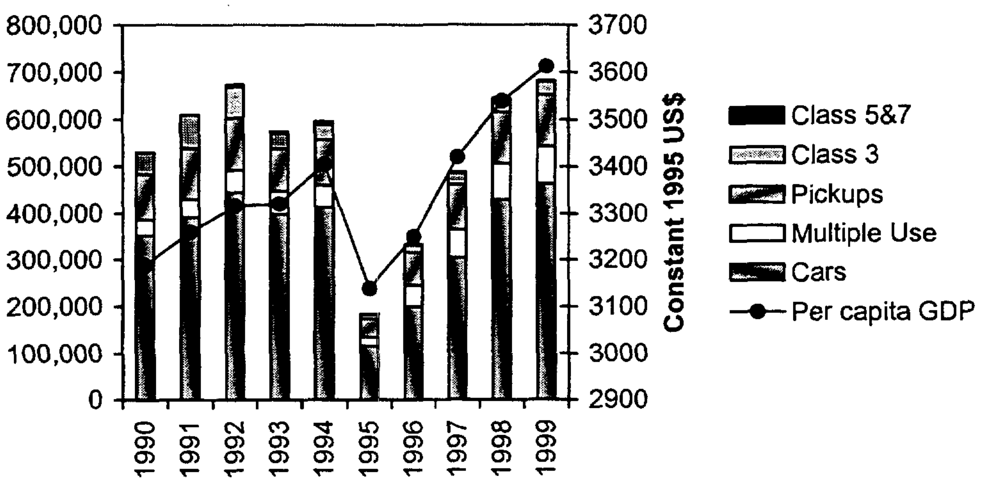
Table 4.8 Diesel Vehicle Population in ZMVM in 1999, by Type

Vehicle type	*Private*	*Taxi*	*Commercial*	*Bus*	*Truck*	*Government*
Cars	80.8%	4.6%	14.0%	0.0%	0.0%	0.7%
Pickups	65.5%	2.4%	28.4%	0.4%	0.6%	2.5%
Vans and wagons	55.9%	0.0%	29.7%	0.1%	10.7%	3.6%
Class 3	2.4%	21.0%	35.3%	2.0%	37.2%	2.1%
Class 5 and 7	1.5%	0.1%	44.4%	3.2%	36.9%	13.9%

Vehicle Sales

4.50 Vehicle sales data were obtained from individual manufacturers and from two vehicle manufacturers associations, Asociación Mexicana de la Industria Automotriz (AMIA) and Asociación Nacional de Productores de Autobuses, Camiones y Tractocamiones (ANPACT). As seen in Figure 4.1, vehicle sales in Mexico fluctuated widely in the 1990s, reflecting the state of the economy (represented by per capita GDP in the figure). The sales volume peaked in 1992 (reaching 675,000), declined somewhat in 1993 and 1994, and fell markedly in 1995. The sales volume reached the level achieved in 1992 only in 1998 and 1999. Vehicle sales in ZMVM—which accounts for 40 to 50 percent of all sales in Mexico—mirrored this national trend, with a high of about 275,000 in 1992, falling to 96,000 in 1995 and increasing to 283,000 by 1999.

Figure 4.1 Vehicles Sales in Mexico



Vehicle Manufacture

4.51 In response to the North American Free Trade Agreement, the number of vehicles manufactured in Mexico and exported to the United States and Canada increased from 250,000 in 1990 to nearly 1 million in 1999. As a result, vehicle manufacture in Mexico is now closely integrated into the North American market. In 1999, six manufacturers built a total of 1,481,629 vehicles in Mexico. Of these, 1,073,155—close to three-quarters—were exported, 92 percent of them to the United States and Canada. Of the remaining 8 percent, about one-half were exported to Europe, and the rest to Central and South America.

4.52 The number of vehicles manufactured and sold in Mexico is broadly comparable to that imported into Mexico. Between January and August 2000, for example, 293,134 were manufactured and sold by seven vehicle manufacturers in Mexico. During the same period, the number of vehicles imported was 229,192.

Distance Traveled

4.53 Odometer readings are recorded when vehicles are inspected. Unfortunately, little importance has been placed on ensuring the accuracy of this data entry at many inspection centers. The data were analyzed to see which odometer readings were repeated with a statistically improbable frequency and the corresponding records were omitted. For example, for the second semester of 1999, about 30 percent of the data were eliminated. 555,000 filtered data points from 1996 to 1999 were used to develop distance-traveled related data for ZMVM. Data on kilometers traveled annually are summarized in Table 4.9 as a function of vehicle usage, model year and converter type. The figures in the table are in line with data obtained in other market surveys, and in some cases on the high side. The average annual distance traveled of 22,000 km per year for private cars is high because the fiscal policy discourages company cars and, consequently, a large number of cars are classified as "private" that would be classified differently elsewhere. The data show that 28 percent of the private vehicles cover less than 5,000 km per year and that 64 percent cover less than 15,000 km per year. The average is being skewed by the remaining one-third with high annual mileage, many of which would be classified as company cars in North America.

4.54 The exception to high annual-mileage figures is the distance traveled by taxis: 580 km a week. Although one might have expected a higher figure, 580 km is not improbable owing to the surplus of taxis currently in ZMVM and passenger security issues promoting the fixed-base style of operation. In the absence of recent market survey information that would justify making changes, 30,000 km was kept.

4.55 Consistent with international experience, new vehicles are driven more than old vehicles. Because vehicles equipped with catalytic converters are newer than those without, they are driven more. Taxis are driven the most, whereas trucks (for local delivery) and private vehicles are driven the least. Comparing the most and least intensively used, taxis are driven 45 percent more than gasoline-powered trucks.

4.56 On the basis of Table 4.9 and Table 4.6, annual kilometers traveled by vehicles with different exhaust control systems can be calculated. The results are shown in Table 4.10. Vehicles with no converters contribute to 32 percent of total kilometers traveled. Those with three-way converters account for two-thirds of all travel. Although vehicles with no catalytic converters contribute less than one-third of total travel, they would be expected to comprise a disproportionately high share of total emissions because of the absence of exhaust control technology.

Table 4.9 Annual Kilometers Traveled in ZMVM

Type of service	*km/year*	*Model year**	*km/year*	*Converter type**	*km/year*
Private	22,000	96-00	31,500	None	18,000
Taxi	30,000	91-95	29,000	Two-way	29,000
Commercial	26,000	86-90	23,000	Three-way open-loop	29,000
Bus	25,000	81-85	15,500	Three-way closed-loop	29,000
Truck	21,000	76-80	13,000		
Government vehicle	25,500	71-75	11,000		
Other	27,000	66-70	11,000		
		61-65	11,000		
		to 60	15,000		
Average	23,300	Average	23,300	Average	23,300

* For all vehicle types.

Note: Based on data collected at I/M and averaged over 1996–1999.

Table 4.10 Percentage of Total Kilometers Traveled in ZMVM

No converter	*Two-way*	*Three-way open-loop*	*Three-way closed-loop*
32%	3%	3%	62%

Note: Based on 1999 population.

Vehicle Emissions

4.57 The team analyzed 3.5 million emissions data from 14 semester periods between 1993 and 1999 to identify parameters that affect emission levels and to assess future emission trends. Some possible hypotheses tested are as follows:

(a) Vehicles with converters have lower emissions than those without.

(b) Three-way catalytic converters in cars manufactured in 1993 and 1994 are seriously deactivated—in part because of availability of leaded gasoline until 1997, resulting in cross-contamination or mis-fueling—justifying the catalytic-converter replacement program mandated in ZMVM.

(c) Older vehicles have higher emissions than newer vehicles.

(d) For the same age vehicles, those with higher odometer readings have higher emissions.

(e) Private vehicles have lower emissions because owners take better care of them and they are not subject to abuse by multiple drivers.

(f) Vehicles that weigh more have higher emissions.

4.58 The emissions data in this report are taken from the test conditions that give higher emissions: 40 km/h for CO, and 24 km/h for NO and HC. The emissions of HC and

CO follow very similar patterns. The data analyzed also include vehicles fueled by LPG. The number of LPG vehicles is small because LPG is not used by taxis or private vehicles.

Catalytic Converter Type

4.59 Hydrocarbon and NO emission levels by model year and converter type are illustrated in Figure 4.2 and Figure 4.3, respectively. Vehicles with two-way converters are no better than those with no converter, and in fact in the case of NO, vehicles equipped with two-way converters have higher emissions than those with no converter. Emission levels decline with increasing model year. After the 1994 model year, there are no marked differences in emission levels by converter type. It should be noted that beginning in 1996, all new vehicles were required to be equipped with three-way closed-loop converters with the exception of a limited number of heavy vehicles that were authorized without converters for use with LPG or natural gas.

Figure 4.2 Mean Hydrocarbon Emissions by Model Year and Converter Type, Data from 1999 Taken at 24 km/h

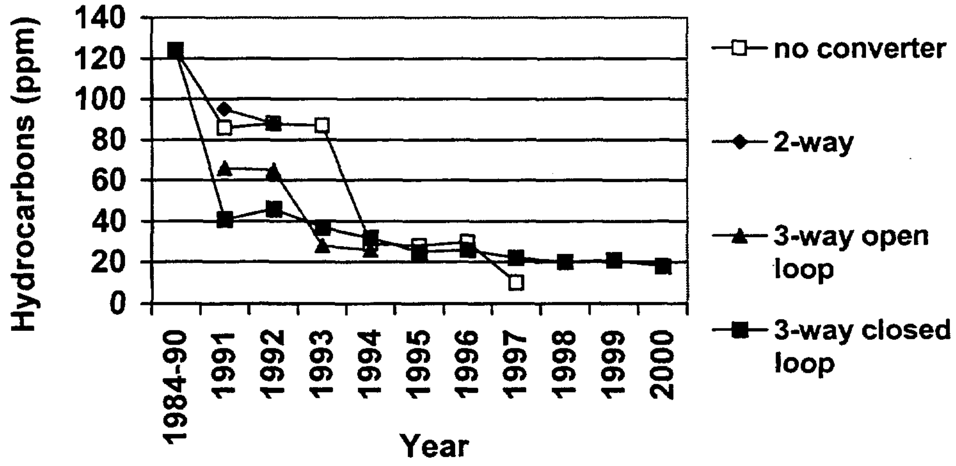
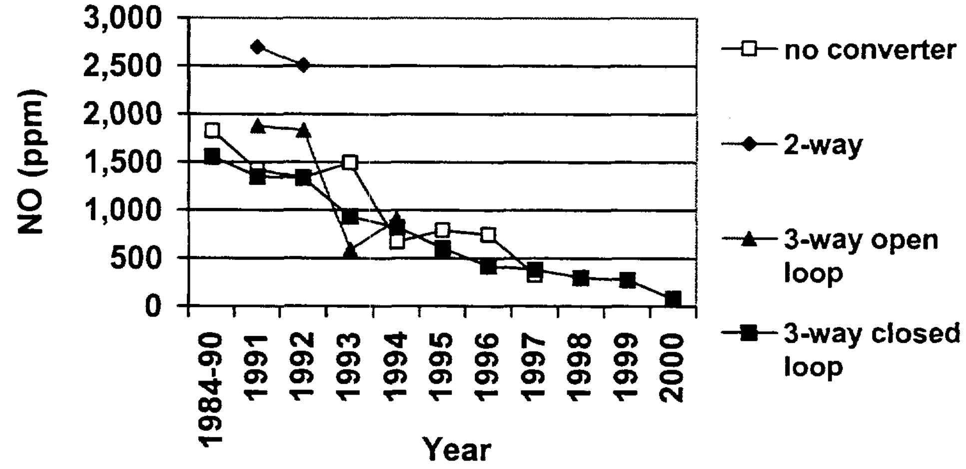


Figure 4.3 Mean NO Emissions by Model Year and Converter Type, Data from 1999 Taken at 24 km/h



4.60 As mentioned earlier, a voluntary converter replacement program for 1993-model-year vehicles was started in 1999, and this was made mandatory during the second half of 1999. This converter replacement program appears to have improved the NO emissions characteristics of three-way open-loop converters, as seen by comparing the 1993 and 1994-model-year vehicles. Vehicles equipped with three-way open-loop converters, however, comprise a mere three percent of the total vehicle population. Furthermore, for both CO and HC, comparing emissions test results between the second semester of 1998 (before the converter replacement program) and the second semester of 1999 showed no marked improvement compared to vehicles with no converter, as shown in Table 4.11. It is therefore not clear if the converter replacement program led to substantially lower emissions for the 1993 model year.

Table 4.11 Emissions Test Results for 1993-model-year Vehicles: Comparison of Data Collected in Second Semester 1998 and 1999

	CO at 40 km/h		*HC at 24 km/h*	
Converter type	*1998.2*	*1999.2*	*1998.2*	*1999.2*
No converter	0.66%	0.56%	155 ppm	82 ppm
Three-way open-loop	0.19%	0.21%	20 ppm	29 ppm
Three-way closed-loop	0.24%	0.24%	46 ppm	36 ppm

4.61 The evaluation of a vehicle's emissions by means of constant-speed loaded-mode testing is a simple and effective method of determining if the overall emissions control systems and engine systems in the vehicle are functioning well. Should the vehicle not meet its emissions limits, however, these tests provide only limited information as to which component has failed. More specifically, for vehicles with catalytic converters, high emission levels of the three pollutants measured could be caused by a converter failure or by the failure or lack of calibration of a number of other components and systems. Unfortunately, rigorously determining the efficiency of a catalytic converter is time-consuming.

4.62 One indication of a converter failure would be a high level of CO in the exhaust gas in the presence of sufficient oxygen (O_2) that would have allowed the oxidation reaction to take place. The maximum level of CO_2 should also be below a certain level to ensure that the lack of conversion was not due to saturation. The California Air Resources Board (CARB) has established a set of criteria for identifying defective catalytic converters from the emissions test results. A catalytic converter is considered defective if the CO level is greater than 0.3 percent, while the O_2 level in the exhaust gas is greater than or equal to 0.4 percent and the CO_2 level is less than 14 percent. This formula is considered favorable to the vehicle owner. It is more likely to "pass" a catalytic converter that should have failed (false pass) than to report it as defective a converter that is actually in good condition (false fail).

4.63 These criteria were applied to the data collected in ZMVM and the results are summarized in Table 4.12. During the first semester of 1997, when the largest fraction of vehicles appeared to have reported for emissions tests, a significant fraction of pre-1993 vehicles were found to have defective converters. In the case of three-way closed-loop converters, more than one-half of vehicles from 1990 and earlier model years did not meet the criteria. By comparing the test results from the second semester of 1998 and 1999 for the 1993 and 1994 model years, this table also gives an indication of the impact of the converter replacement program on the oxidation efficiency of the converter. If there is a marked improvement for the 1993 model year but not for 1994, then the replacement program might be considered effective. In the case of three-way open-loop converter, in contrast to the results of NO emissions discussed earlier, the percentage of vehicles that failed this test increased from 1998 to 1999. For three-way closed-loop converter, it is difficult to draw conclusions because there has been a constant decline in the percentage of failing vehicles beginning with the first semester of 1997. Other data indicate, however, that there was no marked improvement in the emissions of CO for the 1993 model year between the second semester of 1998 and the second semester of 1999. For 1994- and 1995-model-year vehicles, which in 2000 were required to have their converters replaced, the percentage of vehicles with defective converters according to this set of criteria is less than 3 percent.

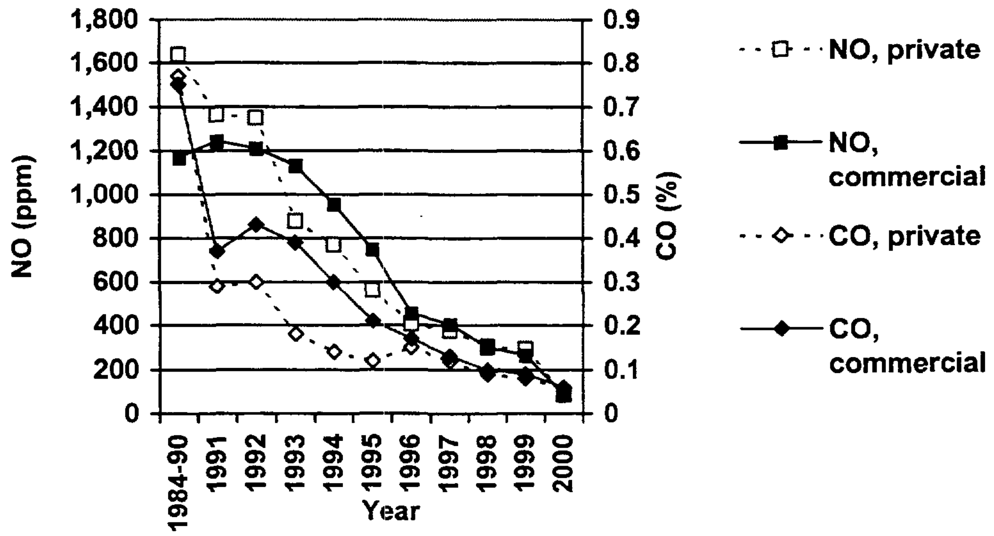
Class of Service

4.64 Differences in emission levels between private and commercial vehicles for NO and CO as a function of model year are given in Figure 4.4. Differences are seen for pre-1996 model years. CO emissions are markedly higher for commercial vehicles from model years 1991–1995. NO levels are mixed, with commercial vehicles having lower emissions up to the 1992 model year (and 1998–2000, albeit only slightly).

Table 4.12 Percentage of "Defective" Catalytic Converters (CO > 0.3%, CO_2 < 14% and $O_2 \geq$ 0.4%)

Model year	*93.1*	*93.2*	*94.1*	*94.2*	*95.1*	*95.2*	*96.1*	*96.2*	*97.1*	*97.2*	*98.1*	*98.2*	*99.1*	*99.2*
2-way converter														
1991			0.0		33.3	27.8	28.6	26.2	29.4	22.7	25.2	19.9	11.1	12.4
1992	0.0	40.0	23.0	20.5	27.0	26.0	30.4	27.3	42.7	28.4	27.3	17.3	23.5	21.9
3-way open-loop converter														
1991	34.5	47.5	45.4	41.4	45.4	47.7	47.9	39.5	38.3	31.1	30.3	23.5	10.6	10.8
1992	37.7	44.0	44.9	41.9	41.8	45.6	45.0	36.0	37.0	29.5	29.9	24.3	10.2	11.4
1993	0.0	0.6	1.1	0.8	0.8	0.4	1.5	1.8	7.4	4.1	4.3	0.9	2.4	1.9
1994		0.0	0.6	0.2	1.2	0.4	1.1	1.4	5.7	3.4	2.5	1.7	2.3	2.3
3-way closed-loop converter														
to 1990	50.0	20.0		0.0	51.7	46.3	38.8	42.5	51.9	44.0	43.3	41.5	25.2	23.0
1991	7.3	9.7	9.4	6.6	7.6	5.8	9.5	8.5	17.7	9.9	10.3	8.4	3.9	3.8
1992	5.0	6.6	7.3	4.7	5.9	5.7	8.4	7.3	16.9	9.5	7.6	5.2	4.1	4.4
1993	2.8	3.1	4.4	4.4	6.9	9.7	12.2	7.2	15.7	8.3	8.9	6.2	3.9	3.2
1994		1.1	2.0	2.0	2.4	2.4	5.6	4.5	11.4	5.7	4.8	3.6	3.2	2.7
1995				0.3	1.2	1.6	3.2	2.8	8.7	3.8	2.7	1.9	2.0	1.6
1996						0.0	1.1	1.4	4.4	1.7	1.6	0.9	1.1	1.0
1997								0.4	4.0	1.4	0.7	0.3	0.4	0.4
1998										0.4	0.3	0.1	0.2	0.2
1999												0.0	0.1	0.1

Figure 4.4 Mean NO and CO Emissions by Vehicle Service Type and Model Year, Data from 1999 Taken at 40 km/h for CO and 24 km/h for NO



Vehicle Weight

4.65 The emissions data were analyzed by vehicle type for vehicles equipped with three-way closed-loop converters. The results, given in Table 4.13, show that emissions tend to increase with increasing vehicle weight.

Table 4.13 Percentage of Gasoline Vehicles, by Type, Exceeding Emissions: 200 ppm HC, 1 percent CO and 1,600 ppm NO

Vehicle class	*Hydrocarbons*	*Carbon monoxide*	*Nitric oxide*
Cars	0.9	2.1	11
Vans/wagons	1.1	1.8	6
Pickups	1.3	3	5
Class 3	2.9	8.2	17
Class 5 & 7	1.9	3.8	13

Total Distance Traveled

4.66 One may argue that for a given model year, the more the vehicle is driven, the higher the emissions expected at testing because of wear and tear and deterioration of exhaust control systems. This hypothesis is examined in Table 4.14. There is no monotonic increase in test emissions levels with increasing distance traveled (with the exception of CO and HC for the 1999 model year). The falling emissions with increasing distance over 200,000–300,000 km may be due to engine overhauls and other major repairs. It appears from these results that the model year is a much more significant determinant of emissions than the total distance traveled.

Enforcement of Emissions Inspection

4.67 In 1996 and 1997, all vehicles in ZMVM had to be tested at the macro-centers in the same federal entity—Federal District or the State of Mexico—that had issued their license plates. (For example, vehicles with Federal District plates had to be tested in the Federal District.) This restriction was later lifted, allowing vehicle owners to go to any inspection center in ZMVM. Owing to the lack of centralized operational control of the two programs, this added flexibility caused control to be lost, enabling a number of vehicles to escape inspection altogether. On the basis of the mortality curve developed for ZMVM, the study team estimated (1) the number of vehicles tested in the Federal District in the first semester of 1997 and (2) the number operating but not tested in the Federal District in the second semester of 1999. Approximately 500,000 vehicles that would have been tested in the Federal District under the old system are calculated to have "disappeared" from the Federal District program between the two semesters. The results are shown in

Table 4.15. Of those vehicles that "disappeared," the 1981-85 model-year range—possibly the worst in terms of pollution—was the most affected, with approximately 158,000 cars, 20,000 vans and wagons, 31,000 pickups and 5,000 Class-3 vehicles failing to report for emissions tests.

Table 4.14 Percentage of Gasoline Vehicles, by Type, Exceeding Emissions: 200 ppm HC, 1 percent CO and 1,600 ppm NO

Model year	*less than 20,000 km*	*20,000–49,999 km*	*50,000–99,999 km*	*100,000–199,999 km*	*200,000-299,999 km*	*300,000–499,999 km*	*more than 500,000 km*
CO, percent							
1984 to 90	0.81±0.04	0.85±0.04	0.81±0.03	0.79±0.03	1.01±0.08	0.93±0.07	0.92±0.05
1991	0.29±0.01	0.25±0.01	0.26±0.01	0.29±0.01	0.27±0.03	0.27±0.02	0.30±0.02
1992	0.32±0.01	0.29±0.01	0.29±0.01	0.34±0.01	0.31±0.02	0.33±0.02	0.30±0.02
1993	0.26±0.01	0.23±0.01	0.22±0.01	0.23±0.01	0.28±0.02	0.24±0.01	0.23±0.01
1994	0.18±0.01	0.16±0.00	0.16±0.00	0.18±0.01	0.18±0.01	0.18±0.01	0.17±0.01
1995	0.13±0.01	0.10±0.00	0.13±0.00	0.12±0.01	0.15±0.02	0.11±0.01	0.13±0.02
1996	0.11±0.01	0.12±0.00	0.14±0.01	0.14±0.01	0.11±0.02	0.11±0.02	0.10±0.02
1997	0.08±0.00	0.10±0.00	0.12±0.00	0.10±0.01	0.12±0.02	0.18±0.09	
1998	0.06±0.00	0.08±0.00	0.10±0.00	0.11±0.01	0.08±0.01		
1999	0.06±0.00	0.10±0.01	0.13±0.03	0.14±0.04			
NO, ppm							
1984 to 90	1,010±45	1,042±44	1,266±31	1,518± 37	743±64	639±56	669±39
1991	964±27	859±23	1,137±15	1,363± 20	699±53	550±40	527±25
1992	889±28	821±21	1,168±14	1,429± 24	743±52	587±40	531±27
1993	659±14	669±11	815± 8	927± 16	547±28	410±19	531±18
1994	575±11	587± 8	739± 6	850± 14	489±26	389±18	468±17
1995	413±10	457± 6	574± 6	665± 17	371±26	306±19	500±32
1996	270± 9	341± 6	445± 8	436± 23	217±24	389±37	367±81
1997	256± 5	351± 4	412± 6	351± 17	270±22	468±51	
1998	247± 3	309± 3	342± 8	341± 19	437±61		
1999	281± 5	346±14	401±43	262±120			
Hydrocarbons, ppm							
1984 to 90	154±11	148±11	131±3	137±5	150±13	165±15	167±10
1991	45± 2	44± 2	37±1	48±2	64± 7	51± 3	50± 3
1992	50± 2	46± 2	44±1	52±1	53± 4	51± 3	48± 3
1993	41± 1	37± 1	36±1	42±1	48± 4	48± 4	44± 2
1994	35± 2	30± 1	30±1	38±1	45± 7	38± 5	41± 4
1995	24± 1	21± 0	25±1	30±1	25± 2	23± 1	25± 2
1996	25± 1	23± 0	27±1	32±3	29± 3	25± 2	28± 6
1997	19± 0	19± 0	21±0	22±1	25± 3	23± 5	
1998	16± 0	18± 0	20±0	22±2	18± 2		
1999	17± 0	21± 1	23±2	24±6			

Table 4.15 Percentage of Vehicles Estimated to be "Missing," Second Semester 1999

Type	*to 60*	*61-65*	*66-70*	*71-75*	*76-80*	*81-85*	*86-90*	*91-95*	*96-99*	*Total*
Cars	21.9	18.2	52.5	50.4	53.0	73.4	24.5	0.0	0.0	16.6
vans/ wagons		100.0	100.0	33.0	94.5	84.4	28.3	0.0	0.0	18.0
Pickup	42.1	6.3	21.8	20.5	15.6	59.5	22.9	15.1	0.0	19.7
Class 3	100.0	100.0	84.1	21.9	30.7	33.5	8.7	16.8	0.0	16.7
Class 5/7										
Total	43.6	23.6	48.0	42.1	46.4	67.5	23.5	2.8	0.0	16.8

4.68 500,000 vehicles represent 17 percent of the vehicle population. A great percentage of these vehicles might be suspected of being "gross" polluters and would have had difficulty passing their corresponding emissions test requirements at inspection centers in the Federal District (since these centers adhere to the test protocols more rigorously than those outside).

4.69 The U.S. Auto/Oil Air Quality Improvement Research Program (1997) found that 20 percent of vehicles were responsible for 80 percent of total vehicle emissions. If comparable figures are applicable to ZMVM, then those not reporting to the tests in the Federal District may have considerably higher emissions than those that did. This may explain in part why the percentage of vehicles with defective converters shown in Table 4.12 has been declining since the first semester of 1997.

Conclusions

4.70 Studying the characteristics and emissions-testing performance of ZMVM's vehicle population yields a number of important conclusions. While all the conclusions are directly relevant to Mexico's efforts to control emissions, some are also of general relevance to other countries that are currently less advanced in their approaches to emissions control.

4.71 The revised estimates of the vehicle population in ZMVM—allowing for mortality, and thus discounting many older vehicles that would have been included if a simple measure based on total past sales had been used, as has been the case hitherto—show that the average vehicle age is 9 years. With this life expectancy, the introduction of new technology to improve emissions, through mandating its presence in all new vehicles sold, takes several years before it can have a substantial overall effect. For example, in 1993, when the presence of three-way catalytic converters—which are important for the reduction of NO_x emissions—first became widely available, some 78 percent of vehicles did not have a converter. Six years later this figure was still as high as 46 percent.

4.72 The results of the testing program showed that certain factors are related to the levels of emissions at the initial annual test. Of particular importance is the model year of the vehicle. Vehicle manufacturing technology has steadily improved, so that emissions from the most recent models are lowest. This is true especially for that subset of more-recent years for which catalytic converters were mandatory. This has allowed the emissions-test limits to be tightest for new cars without increasing their failure rate. At the same time, to target the grosser polluters, emissions standards have been tightened most sharply for the oldest vehicles, thus giving an incentive to remove them from the ZMVM population.

4.73 Available data in ZMVM indicate that newer-model-year vehicles are driven more per year, so that the most polluting cars travel less than their absolute numbers might suggest. Although 42 percent of vehicles in ZMVM had no converter in 1999, they contributed 32 percent of the total kilometers traveled. Although comprising only one-third of total travel, these vehicles would be expected to contribute substantially more to total emissions because of the absence of exhaust control technology.

4.74 The study of emissions testing confirmed that technology is important, in that cars with catalytic converters generally emitted less than those without. For cars with catalytic converters dating from 1993 or earlier, the emissions were greater, perhaps in part because leaded gasoline (which deactivates the catalyst) had been available on the market at the time. For model years 1994 and 1995 only 3 percent of the catalytic converters fitted appeared to be seriously deactivated, so that the effectiveness of the program of wholesale mandatory converter replacement for these later years is questionable.

4.75 Emissions were also greater for vehicles with greater weight, which resulted in standards being slightly more generous for this class of vehicles. Taking vehicles as a whole, emissions were higher for the non-private vehicle categories, but this may in part be due to the fact that they are heavier.

4.76 Given a technically efficient testing procedures and an effective enforcement mechanism, the experience in ZMVM shows that it is possible to use a discriminating set of compliance rules. Not only can the pass-level of emissions be tailored to the relevant characteristics of the vehicle population (including age, weight and installed technology), but limits on driving the car can be set so as to reduce the use of the higher (but legal) polluting vehicles on those days when the ambient pollutant concentrations are especially high. By contrast, many families circumvented the restrictions of the "day-without-a-car" program—in which the permission to drive a car initially depended only on the termination of number plates—by buying a second car, thus increasing the total vehicle population that could be used on those days when there was no ban in force.

4.77 One of the key aspects of any emissions testing program is the relationship between testing and enforcement. The experience in Mexico City shows that for a testing program to be effective, a number of conditions have to be met:

- The testing stations should provide accurate evaluations of the emissions levels and not issue "false pass" certificates to vehicles that in fact are exceeding the legal limits.
- A legal framework has to be established that allows testing stations to be penalized for failure to carry out the testing protocols correctly. The testing stations must be subject to monitoring by independent bodies, and in cases of noncompliance, sanctions must be applied.

- The sticker certifying that a vehicle has passed an emissions test must be easily displayed and highly visible, and there should be sufficient monitors (for example, traffic police) to ensure a high probability of catching vehicles that do not display such a certificate.
- The fine for not displaying or not having a legal emissions test certificate must be sufficiently high to act as an incentive to pass the test.
- The testing technology must be able to prevent the use of temporary "tuning," which enables a vehicle to pass the test but cannot be sustained for regular driving. In the absence of such a technology, motorists and garages become adept at circumventing the purpose of the testing procedure—to identify high-polluting vehicles.
- All testing centers must be subject to equally rigorous implementation of protocols and inspection of their procedures; otherwise, owners of the highest-polluting vehicles easily identify the "softest" centers for passing the test.
- Although Mexico's private sector has been able to provide a competitive supply of testing centers, it remains necessary for the government to regulate the sector to prevent profit-seeking activities that were against the public interest (for example, supplying "false passes" to motorists, thus saving them money but increasing pollution levels).
- The optimal number of licensed centers should be relative to the volume of traffic to be tested. If there are too many centers, the rigor of the tests tends to be watered down as each garage tries to increase market share.
- The use of garages that were permitted to both test and repair resulted in very poor implementation, leading to a high level of "false passes." This conflict of interest needs to be resolved; in the case of Mexico, it meant that all test-and-repair garages were closed down.

5

Policy Options for Transport Fuels

5.1 Chapter 4 examined different measures implemented by the Mexico City government to address vehicle exhaust emissions. Another important parameter in controlling vehicle emissions is the quality of transport fuels. This chapter outlines some of the main issues policymakers may consider as they examine different options for improving transport fuel quality in Mexico. It begins by discussing the trends in fuel specifications in the 1990s and during the coming decade in North America and the EU, as well as the future vehicular emission and sulfur standards in the United States. The trends in these regions would represent the "best available technology" rather than what might be the most cost-effective alternatives for Mexico. Nevertheless, these two industrialized regions are discussed at length because the quality of transport fuels in Mexico is already broadly in line with that in the United States, particularly in the three major metropolitan areas, and Mexican vehicle manufacture is closely integrated into the North American market.

5.2 The chapter then turns to Mexico, describing the current status of fuel quality and vehicular emission standards and discussing the status of the refining sector, including investment plans currently being implemented. It concludes with a treatment of options for Mexico and their implications, underscoring some of the key technical and policy considerations.

Worldwide Trends in Fuel Specifications and Emissions Standards

5.3 Fuel specifications worldwide have changed enormously in recent years. Perhaps the most significant change has been the elimination of lead in gasoline in a number of countries, including the Slovak Republic (1996), Thailand (1995), the United States (finally phased out on 1 January 1996), Mexico (1997), Hungary (1999), Bangladesh (1999), India (2000) and a host of Central and South American countries. Because lead in gasoline has been eliminated in Mexico, airborne lead from gasoline is no longer a public health threat.

5.4 North America and Europe are setting increasingly stringent limits on benzene, aromatics, olefins and sulfur in gasoline, on gasoline volatility, and on sulfur in diesel. The drive to limit sulfur considerably below 500 wt ppm stems primarily from the incompatibility of sulfur at that level with emerging exhaust-control technologies (such as continuously regenerating traps for diesel-powered vehicles and catalyst systems for reducing NO_x at a high air-to-fuel ratio) as well as the fact that sulfur acts as a poison for the platinum and palladium that are the active components in conventional catalytic converters (although the effects may be reversible).

5.5 Because of the complex and closely linked interactions between fuels and vehicle technology, fuel specifications and emission standards should be treated jointly. For the purpose of discussing fuel specifications in Mexico, the most relevant are the trends in the United States because vehicle manufacture in Mexico is effectively integrated into that in the United States from the standpoint of vehicle technology. As mentioned in Chapter 4, 73 percent of all vehicles manufactured in Mexico were exported in 1999, 92 percent of them to North America. The EU is discussed here to illustrate the approach of another highly industrialized region of the world. In addition, a proposal for the harmonization of fuel standards worldwide—recently published by the automakers in North America, Europe and Japan—is discussed briefly. Finally, two major auto/oil industry studies, one undertaken in the United States and the other still in progress in Europe, are treated at some length as they provide valuable data on the complex relationships between vehicular emissions, fuel quality and vehicle technology. These studies contain useful lessons for Mexico.

U.S. Trends in Vehicular Emission Standards and Fuel Specifications

5.6 The United States reformulated gasoline (RFG) program came into force in 1995. It affords more flexibility than perhaps any other program worldwide, allowing refiners to seek the least-cost approach to meeting vehicular emission standards. A U.S. auto/oil industry study—the Air Quality Improvement Research Program—generated a large amount of data correlating vehicular emissions, fuel quality, vehicle technology and air quality. The vehicular emission and fuel quality standards will be considerably tightened in the United States with the introduction of the so-called Tier 2 emission standards in the middle of this decade.

Clean Air Act (CAA) Amendments of 1990

5.7 The CAA Amendments of 1990 have required significant changes in the U.S. refining industry. They define two categories of regulated gasoline: oxygenated gasoline (OxyFuel) and RFG. OxyFuel, which is gasoline with an oxygen content of 2.7 percent by weight (wt%), is specified for CO non-attainment areas[14] during the winter months when CO emissions are high. *RFG* refers to a more extensive change in gasoline properties that reduces VOC emissions and toxic emissions. RFG is required in the areas in the United States that have the most serious problems with ozone pollution.

5.8 The CAA Amendments require vehicle emission reductions in two phases. For Phase I, beginning in 1995, the law specifies a minimum 15 percent reduction in VOC emissions during the high-ozone season and a minimum 15 percent reduction in toxics during

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[14] *Non-attainment areas* are areas that are not in compliance with national air quality standards. Separate regulations apply to CO and ozone non-attainment areas. Noncompliance with CO standards is primarily a winter problem. Noncompliance with ozone standards is primarily a summer problem in the United States.

the entire year. Under Phase II, which began in 2000, the law calls for a minimum reduction of 29 percent in VOC and a minimum reduction of 21 percent in toxics emissions from the 1990 industry baseline. The fuel specifications to meet these reductions are given in Annex 3, as are Federal diesel standards.

5.9 One prominent feature of the U.S. fuel specifications, in sharp contrast to those in the rest of the world, is that they are performance-based. These performance-based specifications rely on empirically derived models to identify a range of fuel compositions that will achieve emission targets. They require an extensive database of emission levels as a function of fuel composition and vehicle characteristics. The empirical relationships may have to be updated from time to time as the vehicle fleet characteristics evolve. Monitoring is more complicated, because the compositional analysis of the fuel must be checked against empirical equations. These standards may hence be more expensive to implement and enforce than the composition-based standards currently in force in Mexico.

5.10 Once the mathematical models are set up, however, these specifications offer far greater flexibility to refiners, enabling them to select the most economic way to meet emission targets. This, together with regionally differentiated fuel standards, has provided a significant cost-advantage to the refining sector in the United States, making it less expensive to meet clean air targets than if there had been uniform, nationwide, composition-based fuel specifications.

5.11 Another example of the flexibility offered by performance-based standards is the California diesel standard. California has been a leader in emission control legislation and has generally adopted limits more severe than the Federal (CAA) limits that apply to the rest of the United States. With respect to diesel, the CARB adopted a diesel fuel specification of 500 wt ppm sulfur and 10 percent by volume (vol%) aromatics effective from October 1993. It is important to recognize that there are different ways of certifying diesel in California. Reducing aromatics to 10 percent would be very costly, and an alternative approach is used in California—adjusting other fuel parameters to meet the same emission standards. According to CARB, none of the refiners are using the default 10 percent aromatics limit in the CARB diesel rule, but instead use certified alternative formulae that usually include achieving a high cetane number by means of cetane improvers while reducing sulfur.

5.12 Up until now, MTBE has been widely used in gasoline in the United States, in part to meet the minimum oxygen content requirement. MTBE is currently being added to gasoline in three metropolitan areas in Mexico. In March 1999 the governor of California announced that the state would begin immediate phaseout of MTBE from gasoline, with complete elimination to be achieved no later than 31 December 2002. The principal reasons cited were MTBE contamination of lakes, particularly in recreational areas, as well as fears that MTBE may be making its way in significant amounts into the state's groundwater supplies. With respect to recreational areas, the dispute over MTBE has become particularly acute where large numbers of personal watercraft such as Jet Skis and small boats are common, many of them powered by two-stroke engines. According to some estimates, up to 30 percent of the fuel in the Jet Skis' two-stroke engines is released unburned into the water. More recently, the governor of New York also signed legislation prohibiting the sale of gasoline containing MTBE by the end of 2003. There are even moves to ban the use of MTBE in gasoline altogether in the United States.

5.13 In response, the US EPA appointed a Blue Ribbon Panel in November 1998 to investigate the air quality benefits and water quality concerns associated with oxygenates in gasoline. The panel found that incidences of MTBE in drinking water supplies at levels well above EPA and state guidelines and standards had occurred but were rare. The panel recommended a substantial reduction (but not a ban) of the use of MTBE in gasoline and removal of the current two-percent oxygen requirement.[15]

U.S. Auto/Oil Air Quality Improvement Research Program (AQIRP)

5.14 The AQIRP, conducted by three domestic auto companies and fourteen oil companies at a cost of $40 million, spanned a six-year period between 1989 and 1995. Its purpose was to provide data to help legislators and regulators achieve the nation's clean air goals through a research program consisting of (1) extensive vehicle emission measurements, (2) air quality modeling studies to predict the effects of the measured emissions on ozone formation and (3) economic analysis of some of the fuel/vehicle systems. The program focused on gasoline and alternative fuels but did not cover diesel. It was the largest and most comprehensive research program of this nature ever conducted in the United States. Some of the findings (AQIRP 1997) include the following:

Ozone

- ➢ Reducing aromatics in gasoline from 45 percent to 20 percent had no statistically significant impact on predicted ozone. (*Note*: Aromatics with two or more alkyl branches are ozone precursors.) Fuel composition changes that reduced the predicted ozone contributions of light-duty vehicles included reductions in T_{90} (temperature at which 90 percent of gasoline evaporates) and T_{50}, olefins, sulfur (for catalytic converter-equipped cars) and volatility (RVP).
- ➢ Reducing gasoline olefins from 20 percent to 5 percent increased exhaust HC and reduced NO_x, reduced the photochemical reactivity of exhaust and evaporative emissions, and led to a marked decrease in predicted ozone.
- ➢ Decreasing RVP from 9 psi to 8 psi reduced evaporative emissions as well as exhaust HC and CO, and led to a marked decrease in predicted ozone.

Gross Emitters

- ➢ High-emitting, poorly maintained vehicles on the road contributed about 80 percent of total vehicular emissions but represented only about 20 percent of the population. Identification and repair of these vehicles can result in substantial emission reductions.

Toxics

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[15] The panel also recommended (1) accelerating enforcement of the replacement of existing underground storage tank systems for gasoline and (2) more systematic monitoring of MTBE and other components in groundwater at all underground storage release sites.

- Of the four toxics measured, benzene (a carcinogen) had the largest concentrations in the emissions. Decreasing fuel benzene or the total aromatic content reduced benzene emissions.

Oxygenates

- Adding oxygenates to gasoline reduced exhaust HC and CO in 1989 and earlier vehicle models, and raised NO_x with low-aromatic fuels. Vehicles from1993 and later model years did not show any emission change; this was to be expected because these cars are equipped with oxygen sensors.

Sulfur

- Decreasing sulfur generally reduced exhaust toxics, HC, CO and NO_x for cars equipped with three-way converters.

5.15 Of particular interest is the surprising result that reducing the amount of aromatics more than two-fold in gasoline had no impact on predicted ozone. Because aromatics are an important source of octane as well as hydrogen (which is needed to reduce sulfur in fuels), dramatic aromatics reductions would have a considerable adverse impact on refinery economics, while not having much benefit in the way of air quality improvement once the vehicle fleet is equipped with catalytic converters. This implies that once the majority of gasoline-fueled vehicles are equipped with catalytic converters, the only significant adverse health impact of aromatics will be benzene emissions. However, for benzene control, it is typically more cost-effective to control benzene in gasoline than total aromatics.

Tier 1 and Tier 2 Emission Standards

5.16 The so-called Tier 1 vehicle emission standards for light-duty vehicles in the United States were introduced progressively from 1994. Starting in 1996, vehicles have had to be certified up to 100,000 miles (160,000 km), or to the higher of "useful life" limits. The durability of the emission control device must be demonstrated over this distance, with allowed deterioration factors. Heavy-duty truck regulations for 1987 and later require compliance over longer periods, representative of the vehicle's useful life.

5.17 The emission levels of new vehicles are measured in a certified driving cycle. A test driving cycle called FTP75 (Federal Test Procedure 75) has been used in the United States since 1975. Mexico currently uses FTP75 also. As required by the CAA Amendments, the US EPA re-evaluated typical driving patterns and found that the FTP test cycle does not cover about 15 percent of driving conditions. As a result the US EPA issued a Final Rule in August 1996 setting out modifications. The main element of this rule is a Supplemental Federal Test Procedure (SFTP), covering the driving patterns not included in FTP75. SFTP includes two new driving cycles, one representing aggressive driving, and another representing driving immediately following vehicle startup. A potential concern is what is known as "cycle beating," referring to scenarios whereby vehicle manufacturers design vehicles to meet the emission standards in FTP75, but where emission levels increase significantly in other driving cycles. SFTP has not yet been adopted in Mexico.

5.18 In October 1993, to meet the Tier 1 emission standards for particulate emissions from diesel-fueled vehicles, the United States imposed a sulfur limit of 500 wt ppm. Up until that point particulate emissions had been controlled by continuous improvement in vehicle technology. Vehicle exhaust particulate emissions consist of carbonaceous particles and sulfate-based particles. Because the vehicle technology improvement addresses carbonaceous particles only, sulfate contributions to particulate emissions, which are a function only of diesel sulfur content, became significant by 1993 in percentage terms, giving rise to the need to reduce sulfur in diesel to 500 wt ppm.

5.19 Beginning with the 1994 model year (autumn 1993), light-duty vehicles and light-duty trucks (equivalent to vehicle categories CL1–CL4 in Mexico) have been required to be equipped with on-board diagnostic (OBD) systems. OBD systems monitor emission control components for any malfunction or deterioration that cause emission limits to be exceeded, and alert the driver of the need for repair via a dashboard light when the diagnostic system has detected a problem. The US EPA made changes to the federal OBD requirements starting in the 1999 model year (autumn 1998). The modifications include harmonization of the emission levels above which a component is considered malfunctioning with California's OBD Generation Two (OBD II) requirements. OBD systems are seen as a complement to traditional I/M programs rather than a substitute. By January 2001, all areas with basic and enhanced I/M programs are required to implement OBD checks as a routine part of I/M programs. Failure of the OBD test would require mandatory repair.

5.20 In the area of future vehicular emissions and transportation fuel reformulation, the debate in the United States is currently focused on the introduction of Tier 2 vehicle emission standards. Tier 2 is a comprehensive national control program that regulates the vehicle and its fuel as a single system. The new tailpipe emission standards for passenger vehicles will reduce NOx emissions by 77 percent from cars and up to 95 percent from SUVs (sport utility vehicles) and trucks. The standards for SUVs and trucks are to be brought in line with those of other cars for the first time and the same standards are to be applied to gasoline and diesel vehicles. The emission standards for these light-duty vehicles will be phased in between 2004 and 2009, as shown in Table 5.1. The corresponding schedule for gasoline sulfur standards is given in Table 5.2. Sulfur in gasoline is required to be reduced from the current national average of about 300 wt ppm to a mandatory average of 30 wt ppm. "Small refiners" (with an average crude capacity of less than 155,000 b/d and employing fewer than 1,500 people) are eligible for hardship provisions that permit an annual average sulfur limit of up to 300 wt ppm until 31 December 2007. The US EPA estimates the cost to consumers to be less than $100 for cars, $200 for light-duty trucks and less than $0.02/gallon for gasoline sulfur reduction, with the overall cost to industry on the order of $5.3 billion against health and environmental benefits of about $25 billion.

Table 5.1 Phase-in Percentages for Tier-2 Gasoline Vehicle Emission Requirements

Model year	*Percentage of vehicles that must meet Tier 2 requirements*
Light-duty and light light-duty trucks	
2004	25
2005	50
2006	75
2007 and subsequent	100
Heavy light-duty trucks and medium-duty passenger vehicles	
2008	50
2009	100

Table 5.2 Gasoline Sulfur Limits in the United States

Averaging period beginning	*January 2004*	*January 2005*	*January 2006 and subsequent*
Refinery or importer average	Not applicable	30 wt ppm	30 wt ppm
Corporate pool average	120 wt ppm	90 wt ppm	Not applicable
Per-gallon limit	300 wt ppm	300 wt ppm	80 wt ppm

5.21 For gasoline sulfur reduction, the US EPA has based its incremental cost calculations on two new hydrodesulfurization technologies, Mobil's Octgain and CD Tech's CDHydro/CDHDS, neither of which had been commercially proven at the time the incremental costs were computed. For the U.S. refining industry overall, the difference in capital investment between using conventional technologies and emerging technologies may be dramatic. One estimate gives $7 billion versus $3.5 billion. Separate refinery modeling exercises by the US EPA, the auto industry and the oil industry confirm that newer desulfurization technologies are nearly 50 percent less costly than older technologies. On the basis of a spreadsheet analysis, the US EPA calculated the cost of achieving 30 ppm sulfur with the older converters to be 2.9 U.S. cents/gallon, while the newer technology achieved that reduction at a cost of 1.5 U.S. cents/gallon.

5.22 The US EPA issued, in July 2000, a final rule for the first phase of the program on heavy-duty trucks and buses, taking effect beginning in 2004. The emissions standards for heavy-duty diesel vehicles represent a reduction of more than 40 percent in NO_x emissions. The rule adds new test procedures and compliance requirements to ensure that emission standards are met in actual use across a wide range of operating conditions that come into effect with the 2007 model year. The rule requires OBD systems for engines weighing between 8,500 and 14,000 pounds (3,864 to 6,364 kg) to be phased in beginning in 2005. Vehicles weighing less than 14,000 pounds are subject to emission standards and testing similar to the current program for light-duty vehicles and light-duty trucks. The US EPA estimates that the average incremental cost of this program, projected over the long term, would be less than $400 per vehicle for heavy-duty diesel engines and less than $300 per vehicle for heavy-duty gasoline engines.

5.23 In December 2000 the US EPA also finalized new emission standards for heavy-duty vehicles that go into effect in 2007 and corresponding diesel fuel requirements that take effect in 2006. This is the second phase of the control program for heavy-duty vehicles and will achieve emission reductions of upwards of 90 percent over levels achieved by the phase 1 reductions described in the preceding paragraph. The implementation of these regulations, the schedule of which is shown in Table 5.3, will enable diesel vehicles of all sizes to achieve gasoline-like exhaust emission levels—in addition to their inherent advantages over gasoline vehicles with respect to fuel economy and lower evaporative hydrocarbon emissions. Diesel sulfur is limited to 15 wt ppm beginning 1 June 2006. This limit is based on the US EPA's assessment of the extent to which advanced aftertreatment technologies will be sulfur-intolerant. The US EPA estimates the cost of the program to be about $1,000 to $1,600 per new vehicle, and the incremental production and distribution cost of lowering sulfur from the current limit of 500 wt ppm to 15 wt ppm to be approximately 4 U.S. cents/gallon.

Table 5.3 Proposed Phase-in Schedule for Phase 2 Heavy-duty Vehicle Standards

Model year	*Percentage of vehicles that must meet the proposed requirements*
2007	25
2008	50
2009	75
2010	100

5.24 In response to these new rulings and proposals, the automotive industry is confident of being able to meet Tier 2 standards for cars, but is less certain about SUVs. As for diesel vehicles, particulate control technology is considered feasible, NO_x emission control is not yet proven but there is a general consensus that road maps for commercializing the technology exist. What the automotive industry is concerned about are the supplementary requirements, and especially the NTE (not-to-exceed) requirements,[16] which are proposed to take effect starting in the 2007 model year. This illustrates the interdependence between test driving cycles and emission levels, and the importance of not merely concentrating on establishing emission levels only.

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[16] The NTE approach establishes an area under the torque curve of an engine where emissions must not exceed a specified value of any of the regulated pollutants. The NTE requirement would apply under any engine operation conditions that could *reasonably* be expected to be seen by that engine in normal vehicle operation and use, as well as a *wide* range of *real* ambient conditions.

5.25 As for sulfur levels, one significant consideration in the United States is cross-contamination of low-sulfur fuels, particularly diesel, in the distribution system by higher sulfur fuels. If chances of cross-contamination are not negligible, having to ensure a maximum of 15 wt ppm sulfur in diesel at the pump would mean even lower sulfur levels at the refinery gate. In addition, in the case of diesel, there could be as many as three different sulfur levels for what is essentially the same product: on-road diesel, off-road diesel, and home heating oil. The uncertainty surrounding future sulfur specifications for the latter two categories of diesel makes refinery investment decisions difficult.

European Trends in Vehicle Emission Standards and Fuel Specifications

5.26 The EU introduced Euro III vehicle emission standards in 2000, and Euro IV emission standards will come into effect in 2005. Correspondingly, EU fuel specifications were tightened significantly in 2000, and will be made tighter in 2005. The EU standards are composition-based, and do not give the kind of flexibility allowed in the United States. OBD systems will become compulsory on European gasoline-engine cars only in 2001, several years behind the United States.

5.27 In 2000 the EU limited benzene in gasoline to 1 percent and aromatics to 42 percent (35 percent in 2005). Olefins in gasoline are limited to 18 percent in 2000. The limits on aromatics and olefins are more lenient that those already in force in ZMVM. Sulfur limits for gasoline are 150 wt ppm and 50 wt ppm in 2000 and 2005, respectively, and the corresponding figures for diesel are 350 wt ppm and 50 wt ppm.

5.28 Concerned about the effects of sulfur in diesel on particulate control aftertreatment devices, Germany has taken steps to make diesel fuel specifications more stringent and set the maximum limit to 10 wt ppm from January 2003. As a preliminary step, sulfur in diesel sold in Germany from November 2001 will have to be limited to 50 wt ppm. Germany also intends to urge other EU countries to adopt the 10-ppm diesel sulfur standards in time for the scheduled 1 October 2005 implementation date for Euro IV truck and bus emission legislation.

5.29 Leaded gasoline is still allowed in three countries in the EU—Greece, Italy and Spain—which were allowed until 2002 to phase lead out.

European Programme on Emissions, Fuels and Engine Technologies (EPEFE)

5.30 The EPEFE (also known as the European auto/oil industry study) is designed to (1) enhance the understanding of the relationships between fuel properties and engine technologies and (2) quantify the reduction in vehicular emissions that can be achieved by combining advanced fuels with the vehicle/engine technologies. The first phase (referred to as Auto/Oil 1) has been completed and the second phase is underway. The EPEFE marks an unprecedented degree of cooperation between the European motor industry (represented by the Association des Constructeurs Européens d'Automobiles, ACEA) and the European oil industry (represented by the European Petroleum Industry Association, or EUROPIA, a European government-affairs organization of the oil refining and marketing industry in the EU and the European Economic Area). Unlike the U.S. auto/oil AQIRP, EPEFE examined diesel in addition to gasoline.

5.31 Auto/Oil 1 confirmed that the relationships between fuel properties, engine technologies and exhaust emissions are complex. Changes in a given fuel property may lower the emissions of one pollutant but increase those of another (for example, decreasing aromatics in gasoline lowered CO and HC emissions but increased NO_x emissions for converter-equipped cars). In some cases, engines in different vehicle categories, such as heavy-duty and light-duty vehicles, had opposite responses to changes in fuel properties (for example, reducing polycyclics in diesel reduced HC emissions in heavy-duty engines but increased HC, CO and benzene emissions in light-duty vehicles).

5.32 For both gasoline and diesel vehicles, individual vehicles and engines showed a wide range of response to the fuel properties investigated. In the case of gasoline vehicles, some vehicles that showed low fuel sensitivity for CO and HC emissions showed high sensitivity for NO_x and vice versa. In the case of diesel vehicles, the impact of the vehicle/engine set on emissions was larger than that of the matrix of fuel properties except for NO_x emission on heavy-duty engines. These findings underscore the importance of targeting the vehicle hardware.

Worldwide Fuels Charter

5.33 The Worldwide Fuels Charter was developed by three automobile groups: the now-defunct American Automobile Manufacturers Association, ACEA and the Japanese Automobile Manufacturers Association. The objective of the global fuel harmonization effort, according to the automakers, is to develop common, worldwide recommendations for "quality fuels," taking into consideration customer requirements and vehicular emissions technologies that will in turn benefit customers and all other affected parties. The automakers hope that implementation of the recommendations will

- reduce vehicular emissions,
- consistently satisfy customer performance expectations, and
- minimize vehicle equipment complexities with optimized fuels for each emissions control category.

5.34 The charter establishes four categories of unleaded gasoline and diesel. "Category 1" fuel is intended for markets that require minimal emissions controls. "Category 2" fuel is for markets with stringent requirements for emissions controls. "Category 3" fuels are designed for markets with advanced requirements for emissions control as these technologies are designed today. "Category 4," which was not included in the original charter but was added in the April 2000 edition, is for markets with further advanced requirements for emission control (such as Euro IV and U.S. Tier 2) to enable the use of sophisticated aftertreatment technologies addressing NO_x and particulate matter. The only difference between Category 3 and Category 4 is the level of sulfur. The gasoline and diesel specifications for Categories 2–4 are given in Table A3.5 and Table A3.6 in Annex 3, respectively.

5.35 The environmental goals of different countries vary according to their level of economic activity, air quality problems, and climatic and geographical conditions. Emission standards and, equally important, test cycles differ from country to country, and they are in turn met by different combinations of vehicle and fuel technologies. Under these circumstances, the cost-effectiveness of worldwide harmonization of either fuel quality or vehicle emission standards is far from clear. To the extent that harmonization is called for, fuel specifications should be harmonized with emission limits, vehicle technology and test cycles. Not doing so and going after Category 2 or Category 3 fuel specifications could result in the selection of sub-optimal mitigation strategies.

5.36 With the exception of sulfur, the gasoline specifications for ZMVM are already more stringent than those found for Category 3 in the Worldwide Fuels Charter, particularly for total aromatics. The diesel specifications, in contrast, for Category 3 in the Worldwide Fuels Charter are extremely stringent, and it is not even clear that they would be cost-effective. It is possible to trade-off total aromatics and polycyclic aromatics with sulfur and cetane to achieve comparable emission levels. Reducing total aromatics and polycyclic aromatics can be very costly because of the severe hydrotreating required.

Current Status of Fuel Quality and Vehicle Emission Standards in Mexico

5.37 As a result of the investment program undertaken to improve fuel quality in Mexico in the early to mid-1990s, the gasoline and diesel quality standards in Mexico today are broadly comparable to federal standards in the United States. In terms of actual fuel quality, one of the significant differences is the level of sulfur in gasoline, which averages about 300 wt ppm in the United States but closer to 700 wt ppm in Mexico. Vehicular emission standards have not kept pace with the improvement in fuel quality standards. Some of the differences between the current vehicular emission standards for new vehicles in the United States (Tier 1) and those that are intended to correspond to Tier 1 effective 2001 include particulate emissions for diesel-fueled vehicles and lack of durability requirements.

5.38 From the viewpoint of public health, the most significant impact of the investment program in the first half of the 1990s was perhaps the elimination of lead in gasoline in 1997. Sulfur in diesel was lowered to 500 wt ppm throughout Mexico in 1996, the same year as the EU. The fuel parameters that affect air quality as well as the present and future vehicle emission standards in Mexico are given in Annex 3. The emission standards for new vehicles, to be compared with the U.S. Tier 1 emission standards, are given in Table A3.11 and Table A3.12 for gasoline- and diesel-fueled vehicles, respectively.

Fuel Specifications

5.39 The current fuel specifications in Mexico came into effect in 1996. The gasoline specifications in Mexico are regionally differentiated. The specifications are composition-based and are on a per-liter basis (i.e., every liter of gasoline produced must meet the specifications) and not on an averaging basis (for the latter case, the average values together with maximum limits are specified, with the average values being lower than the corresponding limits on a per liter basis), thereby making compliance potentially more costly for the refining industry. In polluted regions the addition of oxygenates is mandatory. The presence of oxygenates in gasoline will (1) achieve more complete combustion in older vehicles, thereby decreasing CO and hydrocarbon emissions; and (2) dilute gasoline, thereby decreasing the amounts of gasoline components that have adverse environmental impact.

5.40 The quality of automotive diesel in Mexico is broadly comparable to that in North America with the exception of T_{90}, which is 345°C in Mexico in contrast to 288°C in the United States. Because the components responsible for particulate and NO_x emissions (e.g., polycyclic aromatics) tend to concentrate in the heavier portion of diesel, reducing T_{90} to 288°C tends to make diesel "cleaner." On the other hand, discussions held with PEMEX indicate that at present fluidized catalytic cracker (FCC) light cycle oil (LCO)[17] is not blended into diesel, making the content of polycyclic aromatics in diesel lower in Mexico than in the United States for the same end point.

5.41 There is a proposal to reduce sulfur in gasoline to 300 wt ppm by 2005 and further to 50 wt ppm by 2009. These sulfur-reduction steps are discussed in more detail below.

Vehicular Emission Standards

5.42 Mexico is currently in the process of introducing U.S. Tier 1 emission standards. These standards came into effect in the United States in the 1994 model year, and in Mexico they will be enforced fully in 2001. In ZMVM new vehicles meeting the 2001 emission standards beginning in 1999 have been exempt from having to obtain the vehicular emissions certificate for two years and are given a Certificate "00" status as described in Chapter 4.

5.43 The particulate standards for light-duty diesel-fueled vehicles are not expressed in grams per kilometer, as in the United States and Europe, but in grams per test (see Table A3.12). Before imposing more stringent specifications on diesel fuel quality, policymakers may consider bringing the particulate emission limits in line with those of U.S. Tier 1.

5.44 A significant departure from the U.S. emission standards is perhaps the absence of durability requirements in Mexico. The principal reason for lowering the level of sulfur in gasoline is to ensure that catalytic converters operate adequately throughout the "useful life" of the vehicle. As discussed earlier, sulfur acts as a (temporary) poison to the active components in the catalytic converter. To ensure that the additional capital and operating expenditures incurred as a result of reducing sulfur in gasoline (and eventually in diesel once the installment of advanced aftertreatment devices becomes necessary in diesel-fueled vehicles) reap the full public health benefits that they are designed to achieve, it is extremely important to implement durability requirements.

5.45 Four automotive companies supply catalytic converters in Mexico: Allied Signal, Degussa, Engelhard, and Johnson Matthey. A telephone conversation with Allied Signal indicated that the converters supplied in Mexico are made to the same specifications as

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[17] A fraction in the FCC product, the boiling point range of which corresponds to that of diesel, containing a high concentration of polycyclic aromatics. FCC LCO is used extensively in diesel in the United States.

those in the United States. It appears reasonable to assume that the other three converter suppliers are following the same policy.

5.46 Recently, there has been a breakthrough in the area of pursuing durability requirements. The auto manufacturers in Mexico have agreed in principle to phase-in durability requirements up to 80,000 km (one-half that in the United States) and installation of OBD II beginning in the 2001 model year and reaching complete compliance by 2005. The auto manufacturers have also agreed in principle to supply Tier-2 compliant light-duty gasoline vehicles with a two-year delay starting in 2006, so that by 2009 all of the light-duty gasoline vehicles in Mexico will be Tier-2 compliant. In ZMVM 56 percent of gasoline vehicles are equipped with three-way converters and they account for 65 percent of total vehicle kilometers traveled. For Mexico as a whole the corresponding figures are slightly lower, with 52 percent of vehicles equipped with three-way catalytic converters. Given an average age of less than 10 years for gasoline vehicles in Mexico, the majority of vehicles would be expected to be equipped with three-way converters by the end of this decade, benefiting from sulfur reduction. There is a parallel move to lower the limit on gasoline sulfur nationwide to 300 wt ppm by 2005. Based on the U.S. experience, if sulfur in gasoline is limited to 300 wt ppm, durability requirements up to 160,000 km for Tier 1 should be enforceable for all gasoline vehicles including heavy light-duty trucks.

5.47 As mentioned earlier, sulfur acts as a temporary poison to catalytic converters, meaning that the efficiency of catalytic converters is decreased by the presence of sulfur in gasoline. A three-way converter that has been exposed to a high concentration of sulfur can still regain its efficiency to a considerable extent once the level of sulfur in gasoline with which the vehicle is fueled is reduced. If the converter regains its efficiency completely, any government-mandated reduction in the gasoline sulfur levels will have an immediate impact on all cars equipped with catalytic converters. If the converter cannot recover completely, it may be that the longer the vehicle fleet is exposed to high-sulfur gasoline, the less effective the immediate impact of sulfur reduction would be. The important policy question thus becomes the extent to which converters can recover from prolonged contact with sulfur. The U.S. auto/oil industry study showed that sulfur effects were completely reversible for Tier 0 and Tier 1 vehicles after a limited amount of driving. To probe the impact of sulfur on Tier 2 vehicles, the Coordinating Research Council conducted a program (Schleyer and others 1999) to measure the reversibility of fuel sulfur effects on emissions from California low-emission vehicles (LEVs). Six LEV models were tested using two conventional Federal fuels with 30 and 630 wt ppm sulfur. The participants in this program included two automakers, several oil companies and one university group. The reversibility of sulfur effects was found to be dependent on the vehicle, the driving cycle and the pollutant. For the test fleet as a whole, most but not all of the sulfur effects were reversible. Because vehicles in this program were run for a total of less than 900 miles (1,440 km), no conclusions on long-term effects may be drawn from this study. Given Mexico's plan to introduce Tier 2-compliant light-duty gasoline vehicles ahead of gasoline sulfur reduction to 30 wt ppm, the question of long-term effects of sulfur is important. If the exhaust control devices are seriously deactivated after tens of thousands of kilometers driven on high-sulfur (that is, hundreds of wt ppm sulfur) gasoline, then the benefits of this policy would be compromised.

5.48 Three-way catalytic converters were installed in most new vehicles starting in the 1993 model year in Mexico. The emission standards for in-use public transport vehicles introduced in ZMVM in July 1999 are quite strict. The intention is to target high-usage vehicles. In theory, focusing the pollution control strategy on vehicles in this category can be cost-effective because they are driven more. Setting too strict a standard, however, invites widespread evasion and/or corruption, making effective enforcement difficult. In designing in-use vehicle emission standards, it may be useful initially to target a reasonable percentage (for example, 20 percent) for failure, so that most vehicles can comply provided the owners follow regular maintenance; and then subsequently tighten standards in steps. Standards that are too stringent will result in non-compliance because the owners will not have as much incentive to try to meet the standards—which may require buying new vehicles or spending a significant amount of money for a complete overhaul of the vehicle. In addition, the owners may even neglect regular maintenance because trying to meet the emission standards would be considered out of reach. If a large fraction of public transport vehicles is not maintained regularly as a result, the benefits of improving fuel quality may be substantially diminished.

Status of the Mexican Refining Sector

5.49 So that it can process heavier domestic crude with higher sulfur content, PEMEX is currently undertaking a multi-billion dollar investment program to upgrade all six refineries. When the program is completed, currently estimated to be by 2004, Mexico will no longer need to import as much high-octane gasoline, but the quality of gasoline and diesel will remain unchanged.

5.50 PEMEX's six refineries have a combined nameplate capacity of 1.5 million b/d. Mexico imports about 120,000 b/d of high-octane gasoline or blending components today. All six refineries have FCC units designed to increase the production of gasoline. When all the upgrades are completed—an effort that includes expanding the FCC capacity of the refineries as well as installing coking units for refining Mexico's heavy crude grades—PEMEX will be able to process an additional 647,000 b/d of Maya crude and produce a greater quantity of higher-octane gasoline.

5.51 The decision to increase the amount of Maya crude processed by installing coking units and at the same time further expand FCC capacity has consequences for upgrading the quality of fuels in Mexico. Maya crude is heavy and high in sulfur content. FCC units increase the production of high-octane gasoline, but FCC naphtha is by far the most significant source of sulfur in gasoline, while FCC LCO makes poor-quality diesel (low cetane, high density, high polycyclics). The installation of coking units will increase the production of diesel, possibly introducing a supply-demand imbalance. Coker naphtha is high in sulfur and olefins and low in octane. Coker diesel is high in sulfur and low in cetane. Therefore, the refineries in Mexico are faced with the prospect of having to incur substantial capital expenditures to meet increasingly stringent fuel specifications. Upgrading the quality of fuels in this context would require a significant increase in the consumption of hydrogen, a costly feed, to hydrotreat FCC feed or FCC naphtha and diesel, particularly if the latter contains FCC LCO (although FCC LCO is said not to be blended into diesel in Mexico at this time).

5.52 As mentioned earlier, Mexico is currently proposing to lower sulfur in gasoline in two steps. In the first stage, sulfur will be lowered to a limit of 300 wt ppm nationwide. Hydrotreating FCC naphtha alone is considered to be sufficient to achieve this objective. While hydrotreating FCC naphtha is less expensive than hydrotreating the entire FCC feed, FCC naphtha hydrotreatment reduces octane because it saturates olefins and aromatics, which have high blending octane. The new technologies that the US EPA considered to calculate the incremental costs of reducing sulfur in gasoline (Octgain and CDHydro/CDHDS) claim to reduce sulfur in FCC naphtha with minimal loss of octane. These emerging technologies will have implications for the cost of reducing sulfur in gasoline in Mexico.

5.53 In the second stage, gasoline sulfur will be reduced further. Although a figure of 50 wt ppm has been mentioned (as opposed to the 30 wt ppm required for Tier 2), it is assumed that a sulfur limit will be set that will enable full implementation of Tier 2 with durability requirements. This second step would require FCC feedstocks to be hydrotreated. This is significantly more costly than hydrotreating FCC naphtha because the hydrotreating unit will have to be several times larger in size compared to the one for FCC naphtha. The advantages of hydrotreating FCC feedstocks include higher FCC conversion and substantial improvements in the yields of more valuable FCC products. The gasoline octane and LCO cetane index increase slightly when the FCC feed is hydrotreated. The sulfur content of all other FCC products is also reduced, including that of heavy fuel oil products.

5.54 The configuration of the refineries in Mexico, all of which are FCC-based, also has implications for fuel quality improvement. FCC naphtha is high in olefins, which are strong ozone precursors, and the heavy end of FCC naphtha is also high in sulfur and polycyclic aromatics. As mentioned previously, the U.S. Auto/Oil AQIRP showed that reducing RVP from 9 psi to 8 psi led to a marked decrease in predicted ozone as a result of a reduction in light olefins. Reducing RVP further to 7 psi (which is the limit in California during the ozone season) has been discussed in Mexico. This would represent butane-free gasoline (butane is one of the cheapest sources of octane) and possibly removing some C_5 hydrocarbons (hydrocarbons with five carbon atoms). Taking C_5 hydrocarbons out of gasoline would affect the operation of isomerization units. To mitigate some of the adverse impact on refinery economics, Mexico may consider differentiation of RVP limits between the ozone season and the months outside of the ozone season.

5.55 At this time PEMEX adds MTBE to gasoline sold in three metropolitan areas. The addition of MTBE serves three purposes: (1) it makes gasoline burn more completely in older vehicles; (2) it is an importance source of octane, which is a significant consideration now that lead has been phased out of gasoline in Mexico; and (3) it acts as a diluent for other gasoline parameters on which limits have been imposed, such as aromatics, benzene and olefins. However, the future of MTBE in North America is uncertain. Some industry observers believe that MTBE will eventually be banned throughout the United States. The principal concern is the contamination of groundwater. In theory it should be possible to address this problem by ensuring that underground gasoline storage tanks are leak-proof. Given the political forces in North America, however, PEMEX has suspended the plan to install a number of MTBE units at their refineries. In the absence of MTBE, alternative sources must be found of clean gasoline blending components that have high octane. Options include increased use of alkylation (more alkylation units are being built in the current revamp program), and isomerization with effluent recycle to maximize octane.

5.56 As mentioned earlier, much of the concern in California about MTBE has to do with the extensive use of two-stroke engine recreational boats in state and national parks. This is much less likely to be an issue in Mexico. From the standpoint of health impact, MTBE is no more toxic than gasoline itself. MTBE has an extremely low threshold level for taste and odor, so that a small trace in drinking water is readily detected. Before Mexico decides to follow the United States in considering whether or not to ban the use of MTBE in gasoline, the benefits of using MTBE (high octane, dilution effects, potential fall in the future price because of the ban in the United States) should be weighed against its negative effects.

Options for Mexico

5.57 The North American and European experience contains many lessons for Mexico as it considers different options for mitigating transport pollution. Mexico's final policy decisions should be based primarily on sound science and cost-effectiveness. The U.S. auto/oil industry study showed, for example, that for controlling ozone, it might not be necessary to impose a drastic limit on the content of total aromatics once the majority of gasoline-fueled vehicles are equipped with catalytic converters. Because aromatics from reformers are an important source of octane as well as hydrogen, not having to limit aromatics to a very low level would have a favorable impact on refinery economics.

5.58 Mexico City has one of the worst air pollution problems in the world, and some of the measures adopted to combat air pollution represent the best available technology of the time (for example, limits on aromatics, benzene and olefins in gasoline in ZMVM). In response to the North American Free Trade Agreement, the number of vehicles exported to the United States and Canada increased from 250,000 in 1990 to nearly 1 million in 1999. Because manufacturers of vehicles and catalytic converters have become increasingly integrated with those in the United States, it seems reasonable for Mexico to follow U.S. regulations with respect to fuel quality and vehicle emission standards.

5.59 The key issue for Mexico is how to phase in the U.S. standards. It is important to recognize that vehicle emission standards, fuel specifications and driving cycles are closely interlinked, so that selectively adopting some U.S. standards without adopting other measures might not be nearly as effective in improving air quality. An example given in the foregoing sections is enforcing Tier 1 without simultaneously requiring durability. Without durability requirements, there is no pressure on manufacturers of vehicles and catalytic converter to ensure that emission control systems function adequately during the vehicle's useful life. If emissions control systems are not durable, mandating the use of low-sulfur gasoline (or the supply of Tier 2-compliant vehicles) might not bring the intended benefits in terms of reducing exhaust emissions.

5.60 The dramatic reductions of sulfur proposed in North America and Europe are intended largely to utilize "enabling technologies." Because many of these technologies have not yet been commercially proven, it would make sense for Mexico to adopt these standards with a time lag. In addition, preliminary data indicate the potential for unexpected consequences that are not fully considered at the time of implementation of the new technologies. An example is a marked increase in the emissions of ammonia in advanced technology vehicles when operating on gasoline containing 30 wt ppm sulfur. Ammonia in turn reacts further with oxides of nitrogen and sulfur to form fine particles. Another example is from California, where an increase in the number of fine particles occurred as the ambient level of sulfur dioxide (SO_2) was reduced without a corresponding decrease in the level of ammonia. Ammonium ions that would otherwise have reacted with sulfate ions now react with nitrate ions, producing twice as many fine particles.[18]

5.61 Following are several considerations for policymakers formulating a strategy for mitigating vehicle emissions:

- Fuels and vehicles should be treated as a single system. Introducing Tier 2-compliant gasoline vehicles years ahead of the requisite gasoline sulfur reduction would be costly to consumers who might not benefit from the higher price paid for these vehicles. More specifically, if there is a delay in the gasoline sulfur reduction program, the advanced aftertreatment devices found in Tier 2-compliant vehicles may become deactivated. There are no comprehensive data to examine the long-term impact of driving tens of thousands of kilometers on high-sulfur gasoline on low emission vehicles, but even after only 1,400 km, converter activity did not recover completely after switching back to low-sulfur gasoline in a recent U.S. study. With respect to Tier 2, although the figure of 50 wt ppm sulfur for gasoline has been discussed in Mexico, the final sulfur content regulated should be consistent with what would be required for enable Tier 2 (for example, average of 30 wt ppm with a cap of 80 wt ppm as in the United States), so that durability requirements and other standards can be fully implemented.
- The auto/oil industry needs to be given sufficient lead time. In the United States, the EPA is required to give the industry four years of lead time under the Clean Air Acts. Therefore, there is an urgent need to reach a consensus and issue final regulatory rulings on vehicle emission and fuel quality standards if 2005 is to be one of the deadlines (for durability requirements and reducing sulfur in gasoline to 300 wt ppm).
- PEMEX's refinery investment is influenced not only by financial considerations and the need to obtain approval from the finance ministry and Congress, but also by the timing of the introduction of Tier 2 standards in the United States. Engineering/construction firms that are candidates revamping PEMEX refineries to hydrotreat FCC naphtha to bring sulfur in gasoline down to 300 wt ppm will also be involved in revamping a large number of U.S. refineries to meet the Tier 2 gasoline sulfur standard between 2003 and 2006, and diesel sulfur standard by 2007. They expect to be fully occupied until

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[18] A sulfate ion ties up twice as many ammonium ions as nitrate. The chemical reactions illustrating this point are (1) $2NH_4^+ + SO_4^{-2} \rightarrow (NH_4)_2SO_4$ and (2) $NH_4^+ + NO_3^- \rightarrow NH_4NO_3$.

January 2007. In parallel, the European refineries will be engaged in revamp programs to meet the next EU sulfur regulations coming into effect in 2005. To have the PEMEX sulfur reduction program in place by 2005, PEMEX is likely to need to sign up with a contractor in the next year or two, so as not to be the last one in the queue. It is widely acknowledged in the oil industry that by 2005, there will be escalated costs for all refinery projects because of construction personnel and equipment shortages as a result of the major crunch caused by the timing of the phase-in schedule for sulfur specifications in Tier 2.

- The second stage in the sulfur reduction program is further reducing gasoline sulfur to an average of 30 wt ppm. It would make sense to coordinate these two stages so that the necessary infrastructure can be planned in advance during the installation of FCC naphtha hydrotreaters in the first stage for the second investment program. This would enable rapid implementation of the second sulfur reduction program when the time comes, reducing the cycle time from engineering design to startup.
- The alternative has been proposed to simultaneously introduce Tier 2-compliant vehicles and reduce gasoline sulfur to 30 wt ppm in ZMVM—possibly before reducing the level of sulfur throughout the country from the current 700 wt ppm to a maximum of 300 wt ppm—by revamping the one or two refineries that supply gasoline to ZMVM, supplementing the supply with gasoline imports. ZMVM is undoubtedly the most polluted region in Mexico, and the level of sulfur in gasoline has been limited to 500 wt ppm since 1996. Because the impact of reducing sulfur in gasoline in ZMVM from 500 to 300 wt ppm, while as yet unclear, is not expected to include a substantial improvement in air quality, this alternative proposal merits consideration. However, the auto industry may not want to either (1) guarantee durability even for Tier 1 vehicles if the level of sulfur in the rest of the country remains at 700 wt ppm or (2) agree to meet Tier 2 emission standards in ZMVM (as opposed to building Tier 2-compliant vehicles).
- All the measures currently under discussion address ozone. Because gasoline vehicles, particularly those equipped with catalytic converters, do not contribute much to fine particulate emissions (by weight, although they may contribute in number), high ambient concentrations of PM_{10} remain unaffected by these measures. In the transport sector, it would be useful to better understand the extent to which diesel vehicles contribute to particulate and NO_x emissions. The diesel vehicle population in Mexico is small, but diesel consumption is significant.

5.62 PEMEX faces the formidable task of having to lower sulfur in gasoline (and eventually in diesel) just as it has made the decision to increase the amount of (heavy and high sulfur content) Maya crude processed. PEMEX has a corporate policy of purchasing only commercially proven processes. Upgrading gasoline in Mexico to meet the new sulfur specifications needed for Tier 2 using only conventional (that is, commercially proven) hydrodesulfurization processes would be quite costly. Enormous savings may be realized by using emerging hydrodesulfurization technologies. Some options include Phillips S. Zorb Sulfur Removal Technology (for treating the entire FCC stream without, according to Phillips, requiring costly fractionation equipment or hydrogenation of olefins; Phillips is installing a unit at their Borger refinery in Texas); CD Tech's CDHydro/CDHDS now running at the Motiva Enterprises refinery in Port Author, Texas, United States; PDVSA's ISAL process; IFP's Prime G and Prime G+ processes; and Mobil's Octgain. One or two units are beginning to go onstream commercially but, because incremental operating costs are higher[19] and technologies are continually improving, most refineries in the United States are likely wait until the very end to construct and bring these units onstream.

5.63 In light of Mexico's historical mode of operation with respect to refinery investment projects, it might be difficult to meet the deadline of 2005 for reducing sulfur in gasoline to 300 wt ppm. Two concerns could delay the decision to contract the sulfur reduction program: (1) if PEMEX wants to see a number of units using the above emerging technologies operating successfully with a reasonable amount of time onstream before accepting that they are commercially proven, it may have to wait until mid-2004 or later; and (2) Congress and the finance ministry may not want to consider new investment projects until the current program is completed, which is not expected until 2003 (the last two projects in the current investment program have yet to be approved by Congress). If the final decision for the 2005 sulfur reduction program is delayed until early 2004, a delay in the implementation of the program is highly likely.

5.64 The automotive industry in Mexico is willing to fully implement the 80,000-km durability requirements for Tier 1 emission standards by 2005. Durability requirements cannot be introduced in isolation: independent fuel quality monitoring as well as monitoring of vehicle performance from the viewpoint of emissions would need to be set up and strengthened considerably. Enforcement of durability and other requirements new to Mexico would involve setting up a mechanism for defining and checking when vehicles fail to comply, and correcting the problem when they do fail. Although the U.S. federal sulfur limit until 2004 is 1,000 wt ppm, the same as in Mexico, the U.S. industry average was about 300 wt ppm throughout the 1990s. Therefore, the field experience with durability requirements in the United States has been with gasoline averaging 300 wt ppm sulfur, one-half the Mexican average. Moreover, if vehicle manufacturers in Mexico are to introduce Tier 2–compliant gasoline vehicles beginning in the 2006 model year, it goes without saying that the lower the level of sulfur for these vehicles, the better for their catalytic converters will perform in the long term.

5.65 There is therefore an urgent need to recognize (1) the importance of synchronizing the schedule for fuel and vehicle emission standards and (2) the considerable lead time the refining industry needs to meet the schedule. The next two years will be crucial

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[19] One leading engineering/construction company in the United States estimates that, over a 10-year life, capital costs comprise 20 percent of the total cost, with the remaining 80 percent being operation and maintenance.

in determining whether Mexico's oil industry will be able to support the auto industry's move towards the gradual phase-in of Tier 1 and Tier 2 emission standards for gasoline vehicles.

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Annex 1. Dynamic General Equilibrium Model

Background

A1.1 Most of the empirical work in economics has relied on "partial equilibrium analysis." This type of analysis concentrates on a single market and quantifies the changes in supply, demand, prices, quantities and welfare brought about by exogenous shocks and/or parametric changes. This approach is well suited to markets with limited size or with weak linkages to other economic sectors.

A1.2 Many economic problems do not fit easily into this category, however. The economic sector analyzed is often large, and changes in that sector can have important repercussions economy-wide. Such problems are more appropriately dealt with using general equilibrium analysis in which all the sectors in the economy are seen as one linked system where changes in any part affect prices and output economy-wide. Mathematically, an interlinked economy cannot be described in one or two equations, but rather by a large system of simultaneous equations. More precisely, in an economy with n markets, n-1 equations are required to solve for all of the prices and outputs in the system. Although the theory behind general equilibrium can be described fairly easily, the computations involved in solving such a system are fairly complex and difficult. Indeed, it was not until the advent of high-speed computers and efficient solution algorithms that large economy-wide problems could be solved.

A1.3 In a simple static model, the actual solution of a general equilibrium problem requires that the modeler construct a social accounting matrix (SAM). In the SAM, all production in all markets, all tax revenue of the government and all consumption by all household for a specific base year has to be replicated exactly first. Hence, for a country such as Mexico, one must specify the amount of manufacturing, agricultural, energy and all the other sectoral outputs that occurred in the 1996 base year. Supply and demand elasticities must also be specified, and the model calibrated through constants in each equation so that each consumer group is assigned the amount they consumed in that year. The equations are solved and the results are checked to see that the base year is indeed replicated. The model is then run under a counterfactual scenario. One or more supply, demand, or tax is altered and the results from resolving the model are compared with the original "benchmark" run to show the changes in prices and output in each of the model's sectors. In both runs, the total level of consumer welfare and GDP are also calculated and the two are compared to see the impact of the exogenous changes on these economy-wide variables.

A1.4 The use of equilibrium analysis to calculate the impact of various economic policies dates back to the early work of Harberger (1962, 1964). Such analyses, however, were generally limited to two or three sectors until the advent of the more complicated CGE models in the early 1970s. Cornerstone works related to taxation models include Shoven and Whalley (1972), Whalley (1975), Shoven (1976), Ballentine and Thirsk (1979), Keller (1980), Piggot (1980), Slemrod (1983), Serra-Puche (1984), Pigott and Whalley (1985), and Ballard and others (1985). The policies that have been analyzed through these models include changes in various types of taxes and tariffs, technological change, natural resource policy, and employment policy. Both efficiency and distribution impacts are presented in these studies (for the main features of the above models, see Shoven and Whalley 1992).

A1.5 The extension of a static CGE model to a dynamic one is fairly straightforward. Although computationally more complex, a dynamic CGE model differs from its static counterpart only by the inclusion of a driving force to move the economy from period to period. In most dynamic models, this force is provided by the growth in the underlying labor force and/or a change in the level of technology in one or more sectors of the economy. These changes are facilitated by new investments and the growth of the capital stock in the economy.

A1.6 As with the static model, the actual output for each sector in a specific base year is replicated through the calibration. In addition, however, the economy is now expected to grow, and in the initial benchmark run all sectors, quantities, and factors of production are required to grow at the same steady-state rate. When a counterfactual shock is then given to a dynamic CGE model, two things occur. First, the affected prices and quantities traverse to a new growth path in the years following the shock. Second, the new growth path itself returns to a steady state but with economic variables at a level different from that in the benchmark case. Generally, the interest in these dynamic models is on that new path and how much higher or lower it is than the original benchmark path.

A1.7 Analytical treatment of aggregate economic growth has its origin in the work of early theorists such as Ramsey (1928), Solow (1956), and Koopmans (1965). Nonetheless, because of their heavy computational requirements, true dynamic extensions of CGE models are a fairly recent development. In the past few years, authors such as Summers and Goulder (1989), Jorgenson and Wilcoxen (1990), and Rutherford and others (1997) have begun to use dynamic CGE models to explore a variety of policy issues using a single consuming agent.

A1.8 New models have been developed to address the issue of energy policies and carbon taxes to prevent global warming. A comparison of many of these models is found in Goulder (1995b). They all estimate the economic impact of imposing a tax on carbon emissions. Most of these models have been applied to the United States (Shakelton and others 1992, Goulder 1995a and 1995b, Jorgenson and Wilcoxen 1995) and other industrialized nations. However, there are also some applications to India, Indonesia, and Pakistan (Shah and Larsen 1992). Other important studies on this topic may be found in Nordhaus (1993), Bovenberg and Ploeg (1994), Bovenberg and de Mooji (1992 and 1994), Poterba (1991 and 1993), and Manne and Rutherford (1994). Boyd and others (1995) have also developed a model to analyze the net benefit of energy taxation and energy conservation policies to reduce CO_2 emissions.

Recent Computable General Equilibrium Models for Environmental Policy In Mexico

A1.9 Some researchers have studied the impact of environmental taxes in Mexico through the use of static CGE models. The results of two of these studies, Romero (1994) and Fernández (1997), are described to visualize what the expected results will be in the case of this environmental tax reform.

A1.10 Romero (1994) found that under a 20 percent *ad valorem* carbon tax scenario, total emissions decrease 13 percent. The effect on the consumer price index is very small: it increases 0.3 percent. For the year 2001, GDP is only 0.6 percent lower than under a no-tax scenario. The sectors most harmed by a carbon tax in the long run are oil, mining, construction, and chemicals. Long-run demand of oil in each sector declines 13 percent as a response to the tax. The long-run capital stock falls almost 1 percent even though it grows in some sectors such as transport, metals and agriculture. The price of capital goods, reflecting the prices of capital services, increases slightly. The return rate to capital increases and the wage bill drops 1 to 2 percent in most sectors, 14 percent in the transportation sector, and 18 percent in the chemicals sector. However, the wage bill increases 23 percent in the mining sector because of extra hiring in that sector. The overall effect on wages depends on the proportion of workers employed in each sector. The tax policy proposed in Romero's study is not revenue-neutral (that is, the total tax receipts are allowed to vary from the base case).

A1.11 Fernández (1997) introduced an environmental tax to the manufacturing sector and evaluated the policy outcome with and without revenue neutrality. The baseline case considers a maximum tax of 5 percent on the most polluting of the manufacturing industries, that is, basic petrochemical products. The remaining tax rates for the rest of the industries within the manufacturing sector are defined depending on the pollution intensity of each sector relative to the heaviest polluter. His results indicate that the introduction of an environmental tax on manufacturing reduces pollution significantly, decreases output of the heavily polluting sectors, and reallocates resources from the private to the public sector.

Overall Structure of the Present Model

A1.12 The model in this study is disaggregated into nine producing sectors, sixteen production goods, four household (income) categories, seven consumption sectors, a foreign sector, and the government (see Table A1.1 and Table A1.2). The economic variables determined by the model are investment; capital accumulation; production by each sector; household consumption by sector; imports and exports; relative prices; wages and interest rate; the government budget expenditures and revenues; and the level of employment. The level of depreciation and the initial return to capital are taken as exogenous, as is the rate of effective labor force growth.

Table A1.1 Classification of Producing Sectors, Production and Consumer Goods and Services

Producing Sectors	*Production Goods*	*Consumer Goods and Services*
1. Manufacturing	Manufacturing Goods	1. Food
2. Coal Mining	Coal	2. Energy
3. Chemicals and Plastics	Chemicals and Plastics	3. Autos
4. Agriculture	Agricultural goods	4. Gasoline
5. Services	Producer Services	5. Consumer Transport
6. Transportation	Transportation for production	6. Consumer Services

7. Electricity	Electricity	7. Housing and Household goods
8. Oil and Gas	1. Crude Petroleum	
	2. Natural Gas	
9. Refining /petrochemicals	1. Coke	
	2. Diesel	
	3. Fuel oil	
	4. LPG	
	5. Gasoline	
	6. Kerosene	
	7. Petrochemicals	

Table A1.2 Household Categories Based on Income

Category	*Income*
Agent 1	Bottom 2 deciles: 8-10
Agent 2	Deciles 6-8
Agent 3	Deciles 3-5
Agent 4	Top 2 deciles: 1-2

A1.13 This particular model is designed to focus primarily on the workings of the energy sector in Mexico and to show that sector's linkages to the economy at large. Hence, it contains a number of special features not commonly found in country-wide CGE models. For example, refinery output is broken down into petrochemicals and six different fuels—LPG, gasoline, kerosene, diesel, fuel oil, coke—rather than being treated as a single output. These seven outputs in turn are used as inputs for the nine production sectors as well as the seven consumption sectors, and are traded on international markets.

A1.14 Output in the oil and gas extraction is broken down into crude oil production and natural gas production. As with refining, these two outputs do not necessarily occur in fixed proportions and can be altered according to an elasticity of transformation. The oil and gas production outputs are used as inputs in other production and consumption sectors, and are also sold to foreign consumers.

Production

A1.15 The production portion of the model is built on information from a balanced data set that is flexible as regards the substitution between both the primary factor inputs (capital and labor), and the material (semi-finished) inputs from other production sectors. The input-output table used is an updated version of the 1990 table, incorporating information provided by SEMARNAP. The material inputs enter in a manner similar to that of an input-output model except that their substitutability can differ from zero. Technologies are represented by production functions that exhibit constant elasticities of substitution (CES). Technical progress is taken as exogenous to the model (for endogenous technological change, see Romer 1990; another good reference is den Butter and others 1995).

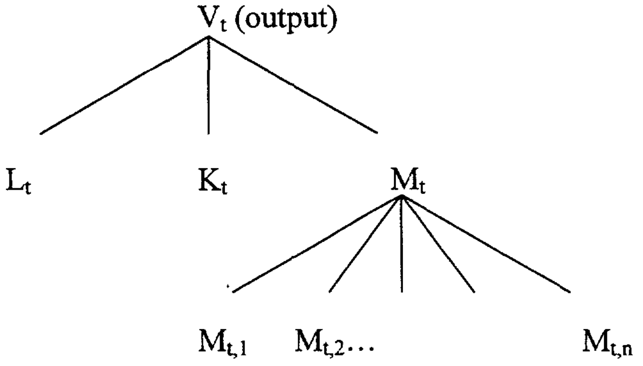
A1.16 Production in each sector for every time period is represented as a CES function of capital, labor, and material inputs where the elasticity of substitution can vary from zero and infinity. Substitution elasticities between capital and labor for agriculture and manufacturing were derived from case studies (Hueter 1997, Skuta 1997, Wylie 1995); the elasticities of substitution for petroleum were U.S. estimates since no appropriate Mexican estimates were found, except for gasoline (SEMARNAP 1995). The equation used is

$$(1) \qquad V_t = \phi_t [\delta_L L_t^{(\sigma-1)/\sigma} + \delta_K K_t^{(\sigma-1)/\sigma} + \delta_M M_t^{(\sigma-1)/\sigma}]^{(\sigma/\sigma-1)}$$

where V_t is value at time t, σ is the elasticity of substitution between inputs that is estimated econometrically for the different sectors, ϕ_t is an efficiency parameter for the entire production function, L_t is labor at time t, K_t is capital at time t, M_t are materials at time t, and the δs are the share parameters defined so that δ_L, δ_K, $\delta_M > 0$ and $\delta_L + \delta_K + \delta_M = 1$.

A1.17 The materials input M_t does not represent a single factor input but rather a host of inputs from the various production sectors. Hence in this model M_t is a composite input produced by a nested CES production functions, the arguments of which are the actual inputs from the model's production sectors. This is depicted in Figure A1.1, which shows the total output of the production good V_t at the apex. The labor, capital, and composite materials inputs are placed at the second tier, and each of the individual materials inputs are placed at the third tier. Besides being more flexible, this setup has the distinct advantage of allowing the elasticity of substitution between materials inputs to vary from the elasticity of substitution between the primary inputs.

Figure A1.1 Model Structure



Producers maximize profits in a competitive environment in each time period. Output and input prices are treated as variables. Taxes are also included with producers facing tax exclusive prices and consumers (and input consuming firms) facing the tax inclusive prices. Profit maximization, based on the described production technology, yields output supply and factor demands for each production sector and factor market in the model.

A1.18 It is important to note that the goods produced in the model's production sectors are not the same goods consumed by final consumers. Agricultural products, for example, must be combined with transportation services, manufacturing, and chemicals before that can be consumed by individuals as food. Hence, a matrix—referred to as a Z matrix by Ballard and others (1985)—is used to map from the vector of production goods to the vector of consumption goods. More specifically, this matrix assigns output to each of seven consumer goods categories in direct proportion to the amount of value added that is given to that good by each of the nine production sectors.

The Labor Market

A1.19 The equilibrium in the labor market is endogenous with a single wage rate clearing the market. The firms in the model pay out a wage gross of all labor taxes while the consumers in the model receive a wage net of all labor taxes. Demand for labor is determined by the firms as a result of their profit maximization process. The growth of the labor force is determined exogenously, but the supply of hours from this is determined by the labor leisure choice, subject to constraint that 60 hours per week is the maximum available. This leisure/labor choice is made by individuals—in this case by the income groups—depending on the marginal tax rate on income. The higher this marginal tax rate, the less labor supplied and the more leisure consumed. Effective labor supply grows at rate γ, the exogenous rate of population growth plus technical progress. This, in effect, means that the underlying growth in the model has two components and depends on both Mexico's growth in population and its rate of technical progress. In so doing, we make the dynamic CGE model consistent with the assumptions made in the BRUS-II-M model.

Consumption

A1.20 On the demand side, the model reflects the behavior of domestic consumers and foreigners (who can also invest), as well as the government. Domestic consumers are assigned to four groups (agents) according to income as shown in Table A1.2 and a demand equation is specified for each group. Each group has a different consumption bundle depending on its income. All four groups are endowed with labor. Since only the wealthy have (formal) savings in Mexico, only the top two groups own capital. These resources are sold to firms to finance the purchase of domestic or foreign goods and services, save, or pay taxes to the government.

A1.21 For each household c, total utility is modeled by the function

$$(2) \qquad U_c = \Sigma_t\, U_{c,t}\,(X_{c,t}, R_{c,t}) \times (1+\rho\,)^{-t} \qquad t = 1, \ldots, n$$

where U_c is household utility over all n time periods, $U_{c,t}$ is the utility derived from the present period consumption of goods and services $X_{c,t}$ (a seven-dimensional vector) and leisure $R_{c,t}$, and ρ is the discount rate (time preference). To rule out the possibility of a Ponzi game, it is assumed that the credit market puts a limit on the amount of consumer borrowing. This is specified by the constraint that the present value of the assets owned by the consumer must be non-negative. Each U_c is taken to be a (nested) CES utility function defined over all consumer goods as well as all time periods. For the purpose of this analysis, all consumers have a constant intertemporal elasticity of substitution utility function, and use values for this elasticity that are consistent with the empirical literature. The value of household utility is given by the addition of the value of consumption plus the value of leisure, which is equal to the number of hours devoted to leisure times the net wage per hour worked; the latter represents the price of leisure (foregone wages).

A1.22 Each consumer's expenditure constraint can be written as

$$(3) \quad \sum_{t=1}^{n} \{TG_{c,t} + TF_{c,t} + (P_{L,t} \times L_{c,t}) + (r \times K_t \times S_{c,t})\} =$$

$$\sum_{t=1}^{n} \{(INV_t \times S_{c,t}) + (P_{I,t} \times X_{c,t}) + (P_{L,t} \times R_{c,t})\}$$

where endowments are given on the left-hand side of the equation and expenditures are placed on the right hand side. $TG_{c,t}$ and $TF_{c,t}$ represent the transfer to the consumer from the government and from the foreign agents; $P_{L,t}$ is the price of labor exclusive of tax; r is the rental rate of capital; K_t is the level of capital stock in period t; $S_{c,t}$ is the share of total capital owned by consumer c; INV_t is the total investment in time period t; and $P_{I,t}$ is the vector of prices for consumer goods inclusive of tax. Thus, transfers to consumers both from the government and the foreign sector (that is, net income from abroad), and income from labor and capital earnings are used towards savings, consumption of goods and services, and consumption of leisure. Theoretically households can borrow with the interest being, in essence, collected by themselves. In this particular model, however, there are net savings and it is used to build up the value of the capital stock through investment.

A1.23 Maximizing the nested utility function (2) subject to the expenditure constraint (3) simultaneously determines the consumption level of the seven consumer goods and services, the amount of labor supply, and the consumers' level of saving and investment in each of the n time periods.

Government

A1.24 The government sector is treated as a separate agent (Ballard and others 1985). The government agent is modeled with an expenditure function similar to the household expenditure functions (that is, based on a CES utility function). Revenues derived from all taxes and tariffs are spent according to an expenditure function. Within this expenditure function, the government spends its revenues on goods and services from the various private production sectors discussed above. It also spends its revenues on labor. Together these arguments represent the government's purchases and payment of employees necessary for it to carry on its work. The government also separately redistributes income through exogenously set subsidies and transfer payments, and all revenues are spent. Hence there is no elasticity of substitution between government expenditures and payroll expenses on the one hand, and subsidies and transfer payments on the other.

A1.25 It should be pointed out, however, that it is assumed that the government sector does not save as such and there is a zero surplus in the government account. Hence the government does not own capital, and the capital needed for government provided goods such as education is rented from the private sector. Interestingly, government revenues were quite close to expenditures in 1996, and the balanced government budget assumption fits well.

A1.26 Taxes in the model are expressed *ad valorem* and include personal income taxes, labor taxes, capital taxes, property taxes, revenue taxes (such as payments from oil and gas activities), value added taxes, sales taxes, and import tariffs and export taxes. As stated above, in the initial calibration of this model, taxes are calculated in such a way as to produce exactly the amount of revenue as they actually did in Mexico in 1996. The taxes on final goods such as gasoline differ from other consumer goods because of special taxes levied on them by the government. By the same token final goods such as electricity differ in treatment because of existing government subsidies. When applicable, taxation is based on marginal tax rates. To capture the incentive effect of the tax system, the highest marginal rate is levied on the relevant revenue base. Since this procedure results in over-taxation, the difference between the revenue generated by the highest marginal tax rate and the average tax rate is rebated to consumers as a lump-sum transfer.

A1.27 Subsidies in the model are essentially treated as negative taxes: the government transfers funds back to a sector in proportion to that sector's output. Thus, if these subsidies are abolished, the government has more revenue, and to keep aggregate revenues equal to aggregate expenditures, the government will increase spending on all items in proportion to existing government expenditures on the different goods and services.

Income Distribution

A1.28 Consumers in this model are divided into four groups according to their level of income. The lowest class, called agent 1, consists of the lowest two deciles in terms of income. Agent 2 is made of the next three deciles. Agent 3 consists of the following three deciles, and Agent 4 includes the top 2 deciles. In steady growth the gross income of each group rises by the rate of population growth plus the rate of technological change, which is taken as labor augmenting. As indicated above, all groups are taxed at their marginal rates and the choice for the group between labor and leisure depends on their relative price. Under steady growth the proportion of time spent in leisure activities is assumed to remain constant.

A1.29 Various forces affect the distribution of income within this model. In the 1996 base year, the distribution of income depends on the actual factor payments going to each agent during that 12 month period. Furthermore, in the initial benchmark run there is no change in distribution since all components of income grow at the same rate, and all relative prices of goods are constant. In subsequent counterfactual scenarios, however, the distribution of income may change if capital grows relative to labor, or the relative price of various consumption goods change. It is not, however, affected by government spending and tax revenue since transfers are divided among different income groups on a 1996 basis.

Trade

A1.30 International trade within the model is handled by means of a foreign agent. Output in each of the producing sectors is exported to the foreign agent in exchange for foreign-produced imports. Under this setup, the aggregate level of imports is set and grows at the steady state level, but the level of individual imports may change in response to changes in relative prices. Exports are also exogenous and are assumed to follow a constant growth path. They are, however, responsive to changing prices, and can change as individual sectors are shocked. Transfers, on the other hand, are endogenous and act so as to clear the model. Price-dependent import supply schedules are derived from elasticity estimates found in the literature (see, for example, Serra-Pache 1984, Romero 1994, Fernández 1997, and Wylie 1995).

A1.31 In specifying the substitutability between foreign and domestically produced goods, we replace the classic Heckscher-Ohlin assumptions and rely instead on the Armington (1969) assumptions. Under these assumptions foreign imports and domestically produced goods are considered to be imperfectly substitutable goods (as opposed to Heckscher-Ohlin where foreign and domestically produced goods are considered to be perfect substitutes). Armington postulates that domestic and foreign goods are both inputs in a CES production process, the output of which is a combination of the two, and it is this combined good that is consumed domestically. The benefit of such a setup is that a country can both import and export goods from the same industry sector. Furthermore, domestic prices can differ from world price levels under this setup, but the more closely substitutable the foreign and domestic goods, the closer the two prices are to each other. Under the Heckscher-Ohlin assumptions, by contrast, all goods are prefect substitutes and foreign and domestic prices must be equal.

A1.32 The balance of trade relationship is given by

$$(4) \qquad \Sigma P_{m,t} \times IM_{j,t} = \Sigma P_{j,t} \times EX_{j,t} + \Sigma TF_{c,t} \qquad t = 1, \ldots, n$$

where $IM_{j,t}$ is a (nine dimensional) vector representing the quantity of each of the producer goods imported, $P_{m,t}$ is the vector of imported goods prices, $EX_{j,t}$ is the vector of producer goods exported, $P_{j,t}$ is the tariff inclusive vector of producer goods prices, and $TF_{c,t}$ is the level of foreign transfers (which can be positive, zero, or negative). Because of the Armington assumptions, the import prices are not required to equal their domestic counterparts. The more highly substitutable foreign and domestic goods are, however, the closer their prices. The prices of exports are identical to their domestic price (adjusting, of course, for any export taxes). For each time period, the value of total imports is equal to the total value of exports plus foreign transfers. Since these transfers are used to finance domestic investment this relation provides the closure rule, namely, that investment is equated to domestic savings minus net exports. This includes balanced trade as a special case. Capital flows are the remainder of the exports minus imports, or net exports, since the deficit in the current account must be made up for by the capital account. Mexican investment abroad is considered here since in 1994 Mexico was a net exporter. Certain goods, such as transportation and electricity, are strictly produced for domestic consumption and enter into the model as non-tradable goods. This serves to make the model a more accurate description of the Mexican economy. It also serves to give a measure of the real exchange rate defined as the price of tradables over the non-tradables.

Labor Growth and Capital Formation

A1.33 Growth within the dynamic CGE model is brought about by the changes over time in both the labor force and the capital stock. In keeping with the theoretical underpinning of the Ramsey model (1928), the changes in the population are modeled as exogenous and constant over the time period considered. More formally, the growth in the effective labor force over time is given by the equation

$$L_{t+1} = L_t(1+\gamma) \tag{5}$$

where γ is the composite of the growth rate of population over time and the growth in the effectiveness of the typical worker; it is assumed that the rate of participation remains constant. In the absence of any perturbation, the Ramsey model predicts that the economy will grow at the same rate of growth as labor supply in the steady state. The labor supply function is then determined by the effective labor force times the "hour supply" function per worker, which reflects the willingness to offer more hours as the wage rate net of tax changes, as modeled by the consumer choice equations.

A1.34 In the model we assume that there is only one type of raw capital good, which goes into the various sectors. In addition, to add realism the capital, which does go into a sector, is assumed to work like putty and clay. More specifically, it is assumed that capital that is new can be readily combined with other inputs to produce outputs. Over time, however, this capital becomes locked into an older technology (hence the analogy with clay) and has a harder time combining with other inputs. This is plausible as illustrated by sectors such as electricity production, which has been subject to a great deal of technological change over the years.

A1.35 The growth rate of capital is modeled in accordance with capital theory and is represented by a system of three equations. For each time period t

$$P_{A,t} = P_{k,t+1} \qquad t = 1, \ldots, T \tag{6}$$

where $P_{A,t}$ is the weighted (aggregate) price of consumption exclusive of tax (that is, the weighted average of the $P_{I,t}$'s) and $P_{k,t+1}$ is the price of capital exclusive of tax in the following year. This says that the opportunity cost of acquiring a unit of capital next year is a unit of consumption in the present period. The following relationship holds for the price of capital,

$$P_{k,t} = (1+r_t) \times P_{k,t+1} \qquad t = 1, \ldots, T \tag{7}$$

meaning that the price of capital in a given period must be equal to the rental value of capital in that period plus the price of capital in the following period. Finally, the following holds for capital

$$K_{t+1} = K_t \times (1-\Delta) + INV_t \qquad t = 1, \ldots, T \tag{8}$$

where Δ stands for the rate of depreciation and INV stands for gross investment. This states that the capital stock in the next period must be equal to this year's capital stock plus net investment. Taken together, Equations (6)-(8) insure that economic growth will be consistent with profit-maximizing behavior on the part of investors.

A1.36 The actual process of calibrating a dynamic CGE model requires the use of exogenous estimates for technology and population growth γ, the return to capital r, and economy-wide depreciation Δ. Their estimates were obtained from the literature (see below) for Mexico and are listed in Table A1.3. Given the values for these three parameters, the model solves for the unique value of ρ, the discount rate. This rate of time preference, in turn, is then used to discount all prices and values in all time periods subsequent to the 1996 benchmark year for Mexico.

Table A1.3 Basic Parametric Assumptions

Sector / parameter	*Value*
Elasticities of Substitution σ between capital, labor and materials by production sector	
Manufacturing	0.98
Coal Ming	0.64
Chemical and Plastics	0.98
Agriculture	0.96
Services	1.0
Transportation	1.0
Electricity	0.4
Oil and Natural Gas	0.4
Refining Output	0.8
Other parameters	
Labor growth	1.3% per year
Technical Progress	2.4%, 3.9%, 4.9%
Depreciation Δ	5% per year
Return to Capital r	21%
Calibrated discount rate ρ	14%

Terminal Conditions

A1.37 One potential drawback of a computable model is that it can be solved only for a finite number of periods. Consequently, a few adjustments are necessary to design a model that, when solved over a finite horizon, approximates infinite horizon choices. To keep consumers from consuming all of the remaining capital in the final period, the model endows them with capital in the initial period, and takes away all capital from the capital owning agents in the terminal period, preventing them from consuming all of it.

A1.38 Following Lau and others (1997) the problem is divided into two distinct sub-problems, one defined over the finite period from $t=0$ to $t=T$ and the second the infinite period from $t=T+1$ to $T=\infty$. Hence, the first problem is

(9) $$\text{Max}\sum_{t=0}^{T}\left(\frac{1}{1+\rho}\right)^{t} U_{c,t}(X_{c,t}, R_{c,t})$$ subject to

(10a) $$\sum_{t=0}^{T} P_{A,t} X_{c,t} = \sum_{t=0}^{T} P_{L,t}\, \overline{L}_{c,t} + P_{k,0} K_{c,0} S_{C,t} - P_{k,T+1} \overline{K}_{c,T+1} S_{C,T+1}$$ and

(10b) $$\overline{L}_{c,t} = L_{c,t} + R_{c,t}$$ for all t = 0, 1, ... T.

The second problem is

(11) $$\text{Max} \sum_{t=T+1}^{\infty}\left(\frac{1}{1+\rho}\right)^{t} U_{ct}(X_{c,t}, R_{c,t})$$ subject to

(12a) $$\sum_{t=T+1}^{\infty} P_{I,,t} \cdot X_{c,t} = \sum_{t=T+1}^{\infty} P_{L,t} L_{c,t} + P_{K,T+1} \overline{K}_{c,T+1} S_{c,t+1}$$ and

(12b) $$\overline{L}_{c,t} = L_{c,t} + R_{c,t}$$ for all t = T+1, ...∞.

where ρ is the rate of time preference, r_0 and $K_{c,0}$ refer to the rental value of capital and quantity of capital before the terminal period, r_{T+1} and $\overline{K}_{c,T+1}$ refer to these variables after the terminal period, and $\overline{L}_{c,t}$ is total labor plus leisure for each agent in the t^{th} time period. $P_{K,t}$ stands for the price of capital exclusive of tax, and $P_{I,t}$ and $P_{L,t}$ stand for the price of consumer goods and the price of labor, respectively, both exclusive of tax.

A1.39 Next, an equation or specific value for $\overline{K}_{c,T+1}$ needs to be specified. At first glance it might seem best to impose the long-run steady state level, but then the model horizon would have to be sufficiently long to eliminate terminal effects. As an alternative, the level of post-terminal capital is included as a variable and a constraint on investment growth in the final period is added, resulting in

(13) $$INV_T/INV_{T-1} = Y_T/Y_{T-1}$$

where Y_T gives GDP at time T. This constraint imposes balanced growth in the final period, but does not require that the model achieve steady-state growth. The advantage of this approach is that it alleviates the need to determine a specific target capital stock or a specific terminal period growth rate.

Calibration and Data

A1.40 The model is calibrated to a 1996 data set with these data coming from a variety of sources. Benchmark year (1996) data were obtained for income and expenditure for each of the income categories. Data on consumer expenditures on final goods by income category are from the *Encuesta Nacional de Ingresos y Gastos de los Hogares 1996*, published by the Instituto Nacional de Estadística, Geografía e Informática (INEGI). Data on imports and exports are from *International Financial Statistics*, various editions, published by the International Monetary Fund (IMF), *The Mexican Economy 1995*, published by the Banco de México, and the *Anuario Estadístico de los Estados Unidos Mexicanos 1996*, published by INEGI. Data on inputs, outputs, and use of labor and capital by production sector comes from data compiled by INEGI and supplied by the Secretaría de Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP). This same source along with the *Anuario Estadístico de los Estados Unidos Mexicanos 1996* were used to calculate the transformation matrix as well as to find investment levels by sector. All results on fossil fuel consumption (both aggregate and sectoral), fuel prices, fuel imports and exports, and government consumption of various fuels were provided by the SE, PEMEX, and INEGI.

A1.41 Tax levels and rates were calculated from the input-output tables as well as from *El Ingreso y el Gasto Público en México 1996*, by INEGI. The latter document along with *The Mexican Economy 1995* and *Encuesta Nacional de Ingresos y Gastos de los Hogares 1996* were also used to obtain data on government expenditures and transfer payments. Finally, data on interest rates, capital earnings, and depreciation were obtained from *The Mexican Economy 1995* as well as from Barro and Sala-i-Martin (1995). Substitution elasticity between capital and labor were taken from Heuter (1997) and Skuta (1997)[20] and import demand elasticities were taken from Wylie (1995) who obtained estimates on various imported items. One central modification to the model is made here: nested functions in the production side of the economy as well as in the production of final consumption goods and services are introduced. These nests allow for different degrees of substitution for the inputs considered; in the particular case of production it allows substitution between labor, capital, energy, and non-energy inputs, and in the case of the production of consumption goods, between food and housing, transport, and household energy use.

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[20] As noted above Heuter (1997) and Skuta (1997) were responsible for most of these. Where necessary these were supplemented by Tarr (1988) and Ballard and others (1985) estimates for the US.

Annex 2. Results of BRUS-CGE Modeling

Consumption of Energy in the Energy Sector Calculated by BRUS-II-M

Table A2.1 Scenario 1:
Energy Demand at 5.2% GDP Growth
(petajoules)

Fuel type	*1996*	*2004*	*2010*	% change 1996–2010
Fuel oil	1,061	1,854	3,363	8.6
Diesel	521	761	1,186	6.0
Kerosene	10	8	11	0.8
LPG	403	503	620	3.1
Gasoline	945	1,387	2,189	6.2
Jet fuel	93	121	189	5.2
Natural gas	1,400	1,953	2,256	3.5
Coal	172	331	331	4.8
Nuclear fuel	87	87	87	0.0
Biomass	328	339	354	0.5
Solar, wind, renewable	0	0	0	0.0
Coke	97	129	156	3.4
Petroleum coke	2	3	4	4.0
Total fuel	5,122	7,477	10,746	5.4
Electricity	592	953	1435	6.5

Table A2.2 Scenario 2 (Current Policy): Energy Demand at All Three GDP Growth Rates (petajoules)

GDP growth	*5.2%*				*3.7%*		*6.2%*	
Year	*1996*	*2004*	*2010*	*% change 1996–2010*	*2004*	*2010*	*2004*	*2010*
Fuel oil	1,061	933	956	-0.7	609	708	1,075	974
Diesel	521	732	1,150	5.8	617	815	837	1,434
Kerosene	10	3	3	-8.6	2	2	4	4
LPG	403	529	698	4.0	516	666	538	724
Gasoline	945	1,379	2,140	6.0	1,168	1,596	1,538	2,600
Jet fuel	93	121	189	5.2	97	127	141	245
Natural gas	1,400	2,573	4,276	8.3	2,464	3,408	2,754	5,224
Coal	172	331	331	4.8	331	331	331	331
Nuclear fuel	87	87	87	0.0	87	87	87	87
Biomass	328	343	364	0.7	335	347	349	376
Solar, wind, renewables	0	0	0	0.0	0	0	0	0
Coke	97	141	168	4.0	132	149	147	181
Petroleum coke	2	40	80	29.7	40	74	40	85
Total fuels	5,122	7,212	10,442	5.2	6,399	8,311	7,838	12,253
Electricity	592	941	1429	6.5	814	1,084	1,037	1,734

Table A2.3 Scenario 2 (5.2% GDP Growth): Energy Demand by Sector (petajoules)

	Residential			*Service*			*Industrial*			*Transport*		
Fuel type	*1996*	*2004*	*2010*	*1996*	*2004*	*2010*	*1996*	*2004*	*2010*	*1996*	*2004*	*2010*
Fuel oil				30	43	61	221	267	206	2	2	2
Diesel				2	3	3	137	197	239	373	530	883
Kerosene	5	0	0				5	3	3			
LPG	311	426	545	53	54	87	19	21	17	19	29	48
Gasoline										945	1,379	2,140
Jet fuel										93	121	189
Natural gas	45	102	136	0	15	24	707	1,026	1,272	0	5	29
Biomass	245	225	216				83	118	148			
Coke							97	141	168			
Petroleum coke							2	40	80			
Total fuels	606	753	897	85	114	175	1,271	1,812	2,132	1,433	2,065	3,291
Electricity	102	128	146	52	73	91	306	546	906	4	4	4

	Electricity			*Refining*			*Gas*			*Oil and gas production/flaring*		
Fuel type	*1996*	*2004*	*2010*	*1996*	*2004*	*2010*	*1996*	*2004*	*2010*	*1996*	*2004*	*2010*
Fuel oil	712	531	598	97	90	90						
Diesel	9	3	25									
Natural gas	200	803	2,001	138	198	238	84	116	153	227	309	423
Coal	172	331	331									
Nuclear fuel	87	87	87									
Total fuels	1,180	1,755	3,042	236	288	328	84	116	153	227	309	423
Electricity	116	161	249	5	9	9	3	6	7	4	14	16

Table A2.4 Scenario 5: Energy Demand with Power Subsidy Elimination (petajoules)

GDP growth		*5.2%*			*3.7%*		*6.2%*	
Year	*1996*	*2004*	*2010*	*% change 1996–2010*	*2004*	*2010*	*2004*	*2010*
Fuel oil	1,061	752	700	-2.9	475	510	990	976
Diesel	521	730	1,127	5.7	615	813	820	1,427
Kerosene	10	3	3	-8.6	2	2	4	4
LPG	403	529	698	4.0	516	666	538	724
Gasoline	945	1,379	2,140	6.0	1,168	1,596	1,538	2,600
Jet fuel	93	121	189	5.2	97	127	141	245
Natural gas	1,400	2,537	4,209	8.2	2,431	3,364	2,612	4,840
Coal	172	331	331	4.8	331	331	331	331
Nuclear fuel	87	87	87	0.0	87	87	87	87
Biomass	328	225	216	-0.9	335	347	349	376
Solar, wind, renewables	0	0	0	0.0	0	0	0	0
Coke	97	141	168	4.0	132	149	147	181
Petroleum coke	2	40	80	29.7	40	74	40	85
Total fuels	5,119	6,993	10,096	5.0	6,231	8,067	7,597	11,876
Electricity	592	864	1,310	5.8	747	993	956	1,598

Table A2.5 Scenario 6: Energy Demand with Carbon Tax, 5.2% GDP Growth (petajoules)

		Low carbon tax			High carbon tax	
Fuel type	*1996*	*2004*	*2010*	*% change 1996–2010*	*2004*	*2010*
Fuel oil	1,061	880	928	-1.0	853	900
Diesel	521	725	1124	5.6	721	1,119
Kerosene	10	3	3	-8.7	3	3
LPG	403	517	686	3.9	512	681
Gasoline	945	1,370	2,126	6.0	1,365	2,119
Jet fuel	93	121	189	5.2	121	189
Natural gas	1,400	2,531	4,202	8.2	2,510	4,176
Coal	172	331	331	4.8	331	331
Nuclear fuel	87	87	87	0.0	87	87
Biomass	328	342	362	0.7	342	361
Solar, wind, renewable	0	4	0		6	0
Coke	97	138	164	3.8	136	162
Petroleum coke	2	40	80	29.6	40	79
Total fuel	5,122	7,089	10,281	5.1	7,028	10,207
Electricity	592	920	1,408	6.4	910	1,396

Table A2.6 Scenario 7: Energy Demand with Carbon Tax and Power Subsidy Elimination at 5.2% GDP Growth (petajoules)

		Low carbon tax			*High carbon tax*	
Fuel type	*1996*	*2004*	*2010*	*% change 1996–2010*	*2004*	*2010*
Fuel oil	1,061	676	613	-3.8	638	569
Diesel	521	722	1,120	5.6	718	1,116
Kerosene	10	3	3	-8.7	3	3
LPG	403	517	686	3.9	512	681
Gasoline	945	1,370	2,126	6.0	1,365	2,119
Jet fuel	93	121	189	5.2	121	189
Natural gas	1,400	2,488	4151	8.1	2,463	4,121
Coal	172	331	331	4.8	331	331
Nuclear fuel	87	87	87	0.0	87	87
Biomass	328	342	362	0.7	342	361
Solar, wind, renewable	0	4	0		6	0
Coke	97	138	164	3.8	136	162
Petroleum coke	2	40	80	29.6	40	79
Total fuel	5,122	6,839	9,911	4.8	6,763	9,818
Electricity	592	832	1,271	5.6	817	1,251

Emissions of Greenhouse Gases Calculated by BRUS-II-M

Table A2.7 GHG Emissions in Scenario 1 (5.2% GDP Growth)

	CO_2 (million tons)				*CH_4 (thousand tons)*				*N_2O (tons)*			
Fuel type	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*
Fuel oil	82	143	260	8.6	1.6	2.5	4.0	6.7	348	608	1,103	8.6
Diesel	38	55	86	6.0	1.4	1.9	3.0	5.6	1,196	3,106	4,963	10.7
Kerosene	0.7	0.6	0.8	0.8	0.06	0.08	0.11	4.5	6	5	7	0.8
LPG	25	32	39	3.1	0.8	0.9	1.0	2.2	1,665	2,252	2,758	3.7
Gasoline	68	100	158	6.2	16	15	16	-0.1	9,321	42,252	67,353	15.2
Jet fuel	6.8	8.8	14	5.2	0.2	0.2	0.4	5.2	187	243	378	5.2
Natural gas	79	113	131	3.7	2.9	3.8	4.3	2.9	1,359	1,911	2,224	3.6
Coal	16	31	31	4.8	0.2	0.3	0.3	4.8	275	530	530	4.8
Biomass	36	37	39	0.5	49	46	44	-0.8	1,057	1,006	992	-0.5
Coke	11	14	17	3.4	19	26	31	3.4	390	515	623	3.4
Petroleum coke	0.2	0.3	0.4	3.8	0.4	0.6	0.7	4.0	8	12	15	4.0
Total fuels	364	536	777	5.6	92	97	105	0.9	15,813	52,439	80,944	12.4

Table A2.8 GHG Emissions in Scenario 2 (Current Policy, 3.7% GDP Growth)

	CO_2 (million tons)				*CH_4 (thousand tons)*				*N_2O (tons)*			
Fuel type	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*
Fuel oil	82	47	55	-2.9	1.6	1.3	1.2	-2.2	348	200	232	-2.8
Diesel	38	45	59	3.2	1.4	1.5	2.0	2.6	1,196	2,570	3,536	8.1
Kerosene	0.7	0.2	0.1	-11.8	0.06	0.02	0.02	-8.6	6	1	1	-11.8
LPG	25	33	42	3.7	0.8	0.8	0.9	1.2	1,665	2,133	2,754	3.7
Gasoline	68	84	115	3.8	16	13	12	-2.0	9,321	33,759	48,078	12.4
Jet fuel	6.8	7.1	9.3	2.2	0.2	0.2	0.3	2.2	187	194	255	2.2
Natural gas	79	140	193	6.6	2.9	8.1	17	13.6	1,359	2,434	3,347	6.7
Coal	16	31	31	4.8	0.2	0.3	0.3	4.8	275	530	530	4.8
Biomass	36	37	38	0.4	49	46	44	-0.8	1,057	1,003	986	-0.5
Coke	10.5	14.3	16.2	3.1	19	26	30	3.1	390	528	597	3.1
Petroleum coke	0.2	4.3	8.0	28.9	0.4	7.9	14.7	28.9	8	159	295	28.9
Total fuels	364	443	567	3.2	92	106	122	2.0	15,813	43,511	60,611	10.1

Table A2.9 GHG Emissions in Scenario 2 (Current Policy, 5.2% GDP Growth)

	CO_2 (million tons)				*CH_4 (thousand tons)*				*N_2O (tons)*			
Fuel type	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*
Fuel oil	82	72	74	-0.7	1.6	1.6	1.5	-0.6	348	306	314	-0.7
Diesel	38	53	84	5.8	1.4	1.8	2.9	5.5	1,196	3,081	4,927	10.6
Kerosene	0.7	0.2	0.2	-8.6	0.06	0.03	0.03	-5.3	6	2	2	-8.6
LPG	25	33	44	4.0	0.8	0.8	1.1	2.4	1,665	2,186	2,885	4.0
Gasoline	68	99	154	6.0	16	15	15	-0.2	9,321	41,960	65,752	15.0
Jet fuel	6.8	8.8	14	5.2	0.2	0.2	0.4	5.2	187	243	378	5.2
Natural gas	79	146	241	8.3	2.9	8.7	23.5	16.2	1,359	2,539	4,155	8.3
Coal	16	31	31	4.8	0.2	0.3	0.3	4.8	275	530	530	4.8
Biomass	36	38	40	0.7	49	46	44	-0.8	1,057	1,010	1,002	-0.4
Coke	11	15	18	4.0	19	28	34	4.0	390	563	671	4.0
Petroleum coke	0.2	4.3	8.7	29.7	0.4	8.0	16.0	29.7	8	160	320	29.7
Total fuels	364	502	709	4.9	92	111	139	3.0	15,813	52,578	80,934	12.4

Table A2.10 GHG Emissions in Scenario 2 (Current Policy, 6.2% GDP Growth)

	CO_2 (million tons)				*CH_4 (thousand tons)*				*N_2O (tons)*			
Fuel type	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*
Fuel oil	82	83	75	-0.6	1.6	1.8	1.6	-0.2	348	353	320	-0.6
Diesel	38	61	104	7.5	1.4	2.1	3.7	7.3	1,196	3,488	6,148	12.4
Kerosene	0.7	0.3	0.3	-6.8	0.06	0.04	0.04	-3.4	6	2.0	2.0	-6.8
LPG	25	34	46	4.3	0.8	0.9	1.2	3.3	1,665	2,225	2,993	4.3
Gasoline	68	111	187	7.5	16	17	18	1.1	9,321	48,242	80,735	16.7
Jet fuel	6.8	10	18	7.1	0.2	0.3	0.5	7.1	187	282	490	7.1
Natural gas	79	156	295	9.8	2.9	9.7	30	18.3	1,359	2,709	5,036	9.8
Coal	16	31	31	4.8	0.2	0.3	0.3	4.8	275	530	530	4.8
Biomass	36	38	41	1.0	49	46	44	-0.8	1,057	1,015	1,013	-0.3
Coke	11	16	20	4.5	19.5	29.4	36	4.5	390	588	726	4.5
Petroleum coke	0.2	4.3	9.2	30.2	0.4	8.0	17	30.2	8	160	339	30.2
Total fuels	364	545	827	6.0	92	115	153	3.7	15,813	59,594	98,331	13.9

Table A2.11 GHG Emissions in Scenario 5 (Power Subsidy Elimination, 3.7% GDP Growth)

	CO_2 (million tons)				*CH_4 (thousand tons)*				*N_2O (tons)*			
Fuel type	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*
Fuel oil	82	37	39	-5.1	1.6	1.1	1.0	-3.3	348	156	168	-5.1
Diesel	38	45	59	3.2	1.4	1.5	2.0	2.5	1,196	2,566	3,532	8.0
Kerosene	0.7	0.2	0.1	-11.8	0.1	0.0	0.0	-8.6	6.0	1.4	1.0	-11.8
LPG	25	33	42	3.7	0.8	0.8	0.9	1.2	1,665	2,133	2,754	3.7
Gasoline	68	84	115	3.8	16	13	12	-2.0	9,321	33,759	48,078	12.4
Jet fuel	6.8	7.1	9.3	2.2	0.2	0.2	0.3	2.2	187	194	255	2.2
Natural gas	79	138	190	6.4	2.9	7.9	17.0	13.5	1,359	2,404	3,307	6.6
Coal	16	31	31	4.8	0.2	0.3	0.3	4.8	275	530	530	4.8
Biomass	36	37	38	0.4	49	46	44	-0.8	1,057	1,003	986	-0.5
Coke	11	14	16	3.1	19	26	30	3.1	390	528	597	3.1
Petroleum coke	0.2	4.3	8.0	28.9	0.4	7.9	14.7	28.9	8.4	159	295	28.9
Total fuels	364	430	549	3.0	92	105	122	2.0	15,813	43,433	60,502	10.1

Table A2.12 GHG Emissions in Scenario 5 (Power Subsidy Elimination, 5.2% GDP Growth)

	CO_2 (million tons)				*CH_4 (thousand tons)*				*N_2O (tons)*			
Fuel type	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*
Fuel oil	82	58	54	-2.9	1.6	1.4	1.3	-1.7	348	247	230	-2.9
Diesel	38	53	82	5.6	1.4	1.8	2.8	5.2	1,196	3,077	4,910	10.6
Kerosene	0.7	0.2	0.2	-8.6	0.06	0.03	0.03	-5.3	6	2	2	-8.6
LPG	25	33	44	4.0	0.8	0.8	1.1	2.4	1,665	2,186	2,885	4.0
Gasoline	68	99	154	6.0	16	15	15	-0.2	9,321	41,960	65,752	15.0
Jet fuel	6.8	8.8	14	5.2	0.2	0.2	0.4	5.2	187	243	378	5.2
Natural gas	79	144	238	8.2	2.9	8.5	23	16.1	1,359	2,505	4,093	8.2
Coal	16	31	31	4.8	0.2	0.3	0.3	4.8	275	530	530	4.8
Biomass	36	38	40	0.7	49	46	44	-0.8	1,057	1,010	1,002	-0.4
Coke	11	15	18	4.0	19	28	34	4.0	390	563	671	4.0
Petroleum coke	0.2	4.3	8.7	29.7	0.4	8.0	16.0	29.7	8	160	320	29.7
Total fuels	364	486	684	4.6	92	110	138	2.9	15,813	52,482	80,772	12.4

Table A2.13 GHG Emissions in Scenario 5 (Power Subsidy Elimination 6.2% GDP Growth)

	CO_2 (million tons)				*CH_4 (thousand tons)*				*N_2O (tons)*			
Fuel type	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*
Fuel oil	82	77	76	-0.6	1.6	1.7	1.6	-0.2	348	325	320	-0.6
Diesel	38	60	104	7.4	1.4	2.1	3.7	7.3	1,196	3,476	6,142	12.4
Kerosene	0.7	0.3	0.3	-6.8	0.1	0.0	0.0	-3.4	6.0	2.3	2.3	-6.8
LPG	25	34	46	4.3	0.8	0.9	1.2	3.3	1,665	2,225	2,993	4.3
Gasoline	68	111	187	7.5	16	17	18	1.0	9,321	48,242	80,735	16.7
Jet fuel	6.8	10	18	7.1	0.2	0.3	0.5	7.1	187	282	490	7.1
Natural gas	79	148	273	9.2	2.9	8.9	28	17.6	1,359	2,578	4,680	9.2
Coal	16	31	31	4.8	0.2	0.3	0.3	4.8	275	530	530	4.8
Biomass	36	38	41	1.0	49	46	44	-0.8	1,057	1,015	1,013	-0.3
Coke	11	16	20	4.5	19	29	36	4.5	390	588	726	4.5
Petroleum coke	0.2	4.3	9.2	30.2	0.4	8.0	17	30.2	8.4	160	339	30.2
Total fuels	364	530	805	5.8	92	114	151	3.6	15,813	59,423	97,970	13.9

Table A2.14 GHG Emissions in Scenario 6 (Carbon Tax, 5.2% GDP Growth)

	CO_2 (million tons)				*CH_4 (thousand tons)*				*N_2O (tons)*			
Fuel type	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*
Low carbon tax												
Fuel oil	82	68	72	-1.0	1.6	1.6	1.5	-0.7	348	289	304	-1.0
Diesel	38	53	82	5.6	1.4	1.8	2.8	5.3	1,196	3,071	4,900	10.6
Kerosene	0.7	0.2	0.2	-8.7	0.06	0.03	0.03	-5.4	6	2	2	-8.7
LPG	25	33	43	3.9	0.8	0.8	1.0	2.1	1,665	2,139	2,836	3.9
Gasoline	68	99	153	6.0	16	15	15	-0.3	9,321	41,688	65,323	14.9
Jet fuel	6.8	8.8	14	5.2	0.2	0.2	0.4	5.2	187	243	378	5.2
Natural gas	79	144	237	8.1	2.9	8.6	23	16.0	1,359	2,498	4,084	8.2
Coal	16	31	31	4.8	0.2	0.3	0.3	4.8	275	530	530	4.8
Biomass	36	38	40	0.7	49	46	44	-0.9	1,057	1,009	996	-0.4
Coke	11	15	18	3.8	19	28	33	3.8	390	550	655	3.8
Petroleum coke	0.2	4.3	8.6	29.6	0.4	8.0	15.9	29.6	8	159	318	29.6
Total fuels	364	493	699	4.8	92	110	137	2.8	15,813	52,177	80,326	12.3
High carbon tax												
Total fuels		489	694	4.7		109	136	2.8		51,977	80,034	12.3

Table A2.15 GHG Emissions in Scenario 7 (Carbon Tax, Power Subsidy Elimination, 5.2% GDP Growth)

	CO_2 (million tons)				CH_4 (thousand tons)				N_2O (tons)			
Fuel type	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*	*1996*	*2004*	*2010*	*% Change 96-10*
Low carbon tax												
Fuel oil	82	52	47	-3.8	1.6	1.4	1.2	-2.2	348	222	201	-3.8
Diesel	38	53	81	5.6	1.4	1.8	2.8	5.2	1,196	3,066	4,895	10.6
Kerosene	0.7	0.2	0.2	-8.7	0.06	0.03	0.03	-5.4	6	2	2	-8.7
LPG	25	33	43	3.9	0.8	0.8	1.0	2.1	1,665	2,139	2,836	3.9
Gasoline	68	99	153	6.0	16	15	15	-0.3	9,321	41,688	65,323	14.9
Jet fuel	6.8	8.8	13.7	5.2	0.2	0.2	0.4	5.2	187	243	378	5.2
Natural gas	79	141	234	8.0	2.9	8.3	22.7	15.9	1,359	2,458	4,037	8.1
Coal	16	31	31	4.8	0.2	0.3	0.3	4.8	275	530	530	4.8
Biomass	36	38	40	0.7	49	46	44	-0.9	1,057	1,009	996	-0.4
Coke	11	15	18	3.8	19	28	33	3.8	390	550	655	3.8
Petroleum coke	0.2	4.3	8.6	29.6	0.4	8.0	16	29.6	8	159	318	29.6
Total fuels	364	475	671	4.5	92	109	136	2.8	15,813	52,066	80,170	12.3
High carbon tax												
Total fuels	364	469	665	4.4	92	109	135	2.8	15,813	51,858	79,870	12.3

CGE Modeling Results

Table A2.16 Production: Scenario 0, 5.2% GDP Growth (trillions of pesos)

Year	*Agriculture*	*Coal*	*Manufacturing*	*Chemicals*	*Transportation*	*Electricity*	*Services*	*Petroleum*
1996	0.275	0.005	1.212	0.137	0.211	0.047	1.354	0.102
2000	0.336	0.006	1.485	0.167	0.258	0.058	1.659	0.125
2004	0.412	0.007	1.818	0.205	0.316	0.070	2.032	0.153
2008	0.504	0.009	2.227	0.251	0.387	0.086	2.488	0.188
2010	0.558	0.009	2.465	0.278	0.429	0.096	2.754	0.208

Year	*Gas*	*Gasoline*	*Coke*	*Kerosene*	*Petrochemicals*	*Diesel*	*LPG*	*Fuel oil*
1996	0.010	0.023	0.00008	0.004	0.012	0.016	0.003	0.003
2000	0.012	0.028	0.00009	0.005	0.015	0.019	0.004	0.004
2004	0.015	0.035	0.00011	0.006	0.018	0.024	0.005	0.005
2008	0.018	0.042	0.00014	0.007	0.022	0.029	0.006	0.006
2010	0.020	0.047	0.00015	0.008	0.025	0.032	0.007	0.007

Year	*Investment*	*GDP*
1996	0.583	2.673
2000	0.714	3.273
2004	0.875	4.008
2008	1.071	4.908
2010	1.185	5.433

Table A2.17 Consumption: Scenario 0, 5.2% GDP Growth (trillions of pesos)

Year	*Food*	*Housing*	*Gasoline*	*Autos*	*Energy*	*Transport*	*Services*
1996	0.465	0.663	0.073	0.078	0.058	0.079	0.369
2000	0.599	0.812	0.090	0.096	0.072	0.097	0.452
2004	0.698	0.994	0.110	0.117	0.088	0.119	0.553
2008	0.855	1.218	0.135	0.144	0.107	0.146	0.677
2010	0.946	1.348	0.149	0.159	0.119	0.162	0.750

Table A2.18 Imports: Scenario 0, 5.2% GDP Growth (trillions of pesos)

Year	*Agriculture*	*Coal*	*Petroleum*	*Manufacturing*	*Chemicals*	*Gasoline*	*Coke*	*Kerosene*	*Diesel*	*LPG*	*Fuel oil*	*Services*	*Gas*	*Balance of payments*
1996	0.028	0.0009	0	0.635	0.108	0.006	0.000022	0.001	0.005	0.00045	0.001	0.00048	0.00072	0.07015
2000	0.035	0.001	0.0000012	0.777	0.132	0.008	0.000028	0.001	0.006	0.00055	0.001	0.00059	0.00088	0.08619
2004	0.043	0.001	0.0000015	0.952	0.162	0.01	0.000034	0.002	0.007	0.00068	0.002	0.00073	0.001	0.10231
2008	0.052	0.002	0.0000018	1.166	0.199	0.012	0.000042	0.002	0.009	0.00083	0.002	0.00089	0.001	0.12530
2010	0.058	0.002	0.000002	1.291	0.220	0.013	0.000046	0.002	0.010	0.00092	0.002	0.00099	0.001	0.13924

Table A2.19 Percent Change in Production: Scenario 1 (5.2% GDP Growth) Relative to Scenario 0

Year	*Agriculture*	*Coal*	*Manufacturing*	*Chemicals*	*Transportation*	*Electricity*	*Services*	*Petroleum*	*Gas*	*Gasoline*	*Coke*	*Kerosene*	*Petrochemicals*	*Diesel*	*LPG*	*Fuel oil*	*Investment*	*GDP*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.000	0.000
2000	0.000	16.667	-0.135	0.000	0.000	-1.724	0.000	0.800	-8.333	0.000	0.000	0.000	0.000	0.000	0.000	25.0	-0.302	-0.082
2004	-0.243	14.286	-0.220	-0.976	0.000	-2.857	-0.098	0.654	-13.333	-2.857	0.000	0.000	0.000	-4.167	0.000	20.0	-0.590	-0.184
2008	-0.198	11.111	-45.352	-1.195	0.000	-4.651	-0.121	0.532	-16.667	-2.381	-7.143	0.000	0.000	-3.448	0.000	33.3	-0.928	-0.293
2010	-0.358	22.222	-0.609	-1.439	-0.466	-1.042	-0.145	0.481	-20.000	-4.255	0.000	0.000	-4.000	-3.125	0.000	28.6	-1.210	-0.419

Table A2.20 Percent Change in Consumption: Scenario 1 (5.2% GDP Growth) Relative to Scenario 0

Year	*Food*	*Housing*	*Gasoline*	*Autos*	*Energy*	*Transport*	*Services*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	-4.841	0.000	0.000	0.000	-1.389	0.000	0.000
2004	-0.143	0.000	0.000	0.000	-1.136	0.000	0.000
2008	-0.117	-0.082	-0.741	0.000	-0.935	0.000	0.000
2010	-0.106	-0.074	-0.671	0.000	-0.840	0.000	0.000

Table A2.21 Percent Change in Imports: Scenario 1 (5.2% GDP Growth) Relative to Scenario 0

Year	*Agriculture*	*Coal*	*Petroleum*	*Manufacturing*	*Chemicals*	*Gasoline*	*Coke*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2004	0.000	0.000	0.000	0.000	0.000	0.000	-2.941
2008	0.000	0.000	0.000	-0.086	0.000	0.000	-2.381
2010	0.000	0.000	0.000	-0.077	0.000	7.692	-2.174

Year	*Kerosene*	*Diesel*	*LPG*	*Fuel oil*	*Services*	*Gas*	*Balance of payments*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.000	0.000	10.227	0.916
2004	0.000	0.000	0.000	-50.000	0.000	0.000	2.015
2008	0.000	0.000	1.205	-50.000	0.000	100.000	0.703
2010	0.000	0.000	1.087	0.000	0.000	100.000	0.626

Table A2.22 Scenario 2 (5.2% GDP Growth) Production: Percent Change Relative to Scenario 0

Year	*Agriculture*	*Coal*	*Manufacturing*	*Chemicals*	*Transportation*	*Electricity*	*Services*	*Petroleum*
1996	0.000	0.000	0.000	-0.730	0.000	0.000	0.074	0.000
2000	0.000	0.000	0.067	1.796	-0.388	5.172	0.000	-1.600
2004	0.243	14.286	0.440	2.927	-0.633	11.429	0.098	-1.961
2008	0.595	11.111	0.853	4.382	-0.775	13.953	0.281	-2.128
2010	0.896	22.222	1.176	4.676	-0.932	13.542	0.327	-1.923

Year	*Gas*	*Gasoline*	*Coke*	*Kerosene*	*Petrochemicals*	*Diesel*	*LPG*	*Fuel oil*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	33.333	7.143	11.111	0.000	6.667	5.263	0.000	0.000
2004	60.000	8.571	45.455	0.000	11.111	8.333	0.000	20.000
2008	94.444	16.667	64.286	14.286	13.636	13.793	16.667	16.667
2010	90.000	17.021	66.667	12.500	12.000	15.625	14.286	14.286

Year	*Investment*	*GDP*
1996	0.000	0.000
2000	0.841	0.136
2004	0.742	0.326
2008	2.229	0.555
2010	2.923	0.748

Table A2.23 Scenario 2 (5.2% GDP Growth) Consumption: Percent Change Relative to Scenario 0

Year	*Food*	*Housing*	*Gasoline*	*Autos*	*Energy*	*Transport*	*Services*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	-5.008	-0.123	-1.111	0.000	0.000	0.000	-0.221
2004	0.000	0.000	-1.818	0.855	1.136	0.000	-0.181
2008	0.117	0.000	-2.963	0.000	2.804	0.000	0.000
2010	0.106	0.000	-2.685	0.629	1.681	0.000	-0.133

Table A2.24 Scenario 2 (5.2% GDP Growth) Imports: Percent Change Relative to Scenario 0

Year	*Agriculture*	*Coal*	*Petroleum*	*Manufacturing*	*Chemicals*	*Gasoline*	*Coke*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.257	0.000	0.000	-21.429
2004	0.000	0.000	0.000	0.210	-0.617	0.000	-35.294
2008	0.000	0.000	5.556	0.257	-1.005	0.000	-47.619
2010	0.000	0.000	5.000	0.232	-0.909	0.000	-47.826

Year	*Kerosene*	*Diesel*	*LPG*	*Fuel oil*	*Services*	*Gas*	*Balance of payments*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	-3.636	0.000	1.695	-35.227	-7.227
2004	0.000	0.000	-7.353	-50.000	0.000	-51.000	-3.584
2008	0.000	0.000	-9.639	-50.000	1.124	-56.000	-1.767
2010	0.000	0.000	-9.783	-50.000	1.010	-51.000	-0.168

Table A2.25 Scenario 2 (5.2% GDP Growth) Production: Percent Change Relative to Scenario 0

Year	*Agriculture*	*Coal*	*Manufacturing*	*Chemicals*	*Transportation*	*Electricity*	*Services*	*Petroleum*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	-0.595	0.000	-0.202	-0.599	-0.388	3.448	0.181	-1.600
2004	-5.340	14.286	0.055	1.951	-0.633	10.000	0.197	-1.961
2008	0.000	11.111	0.404	3.187	-1.034	12.791	0.362	-2.660
2010	0.000	22.222	0.649	3.237	-1.166	12.500	0.363	-2.404

Year	*Gas*	*Gasoline*	*Coke*	*Kerosene*	*Petrochemicals*	*Diesel*	*LPG*	*Fuel oil*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	33.333	7.143	11.111	0.000	0.000	5.263	0.000	0.000
2004	60.000	8.571	45.455	0.000	11.111	8.333	0.000	0.000
2008	94.444	16.667	57.143	14.286	13.636	13.793	16.667	16.667
2010	90.000	14.894	66.667	12.500	12.000	15.625	14.286	14.286

Year	*Investment*	*GDP*
1996	0.000	0.000
2000	0.269	0.023
2004	0.809	0.192
2008	2.665	0.371
2010	2.086	-1.376

Table A2.26 Scenario 5 (5.2% GDP Growth) Consumption: Percent Change Relative to Scenario 0

Year	*Food*	*Housing*	*Gasoline*	*Autos*	*Energy*	*Transport*	*Services*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	-5.342	-0.246	1.111	0.000	-5.556	0.000	-0.221
2004	-0.430	-0.201	1.818	0.000	-5.682	0.000	-0.181
2008	-0.117	-0.082	2.222	0.000	-4.673	0.000	0.000
2010	0.000	0.000	2.685	0.000	-5.042	0.000	-0.133

Table A2.27 Scenario 5 (5.2% GDP Growth) Imports: Percent Change Relative to Scenario 0

Year	*Agriculture*	*Coal*	*Petroleum*	*Manufacturing*	*Chemicals*	*Gasoline*	*Coke*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.129	0.000	0.000	-21.429
2004	0.000	0.000	0.000	0.210	-0.617	0.000	-35.294
2008	0.000	0.000	5.556	0.257	-1.005	0.000	-47.619
2010	0.000	0.000	5.000	0.232	-0.909	0.000	-45.652

Year	*Kerosene*	*Diesel*	*LPG*	*Fuel oil*	*Services*	*Gas*	*Balance of payments*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	-3.636	0.000	0.000	-36.364	-6.276
2004	0.000	0.000	-7.353	-50.000	0.000	-52.000	-3.838
2008	0.000	0.000	-9.639	-50.000	0.000	-57.000	-3.678
2010	0.000	0.000	-9.783	-50.000	1.010	-52.000	-1.921

Table A2.28 Scenario 6 (5.2% GDP Growth, Low Carbon Tax) Production: Percent Change Relative to Scenario 0

Year	*Agriculture*	*Coal*	*Manufacturing*	*Chemicals*	*Transportation*	*Electricity*	*Services*	*Petroleum*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	-0.298	0.000	-0.269	1.198	-0.388	5.172	0.121	-3.200
2004	-0.243	-42.857	-0.385	1.463	-0.633	8.571	0.295	-9.150
2008	-0.198	-44.444	-0.539	1.992	-1.034	11.628	0.281	-10.106
2010	-0.358	-44.444	-0.649	1.799	-1.399	11.458	0.218	-10.577

Year	*Gas*	*Gasoline*	*Coke*	*Kerosene*	*Petrochemicals*	*Diesel*	*LPG*	*Fuel oil*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	25.000	3.571	22.222	0.000	0.000	5.263	0.000	0.000
2004	46.667	5.714	36.364	0.000	5.556	4.167	0.000	0.000
2008	77.778	11.905	57.143	14.286	9.091	10.345	0.000	16.667
2010	75.000	10.638	60.000	12.500	8.000	9.375	0.000	14.286

Year	*Investment*	*GDP*
1996	0.000	0.000
2000	-0.547	0.002
2004	-1.256	-0.026
2008	-1.037	-0.101
2010	-1.210	-0.159

Table A2.29 Scenario 6 (5.2% GDP Growth, Low Carbon Tax) Consumption: Percent Change Relative to Scenario 0

Year	*Food*	*Housing*	*Gasoline*	*Autos*	*Energy*	*Transport*	*Services*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	-5.008	0.000	-1.111	0.000	0.000	0.000	-0.221
2004	0.000	0.201	-1.818	0.000	1.136	0.000	0.181
2008	-0.117	0.082	-2.963	0.000	1.869	0.000	0.148
2010	-0.106	0.074	-2.685	0.000	1.681	0.000	0.000

Table A2.30 Scenario 6 (5.2% GDP Growth, Low Carbon Tax) Imports: Percent Change Relative to Scenario 0

Year	*Agriculture*	*Coal*	*Petroleum*	*Manufacturing*	*Chemicals*	*Gasoline*	*Coke*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.129	0.000	0.000	-21.429
2004	0.000	0.000	0.000	0.210	-0.617	0.000	-35.294
2008	0.000	0.000	5.556	0.257	-1.005	0.000	-45.238
2010	0.000	0.000	5.000	0.232	-1.364	0.000	-45.652

Year	*Kerosene*	*Diesel*	*LPG*	*Fuel oil*	*Services*	*Gas*	*Balance of payments*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	-1.818	0.000	1.695	-34.091	-6.345
2004	0.000	0.000	-4.412	-50.000	0.000	-50.000	-13.837
2008	0.000	0.000	-7.229	-50.000	1.124	-55.000	-14.277
2010	0.000	0.000	-7.609	0.000	1.010	-50.000	-13.571

Table A2.31 Scenario 7 (5.2% GDP Growth, Low Carbon Tax) Production: Percent Change Relative to Scenario 0

Year	*Agriculture*	*Coal*	*Manufacturing*	*Chemicals*	*Transportation*	*Electricity*	*Services*	*Petroleum*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	-0.595	0.000	-0.337	0.000	-0.388	-3.448	0.362	-4.000
2004	-0.728	-42.857	-0.605	0.488	-0.633	1.429	0.492	-9.804
2008	-0.794	-44.444	-0.853	1.195	-1.292	3.488	0.442	-10.638
2010	-1.075	-44.444	-1.014	1.079	-1.399	2.083	0.399	-11.058

Year	*Gas*	*Gasoline*	*Coke*	*Kerosene*	*Petrochemicals*	*Diesel*	*LPG*	*Fuel oil*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	25.000	3.571	11.111	0.000	0.000	5.263	0.000	0.000
2004	46.667	5.714	36.364	0.000	5.556	4.167	0.000	0.000
2008	77.778	11.905	57.143	14.286	9.091	10.345	16.667	16.667
2010	75.000	10.638	60.000	12.500	8.000	9.375	14.286	14.286

Year	*Investment*	*GDP*
1996	0.000	0.000
2000	-1.037	-0.152
2004	-1.723	-0.218
2008	-1.690	-1.242
2010	-1.997	-0.430

Table A2.32 Scenario 7 (5.2% GDP Growth, Low Carbon Tax) Consumption: Percent Change Relative to Scenario 0

Year	*Food*	*Housing*	*Gasoline*	*Autos*	*Energy*	*Transport*	*Services*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	-5.008	0.123	-1.111	0.000	-6.944	0.000	0.000
2004	-0.143	0.402	-1.818	0.855	-5.682	0.000	0.362
2008	-0.234	0.164	-2.963	0.000	-4.673	0.000	0.295
2010	-0.317	0.148	-2.685	0.000	-0.840	0.000	0.133

Table A2.33 Scenario 7 (5.2% GDP Growth, Low Carbon Tax) Imports: Percent Change Relative to Scenario 0

Year	*Agriculture*	*Coal*	*Petroleum*	*Manufacturing*	*Chemicals*	*Gasoline*	*Coke*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	8.333	0.129	0.000	0.000	-21.429
2004	0.000	0.000	0.000	0.105	-0.617	0.000	-35.294
2008	0.000	0.000	5.556	0.257	-1.005	0.000	-47.619
2010	0.000	0.000	5.000	0.155	-0.909	0.000	-45.652

Year	*Kerosene*	*Diesel*	*LPG*	*Fuel oil*	*Services*	*Gas*	*Balance of payments*
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	-1.818	0.000	0.000	-39.773	-8.573
2004	0.000	0.000	-4.412	-50.000	0.000	-54.000	-12.762
2008	0.000	0.000	-7.229	-50.000	0.000	-59.000	-16.576
2010	0.000	0.000	-6.522	0.000	0.000	-54.000	-15.675

Annex 3. Fuel Quality and Vehicle Emission Standards

Fuel Quality and Specifications in the United States

Table A3.1 U.S. Industry Average Baseline Gasoline, 1990

Gasoline parameters	*Units*	*Summer*	*Winter*
RVP	psi	8.7	11.5
Benzene	vol%	1.53	1.64
Total aromatics	vol%	32.0	26.4
Olefins	vol%	9.2	11.9
Sulfur	wt ppm	339	338
Oxygen	wt%	0.0	0.0

Table A3.2 Simple Model, 1 January 1995–31 December 1997

		Reformulated gasoline		*Conventional*
Gasoline parameters	*Units*	*per gallon*	*averaging*	*year-round*
Summer RVP, maximum	psi	7.2 (1) / 8.1 (2)	7.1 (1) / 8.0 (2)	–
Benzene, maximum	vol%	1.0	0.95	–
Oxygen, minimum	wt%	2.0	2.1	–
Toxics reduction	%	15.0	16.5	–
Exhaust benzene emissions		–		same as refinery's 1990 gasoline
Sulfur, olefins and T90		capped at refinery's 1990 levels		capped at 1.25 × refinery's 1990 levels

(1) ≡ VOC control region 1; (2) ≡ VOC control region 2

Table A3.3 Complex Model, 1 January 1998–31 December 1999

		Reformulated gasoline		*Conventional*
Gasoline parameters	*Units*	*per gallon*	*averaging*	*year-round*
Benzene, maximum	vol%	1.0	0.95	–
Oxygen, minimum	wt%	2.0	2.1	–
VOC reduction	%	27.5 (1) / 25.9 (2)	29.0 (1) / 27.4 (2)	
NO_x reduction	%	5.5	6.8	
Toxics reduction	%	15.0	16.5	–
Exhaust toxics emissions		–		same as refinery's 1990 gasoline

(1) ≡ VOC control region 1; (2) ≡ VOC control region 2

Table A3.4 Federal Diesel

Gasoline parameters	*Units*	*Low-sulfur No. 1-D*	*Low-sulfur No. 2-D*
Cetane number, minimum		40	40
Kinematic viscosity at 40°C	centistoke	1.3–2.4	1.9–4.1
Sulfur, maximum	wt ppm	500	500
Cetane index, minimum *		40	40
Aromaticity, maximum *	vol%	35	35
Ramsbottom carton on 10% residue, maximum	wt%	0.15	0.35

* One of the two properties must be met.

Worldwide Fuels Charter

Table A3.5 Gasoline

Gasoline parameters	*Units*	*Category 2*	*Category 3*	*Category 4*
91 RON, minimum	RON	91.0	91.0	91.0
	MON	82.5	82.5	82.5
95 RON, minimum	RON	95.0	95.0	95.0
	MON	85.0	85.0	85.0
98 RON, minimum	RON	98.0	98.0	98.0
	MON	88.0	88.0	88.0
Sulfur, maximum	wt ppm	200	30	sulfur-free (1)
Oxygen, maximum	wt%	2.7	2.7	2.7
Olefins, maximum	vol%	20	10	10
Aromatics, maximum	vol%	40	35	35
Benzene, maximum	vol%	2.5	1.0	1.0
Density	kg/m^3	715–770	715–770	715–770

Note: (1) 5-10 wt ppm based on available data on advanced technology vehicles. As more data become available, a more specific maximum will be defined.
Category 2 for markets with stringent requirements for emission controls or other market demands
Category 3 for markets with advanced requirements for emission controls or other market demands
Category 4 for markets with further advanced requirements for emission control, to enable sophisticated NO_x technologies.

Table A3.6 Diesel

Gasoline parameters	*Units*	*Category 2*	*Category 3*	*Category 4*
Cetane number, minimum		53	55	55
Cetane index, minimum		50	52	52
Density at 15°C	kg/m^3	820–850	820–840	820–840
Kinematic viscosity at 40°C	centistoke	2.0–4.0	2.0–4.0	2.0–4.0
Sulfur, maximum	wt ppm	300	30	sulfur-free
Aromatics, maximum	wt%	25	15	15
Polycyclics, maximum	wt%	5	2	2
T90, maximum	°C	340	320	320
T95, maximum	°C	355	340	340

Notes: cSt centistokes; kg/m^3 kilograms per cubic meter; (1) 5-10 wt ppm based on available data on advanced technology vehicles. As more data become available, a more specific maximum will be defined.

Fuel Quality and Vehicle Emission Standards in Mexico

Table A3.7 Gasoline Specifications in Mexico

Parameter	*Units*	*Value*							
		ZMVM		*Guadalajara*		*Monterrey*		*Rest of Mexico*	
Sulfur, maximum	wt ppm	500		1,000	500	1,000	500	1,000	500
Anti-knock index, minimum	(R+M)/2	87	93	87	93	87	93	87	92/93
Aromatics, maximum	vol%	25		30		30	32	rep.	32
Benzene, maximum	vol%	1.0		2.0		2.0		4.9	2.0
Olefins, maximum	vol%	10		12.5		12.5	15	rep.	15
Oxygen	wt%	1.0–2.0		1.0–2.0		1.0–2.0		n.a.	1.0–2.0
RVP	psi	6.5–7.8		6.5–7.8		class		class	
Detergent, minimum	ppm	450		450		450		290	500

rep. ≡ report; class ≡ varies according to volatility class; n.a. ≡ not applicable

Table A3.8 Diesel Specifications in Mexico

Parameter	*Units*	*Diesel*	*Special marine diesel*
T90	°C	345	350
Cetane index or number, minimum		48	40
Sulfur, maximum	wt%	0.05	0.50
Aromatics, maximum	vol%	30	Not applicable
Ramsbottom carbon on 10% residue, maximum	wt%	0.25	0.25
Kinematic viscosity at 40°C	centistoke	1.9–4.1	1.9–4.1
Ash, maximum	wt%	0.01	0.01

Table A3.9 Gasoline Vehicle Emission Standards

Model year	*Passenger*		*Model year*	*CL1-CL4*	
	HC, ppm	*CO, vol%*		*HC, ppm*	*CO, vol%*
up to 1986	500	4.0	up to 1985	600	5.0
1987–1993	400	3.0	1986–1991	500	4.0
1994+	200	2.0	1992–1993	400	3.0
			1994+	200	2.0

CL1-CL4 ≡ light-duty vehicle category by weight, corresponding to U.S. Light-Duty Truck 1 to 4 (LDT1–LTD4)

Table A3.10 Gasoline Vehicle Emission Standards in ZMVM (HC in ppm, CO in volume %)

Model year	*Passenger*		*Model year*	*CL1-CL4*		*Model year*	*Public*	
	HC	*CO*		*HC*	*CO*		*HC*	*CO*
up to 1990	300	3.0	up to 1993	350	3.0	all	100	1.0
1991+	200	2.0	1994+	200	2.0			
“One”	200	2.0	“One”	200	2.0			
“Zero”	100	1.0	“Zero”	100	1.0			

CL1-CL4 ≡ light-duty vehicle category by weight, corresponding to U.S. Light-Duty Truck 1 to 4 (LDT1–LTD4); public ≡ taxis, microbuses and all other types of vehicles that transport passengers

Table A3.11 Exhaust Emission Certification Standards for Vehicles Fueled by Gasoline, Liquefied Petroleum Gas and Natural Gas

Vehicle type	*Model year*	*THC g/km*	*NMHC g/km*	*CO g/km*	*NO_x g/km*	*Evap. g/test*
passenger	1999-2000	0.25		2.11	0.62	2.0
	2001+		0.156	2.11	0.25	2.0
CL1	1999-2000	0.63		8.75	1.44	2.0
	2001+		0.156	2.11	0.25	2.0
CL2	1999-2000	0.63		8.75	1.44	2.0
	2001+		0.20	2.74	0.44	2.0
CL3	1999-2000	0.63		8.75	1.44	2.0
	2001+		0.20	2.74	0.44	2.0
CL4	1999-2000	0.63		8.75	1.44	2.0
	2001+		0.24	3.11	0.68	2.0

THC ≡ total hydrocarbons; NMHC ≡ non-methane hydrocarbons; evap. ≡ evaporative emissions; passenger ≡ passenger vehicles; CL1-CL4 ≡ light-duty vehicle category by weight, corresponding to U.S. Light-Duty Truck 1 to 4 (LDT1–LTD4)

Table A3.12 Exhaust Emission Certification Standards for Vehicles Fueled by Diesel

Vehicle type	Model year	THC g/km	NMHC g/km	CO g/km	NO_x g/km	PM g/test
passenger	1999-2000	0.25		2.11	0.62	0.07
	2001+		0.156	2.11	0.62	0.07
CL1	1999-2000	0.63		8.75	1.44	0.07
	2001+		0.156	2.11	0.62	0.07
CL2	1999-2000	0.63		8.75	1.44	0.07
	2001+		0.20	2.74	0.62	0.07
CL3	1999-2000	0.63		8.75	1.44	0.07
	2001+		0.20	2.74	0.62	0.07
CL4	1999-2000	0.63		8.75	1.44	0.10
	2001+		0.24	3.11	0.62	0.10

THC ≡ total hydrocarbons; NMHC ≡ non-methane hydrocarbons; PM ≡ particulate matter; passenger ≡ passenger vehicles; CL1-CL4 ≡ light-duty vehicle category by weight, corresponding to U.S. Light-Duty Truck 1 to 4 (LDT1–LTD4)

Joint UNDP/World Bank

ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

LIST OF REPORTS ON COMPLETED ACTIVITIES

Region/Country	*Activity/Report Title*	*Date*	*Number*
	SUB-SAHARAN AFRICA (AFR)		
Africa Regional	Anglophone Africa Household Energy Workshop (English)	07/88	085/88
	Regional Power Seminar on Reducing Electric Power System Losses in Africa (English)	08/88	087/88
	Institutional Evaluation of EGL (English)	02/89	098/89
	Biomass Mapping Regional Workshops (English)	05/89	--
	Francophone Household Energy Workshop (French)	08/89	--
	Interafrican Electrical Engineering College: Proposals for Short- and Long-Term Development (English)	03/90	112/90
	Biomass Assessment and Mapping (English)	03/90	--
	Symposium on Power Sector Reform and Efficiency Improvement in Sub-Saharan Africa (English)	06/96	182/96
	Commercialization of Marginal Gas Fields (English)	12/97	201/97
	Commercilizing Natural Gas: Lessons from the Seminar in Nairobi for Sub-Saharan Africa and Beyond	01/00	225/00
	Africa Gas Initiative – Main Report: Volume I	02/01	240/01
Angola	Energy Assessment (English and Portuguese)	05/89	4708-ANG
	Power Rehabilitation and Technical Assistance (English)	10/91	142/91
	Africa Gas Initiative – Angola: Volume II	02/01	240/01
Benin	Energy Assessment (English and French)	06/85	5222-BEN
Botswana	Energy Assessment (English)	09/84	4998-BT
	Pump Electrification Prefeasibility Study (English)	01/86	047/86
	Review of Electricity Service Connection Policy (English)	07/87	071/87
	Tuli Block Farms Electrification Study (English)	07/87	072/87
	Household Energy Issues Study (English)	02/88	--
	Urban Household Energy Strategy Study (English)	05/91	132/91
Burkina Faso	Energy Assessment (English and French)	01/86	5730-BUR
	Technical Assistance Program (English)	03/86	052/86
	Urban Household Energy Strategy Study (English and French)	06/91	134/91
Burundi	Energy Assessment (English)	06/82	3778-BU
	Petroleum Supply Management (English)	01/84	012/84
	Status Report (English and French)	02/84	011/84
	Presentation of Energy Projects for the Fourth Five-Year Plan (1983-1987) (English and French)	05/85	036/85
	Improved Charcoal Cookstove Strategy (English and French)	09/85	042/85
	Peat Utilization Project (English)	11/85	046/85
	Energy Assessment (English and French)	01/92	9215-BU
Cameroon	Africa Gas Initiative – Cameroon: Volume III	02/01	240/01
Cape Verde	Energy Assessment (English and Portuguese)	08/84	5073-CV
	Household Energy Strategy Study (English)	02/90	110/90
Central African Republic	Energy Assessement (French)	08/92	9898-CAR
Chad	Elements of Strategy for Urban Household Energy The Case of N'djamena (French)	12/93	160/94
Comoros	Energy Assessment (English and French)	01/88	7104-COM
	In Search of Better Ways to Develop Solar Markets: The Case of Comoros	05/00	230/00
Congo	Energy Assessment (English)	01/88	6420-COB

Region/Country	*Activity/Report Title*	*Date*	*Number*
Congo	Power Development Plan (English and French)	03/90	106/90
	Africa Gas Initiative – Congo: Volume IV	02/01	240/01
Côte d'Ivoire	Energy Assessment (English and French)	04/85	5250-IVC
	Improved Biomass Utilization (English and French)	04/87	069/87
	Power System Efficiency Study (English)	12/87	--
	Power Sector Efficiency Study (French)	02/92	140/91
	Project of Energy Efficiency in Buildings (English)	09/95	175/95
	Africa Gas Initiative – Côte d'Ivoire: Volume V	02/01	240/01
Ethiopia	Energy Assessment (English)	07/84	4741-ET
	Power System Efficiency Study (English)	10/85	045/85
	Agricultural Residue Briquetting Pilot Project (English)	12/86	062/86
	Bagasse Study (English)	12/86	063/86
	Cooking Efficiency Project (English)	12/87	--
	Energy Assessment (English)	02/96	179/96
Gabon	Energy Assessment (English)	07/88	6915-GA
	Africa Gas Initiative – Gabon: Volume VI	02/01	240/01
The Gambia	Energy Assessment (English)	11/83	4743-GM
	Solar Water Heating Retrofit Project (English)	02/85	030/85
	Solar Photovoltaic Applications (English)	03/85	032/85
	Petroleum Supply Management Assistance (English)	04/85	035/85
Ghana	Energy Assessment (English)	11/86	6234-GH
	Energy Rationalization in the Industrial Sector (English)	06/88	084/88
	Sawmill Residues Utilization Study (English)	11/88	074/87
	Industrial Energy Efficiency (English)	11/92	148/92
Guinea	Energy Assessment (English)	11/86	6137-GUI
	Household Energy Strategy (English and French)	01/94	163/94
Guinea-Bissau	Energy Assessment (English and Portuguese)	08/84	5083-GUB
	Recommended Technical Assistance Projects (English & Portuguese)	04/85	033/85
	Management Options for the Electric Power and Water Supply Subsectors (English)	02/90	100/90
	Power and Water Institutional Restructuring (French)	04/91	118/91
Kenya	Energy Assessment (English)	05/82	3800-KE
	Power System Efficiency Study (English)	03/84	014/84
	Status Report (English)	05/84	016/84
	Coal Conversion Action Plan (English)	02/87	--
	Solar Water Heating Study (English)	02/87	066/87
	Peri-Urban Woodfuel Development (English)	10/87	076/87
	Power Master Plan (English)	11/87	--
	Power Loss Reduction Study (English)	09/96	186/96
	Implementation Manual: Financing Mechanisms for Solar Electric Equipment	07/00	231/00
Lesotho	Energy Assessment (English)	01/84	4676-LSO
Liberia	Energy Assessment (English)	12/84	5279-LBR
	Recommended Technical Assistance Projects (English)	06/85	038/85
	Power System Efficiency Study (English)	12/87	081/87
Madagascar	Energy Assessment (English)	01/87	5700-MAG
	Power System Efficiency Study (English and French)	12/87	075/87
	Environmental Impact of Woodfuels (French)	10/95	176/95
Malawi	Energy Assessment (English)	08/82	3903-MAL
	Technical Assistance to Improve the Efficiency of Fuelwood Use in the Tobacco Industry (English)	11/83	009/83

Region/Country	*Activity/Report Title*	*Date*	*Number*
Malawi	Status Report (English)	01/84	013/84
Mali	Energy Assessment (English and French)	11/91	8423-MLI
	Household Energy Strategy (English and French)	03/92	147/92
Islamic Republic of Mauritania	Energy Assessment (English and French)	04/85	5224-MAU
	Household Energy Strategy Study (English and French)	07/90	123/90
Mauritius	Energy Assessment (English)	12/81	3510-MAS
	Status Report (English)	10/83	008/83
	Power System Efficiency Audit (English)	05/87	070/87
	Bagasse Power Potential (English)	10/87	077/87
	Energy Sector Review (English)	12/94	3643-MAS
Mozambique	Energy Assessment (English)	01/87	6128-MOZ
	Household Electricity Utilization Study (English)	03/90	113/90
	Electricity Tariffs Study (English)	06/96	181/96
	Sample Survey of Low Voltage Electricity Customers	06/97	195/97
Namibia	Energy Assessment (English)	03/93	11320-NAM
Niger	Energy Assessment (French)	05/84	4642-NIR
	Status Report (English and French)	02/86	051/86
	Improved Stoves Project (English and French)	12/87	080/87
	Household Energy Conservation and Substitution (English and French)	01/88	082/88
Nigeria	Energy Assessment (English)	08/83	4440-UNI
	Energy Assessment (English)	07/93	11672-UNI
Rwanda	Energy Assessment (English)	06/82	3779-RW
	Status Report (English and French)	05/84	017/84
	Improved Charcoal Cookstove Strategy (English and French)	08/86	059/86
	Improved Charcoal Production Techniques (English and French)	02/87	065/87
	Energy Assessment (English and French)	07/91	8017-RW
	Commercialization of Improved Charcoal Stoves and Carbonization Techniques Mid-Term Progress Report (English and French)	12/91	141/91
SADC	SADC Regional Power Interconnection Study, Vols. I-IV (English)	12/93	--
SADCC	SADCC Regional Sector: Regional Capacity-Building Program for Energy Surveys and Policy Analysis (English)	11/91	--
Sao Tome and Principe	Energy Assessment (English)	10/85	5803-STP
Senegal	Energy Assessment (English)	07/83	4182-SE
	Status Report (English and French)	10/84	025/84
	Industrial Energy Conservation Study (English)	05/85	037/85
	Preparatory Assistance for Donor Meeting (English and French)	04/86	056/86
	Urban Household Energy Strategy (English)	02/89	096/89
	Industrial Energy Conservation Program (English)	05/94	165/94
Seychelles	Energy Assessment (English)	01/84	4693-SEY
	Electric Power System Efficiency Study (English)	08/84	021/84
Sierra Leone	Energy Assessment (English)	10/87	6597-SL
Somalia	Energy Assessment (English)	12/85	5796-SO
Republic of South Africa	Options for the Structure and Regulation of Natural Gas Industry (English)	05/95	172/95
Sudan	Management Assistance to the Ministry of Energy and Mining	05/83	003/83
	Energy Assessment (English)	07/83	4511-SU
	Power System Efficiency Study (English)	06/84	018/84
	Status Report (English)	11/84	026/84

Region/Country	***Activity/Report Title***	***Date***	***Number***
Sudan	Wood Energy/Forestry Feasibility (English)	07/87	073/87
Swaziland	Energy Assessment (English)	02/87	6262-SW
	Household Energy Strategy Study	10/97	198/97
Tanzania	Energy Assessment (English)	11/84	4969-TA
	Peri-Urban Woodfuels Feasibility Study (English)	08/88	086/88
	Tobacco Curing Efficiency Study (English)	05/89	102/89
	Remote Sensing and Mapping of Woodlands (English)	06/90	--
	Industrial Energy Efficiency Technical Assistance (English)	08/90	122/90
	Power Loss Reduction Volume 1: Transmission and Distribution SystemTechnical Loss Reduction and Network Development (English)	06/98	204A/98
	Power Loss Reduction Volume 2: Reduction of Non-Technical Losses (English)	06/98	204B/98
Togo	Energy Assessment (English)	06/85	5221-TO
	Wood Recovery in the Nangbeto Lake (English and French)	04/86	055/86
	Power Efficiency Improvement (English and French)	12/87	078/87
Uganda	Energy Assessment (English)	07/83	4453-UG
	Status Report (English)	08/84	020/84
	Institutional Review of the Energy Sector (English)	01/85	029/85
	Energy Efficiency in Tobacco Curing Industry (English)	02/86	049/86
	Fuelwood/Forestry Feasibility Study (English)	03/86	053/86
	Power System Efficiency Study (English)	12/88	092/88
	Energy Efficiency Improvement in the Brick and Tile Industry (English)	02/89	097/89
	Tobacco Curing Pilot Project (English)	03/89	UNDP Terminal Report
	Energy Assessment (English)	12/96	193/96
	Rural Electrification Strategy Study	09/99	221/99
Zaire	Energy Assessment (English)	05/86	5837-ZR
Zambia	Energy Assessment (English)	01/83	4110-ZA
	Status Report (English)	08/85	039/85
	Energy Sector Institutional Review (English)	11/86	060/86
	Power Subsector Efficiency Study (English)	02/89	093/88
	Energy Strategy Study (English)	02/89	094/88
	Urban Household Energy Strategy Study (English)	08/90	121/90
Zimbabwe	Energy Assessment (English)	06/82	3765-ZIM
	Power System Efficiency Study (English)	06/83	005/83
	Status Report (English)	08/84	019/84
	Power Sector Management Assistance Project (English)	04/85	034/85
	Power Sector Management Institution Building (English)	09/89	--
	Petroleum Management Assistance (English)	12/89	109/89
	Charcoal Utilization Prefeasibility Study (English)	06/90	119/90
	Integrated Energy Strategy Evaluation (English)	01/92	8768-ZIM
	Energy Efficiency Technical Assistance Project: Strategic Framework for a National Energy Efficiency Improvement Program (English)	04/94	--
	Capacity Building for the National Energy Efficiency Improvement Programme (NEEIP) (English)	12/94	--
	Rural Electrification Study	03/00	228/00

Region/Country	*Activity/Report Title*	*Date*	*Number*
EAST ASIA AND PACIFIC (EAP)			
Asia Regional	Pacific Household and Rural Energy Seminar (English)	11/90	--
China	County-Level Rural Energy Assessments (English)	05/89	101/89
	Fuelwood Forestry Preinvestment Study (English)	12/89	105/89
	Strategic Options for Power Sector Reform in China (English)	07/93	156/93
	Energy Efficiency and Pollution Control in Township and Village Enterprises (TVE) Industry (English)	11/94	168/94
	Energy for Rural Development in China: An Assessment Based on a Joint Chinese/ESMAP Study in Six Counties (English)	06/96	183/96
	Improving the Technical Efficiency of Decentralized Power Companies	09/99	222/999
Fiji	Energy Assessment (English)	06/83	4462-FIJ
Indonesia	Energy Assessment (English)	11/81	3543-IND
	Status Report (English)	09/84	022/84
	Power Generation Efficiency Study (English)	02/86	050/86
	Energy Efficiency in the Brick, Tile and Lime Industries (English)	04/87	067/87
	Diesel Generating Plant Efficiency Study (English)	12/88	095/88
	Urban Household Energy Strategy Study (English)	02/90	107/90
	Biomass Gasifier Preinvestment Study Vols. I & II (English)	12/90	124/90
	Prospects for Biomass Power Generation with Emphasis on Palm Oil, Sugar, Rubberwood and Plywood Residues (English)	11/94	167/94
Lao PDR	Urban Electricity Demand Assessment Study (English)	03/93	154/93
	Institutional Development for Off-Grid Electrification	06/99	215/99
Malaysia	Sabah Power System Efficiency Study (English)	03/87	068/87
	Gas Utilization Study (English)	09/91	9645-MA
Myanmar	Energy Assessment (English)	06/85	5416-BA
Papua New Guinea	Energy Assessment (English)	06/82	3882-PNG
	Status Report (English)	07/83	006/83
	Energy Strategy Paper (English)	--	--
	Institutional Review in the Energy Sector (English)	10/84	023/84
	Power Tariff Study (English)	10/84	024/84
Philippines	Commercial Potential for Power Production from Agricultural Residues (English)	12/93	157/93
	Energy Conservation Study (English)	08/94	--
Solomon Islands	Energy Assessment (English)	06/83	4404-SOL
	Energy Assessment (English)	01/92	979-SOL
South Pacific	Petroleum Transport in the South Pacific (English)	05/86	--
Thailand	Energy Assessment (English)	09/85	5793-TH
	Rural Energy Issues and Options (English)	09/85	044/85
	Accelerated Dissemination of Improved Stoves and Charcoal Kilns (English)	09/87	079/87
	Northeast Region Village Forestry and Woodfuels Preinvestment Study (English)	02/88	083/88
	Impact of Lower Oil Prices (English)	08/88	--
	Coal Development and Utilization Study (English)	10/89	--
Tonga	Energy Assessment (English)	06/85	5498-TON
Vanuatu	Energy Assessment (English)	06/85	5577-VA
Vietnam	Rural and Household Energy-Issues and Options (English)	01/94	161/94

Region/Country	*Activity/Report Title*	*Date*	*Number*
Vietnam	Power Sector Reform and Restructuring in Vietnam: Final Report to the Steering Committee (English and Vietnamese)	09/95	174/95
	Household Energy Technical Assistance: Improved Coal Briquetting and Commercialized Dissemination of Higher Efficiency Biomass and Coal Stoves (English)	01/96	178/96
	Petroleum Fiscal Issues and Policies for Fluctuating Oil Prices In Vietnam	02/01	236/01
Western Samoa	Energy Assessment (English)	06/85	5497-WSO
	SOUTH ASIA (SAS)		
Bangladesh	Energy Assessment (English)	10/82	3873-BD
	Priority Investment Program (English)	05/83	002/83
	Status Report (English)	04/84	015/84
	Power System Efficiency Study (English)	02/85	031/85
	Small Scale Uses of Gas Prefeasibility Study (English)	12/88	--
India	Opportunities for Commercialization of Nonconventional Energy Systems (English)	11/88	091/88
	Maharashtra Bagasse Energy Efficiency Project (English)	07/90	120/90
	Mini-Hydro Development on Irrigation Dams and Canal Drops Vols. I, II and III (English)	07/91	139/91
	WindFarm Pre-Investment Study (English)	12/92	150/92
	Power Sector Reform Seminar (English)	04/94	166/94
	Environmental Issues in the Power Sector (English)	06/98	205/98
	Environmental Issues in the Power Sector: Manual for Environmental Decision Making (English)	06/99	213/99
	Household Energy Strategies for Urban India: The Case of Hyderabad	06/99	214/99
	Greenhouse Gas Mitigation In the Power Sector: Case Studies From India	02/01	237/01
Nepal	Energy Assessment (English)	08/83	4474-NEP
	Status Report (English)	01/85	028/84
	Energy Efficiency & Fuel Substitution in Industries (English)	06/93	158/93
Pakistan	Household Energy Assessment (English)	05/88	--
	Assessment of Photovoltaic Programs, Applications, and Markets (English)	10/89	103/89
	National Household Energy Survey and Strategy Formulation Study: Project Terminal Report (English)	03/94	--
	Managing the Energy Transition (English)	10/94	--
	Lighting Efficiency Improvement Program Phase 1: Commercial Buildings Five Year Plan (English)	10/94	--
Sri Lanka	Energy Assessment (English)	05/82	3792-CE
	Power System Loss Reduction Study (English)	07/83	007/83
	Status Report (English)	01/84	010/84
	Industrial Energy Conservation Study (English)	03/86	054/86
	EUROPE AND CENTRAL ASIA (ECA)		
Bulgaria	Natural Gas Policies and Issues (English)	10/96	188/96
Central and Eastern Europe	Power Sector Reform in Selected Countries	07/97	196/97

Region/Country	*Activity/Report Title*	*Date*	*Number*
Central and Eastern Europe	Increasing the Efficiency of Heating Systems in Central and Eastern Europe and the Former Soviet Union	08/00	234/00
	The Future of Natural Gas in Eastern Europe (English)	08/92	149/92
Kazakhstan	Natural Gas Investment Study, Volumes 1, 2 & 3	12/97	199/97
Kazakhstan & Kyrgyzstan	Opportunities for Renewable Energy Development	11/97	16855-KAZ
Poland	Energy Sector Restructuring Program Vols. I-V (English)	01/93	153/93
	Natural Gas Upstream Policy (English and Polish)	08/98	206/98
	Energy Sector Restructuring Program: Establishing the Energy Regulation Authority	10/98	208/98
Portugal	Energy Assessment (English)	04/84	4824-PO
Romania	Natural Gas Development Strategy (English)	12/96	192/96
Slovenia	Workshop on Private Participation in the Power Sector (English)	02/99	211/99
Turkey	Energy Assessment (English)	03/83	3877-TU
	Energy and the Environment: Issues and Options Paper	04/00	229/00

MIDDLE EAST AND NORTH AFRICA (MNA)

Arab Republic of Egypt	Energy Assessment (English)	10/96	189/96
	Energy Assessment (English and French)	03/84	4157-MOR
	Status Report (English and French)	01/86	048/86
Morocco	Energy Sector Institutional Development Study (English and French)	07/95	173/95
	Natural Gas Pricing Study (French)	10/98	209/98
	Gas Development Plan Phase II (French)	02/99	210/99
Syria	Energy Assessment (English)	05/86	5822-SYR
	Electric Power Efficiency Study (English)	09/88	089/88
	Energy Efficiency Improvement in the Cement Sector (English)	04/89	099/89
	Energy Efficiency Improvement in the Fertilizer Sector (English)	06/90	115/90
Tunisia	Fuel Substitution (English and French)	03/90	--
	Power Efficiency Study (English and French)	02/92	136/91
	Energy Management Strategy in the Residential and Tertiary Sectors (English)	04/92	146/92
	Renewable Energy Strategy Study, Volume I (French)	11/96	190A/96
	Renewable Energy Strategy Study, Volume II (French)	11/96	190B/96
Yemen	Energy Assessment (English)	12/84	4892-YAR
	Energy Investment Priorities (English)	02/87	6376-YAR
	Household Energy Strategy Study Phase I (English)	03/91	126/91

LATIN AMERICA AND THE CARIBBEAN (LAC)

LAC Regional	Regional Seminar on Electric Power System Loss Reduction in the Caribbean (English)	07/89	--
	Elimination of Lead in Gasoline in Latin America and the Caribbean (English and Spanish)	04/97	194/97
	Elimination of Lead in Gasoline in Latin America and the Caribbean - Status Report (English and Spanish)	12/97	200/97

Region/Country	***Activity/Report Title***	***Date***	***Number***
LAC Regional	Harmonization of Fuels Specifications in Latin America and the Caribbean (English and Spanish)	06/98	203/98
Bolivia	Energy Assessment (English)	04/83	4213-BO
	National Energy Plan (English)	12/87	--
	La Paz Private Power Technical Assistance (English)	11/90	111/90
	Prefeasibility Evaluation Rural Electrification and Demand Assessment (English and Spanish)	04/91	129/91
	National Energy Plan (Spanish)	08/91	131/91
	Private Power Generation and Transmission (English)	01/92	137/91
	Natural Gas Distribution: Economics and Regulation (English)	03/92	125/92
	Natural Gas Sector Policies and Issues (English and Spanish)	12/93	164/93
	Household Rural Energy Strategy (English and Spanish)	01/94	162/94
	Preparation of Capitalization of the Hydrocarbon Sector	12/96	191/96
	Introducing Competition into the Electricity Supply Industry in Developing Countries: Lessons from Bolivia	08/00	233/00
	Final Report on Operational Activities Rural Energy and Energy Efficiency	08/00	235/00
Brazil	Energy Efficiency & Conservation: Strategic Partnership for Energy Efficiency in Brazil (English)	01/95	170/95
	Hydro and Thermal Power Sector Study	09/97	197/97
	Rural Electrification with Renewable Energy Systems in the Northeast: A Preinvestment Study	07/00	232/00
Chile	Energy Sector Review (English)	08/88	7129-CH
Colombia	Energy Strategy Paper (English)	12/86	--
	Power Sector Restructuring (English)	11/94	169/94
	Energy Efficiency Report for the Commercial and Public Sector (English)	06/96	184/96
Costa Rica	Energy Assessment (English and Spanish)	01/84	4655-CR
	Recommended Technical Assistance Projects (English)	11/84	027/84
	Forest Residues Utilization Study (English and Spanish)	02/90	108/90
Dominican Republic	Energy Assessment (English)	05/91	8234-DO
Ecuador	Energy Assessment (Spanish)	12/85	5865-EC
	Energy Strategy Phase I (Spanish)	07/88	--
	Energy Strategy (English)	04/91	--
	Private Minihydropower Development Study (English)	11/92	--
	Energy Pricing Subsidies and Interfuel Substitution (English)	08/94	11798-EC
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Guatemala	Issues and Options in the Energy Sector (English)	09/93	12160-GU
Haiti	Energy Assessment (English and French)	06/82	3672-HA
	Status Report (English and French)	08/85	041/85
	Household Energy Strategy (English and French)	12/91	143/91
Honduras	Energy Assessment (English)	08/87	6476-HO
	Petroleum Supply Management (English)	03/91	128/91
Jamaica	Energy Assessment (English)	04/85	5466-JM
	Petroleum Procurement, Refining, and Distribution Study (English)	11/86	061/86
	Energy Efficiency Building Code Phase I (English)	03/88	--
	Energy Efficiency Standards and Labels Phase I (English)	03/88	--
	Management Information System Phase I (English)	03/88	--
	Charcoal Production Project (English)	09/88	090/88
	FIDCO Sawmill Residues Utilization Study (English)	09/88	088/88

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Jamaica	Energy Sector Strategy and Investment Planning Study (English)	07/92	135/92
Mexico	Improved Charcoal Production Within Forest Management for the State of Veracruz (English and Spanish)	08/91	138/91
	Energy Efficiency Management Technical Assistance to the Comision Nacional para el Ahorro de Energia (CONAE) (English)	04/96	180/96
	Energy Environment Review	05/01	241/01
Panama	Power System Efficiency Study (English)	06/83	004/83
Paraguay	Energy Assessment (English)	10/84	5145-PA
	Recommended Technical Assistance Projects (English)	09/85	--
	Status Report (English and Spanish)	09/85	043/85
Peru	Energy Assessment (English)	01/84	4677-PE
	Status Report (English)	08/85	040/85
	Proposal for a Stove Dissemination Program in the Sierra (English and Spanish)	02/87	064/87
	Energy Strategy (English and Spanish)	12/90	--
	Study of Energy Taxation and Liberalization of the Hydrocarbons Sector (English and Spanish)	120/93	159/93
	Reform and Privatization in the Hydrocarbon Sector (English and Spanish)	07/99	216/99
	Rural Electrification	02/01	238/01
Saint Lucia	Energy Assessment (English)	09/84	5111-SLU
St. Vincent and the Grenadines	Energy Assessment (English)	09/84	5103-STV
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Trinidad and Tobago	Energy Assessment (English)	12/85	5930-TR

GLOBAL

	Energy End Use Efficiency: Research and Strategy (English)	11/89	--
	Women and Energy--A Resource Guide The International Network: Policies and Experience (English)	04/90	--
	Guidelines for Utility Customer Management and Metering (English and Spanish)	07/91	--
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	Assessing Pollution Abatement Policies with a Case Study of Ankara (English)	11/95	177/95
	A Synopsis of the Third Annual Roundtable on Independent Power Projects: Rhetoric and Reality (English)	08/96	187/96
	Rural Energy and Development Roundtable (English)	05/98	202/98
	A Synopsis of the Second Roundtable on Energy Efficiency: Institutional and Financial Delivery Mechanisms (English)	09/98	207/98

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Global	The Effect of a Shadow Price on Carbon Emission in the Energy Portfolio of the World Bank: A Carbon Backcasting Exercise (English)	02/99	212/99
	Increasing the Efficiency of Gas Distribution Phase 1: Case Studies and Thematic Data Sheets	07/99	218/99
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	Global Lighting Services for the Poor Phase II: Text Marketing of Small "Solar" Batteries for Rural Electrification Purposes	08/99	220/99
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	Energy, Transportation and Environment: Policy Options for Environmental Improvement	12/99	224/99
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	Reducing the Cost of Grid Extension for Rural Electrification	02/00	227/00
	Undeveloped Oil and Gas Fields in the Industrializing World	02/01	239/01

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