MITIGATING CARBON EMISSIONS WHILE ADVANCING NATIONAL DEVELOPMENT PRIORITIES: THE CASE OF MEXICO

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Abstract. We analyze and integrate energy and forestry carbon mitigation scenarios for Mexico between the year 1994 and 2010. The energy options range from efficient end-use technologies to renewable technologies for electricity generation. Forestry options include avoiding deforestation through the management of native forests, and two afforestation options: restoration plantations and agroforestry systems. The methodology utilized to evaluate different energy and forestry scenarios is based on a 'bottom up' model. In the year 2010, total carbon emissions will reach 879 Tg of CO_2, of which 83% comes from energy consumption. The total carbon mitigation potential reaches 348 Tg of CO_2 by 2010, 62% of which comes from forestry options. Mitigation costs range from \$–45.9/ton CO_2 to \$106.4/ton CO_2. Several options, particularly concerning energy technologies, are cost effective from a national perspective. In each sector, different barriers can hinder the implementation of mitigation alternatives.

1. Introduction

Mitigating the negative effects of a potential change in the earth's climate will require definite and coordinated actions by the international community, according to their 'common but differentiated' responsibilities (UN, 1992). The Kyoto Protocol issued in December 1997 by the Conference of the Parties establishes for the first time mandatory greenhouse gas emission reductions with respect to 1990 levels for industrialized countries (Annex I). The protocol also opens the possibility for trading emission reductions between Annex I and developing countries (Non-Annex I) through the so-called Clean Development Mechanism (CDM). The CDM is expected to begin operating in the year 2000 (UN, 1997).

Under these circumstances, it is key for Non Annex I countries, such as Mexico, to examine carefully the technical and economic feasibility of greenhouse gases emission reduction scenarios. These scenarios would help to estimate Mexico's potential for both reducing their own greenhouse gases emission growth and for trading emission reductions through the CDM. Critical for the success of these scenarios and for effective participation of Non Annex I countries is to identify mitigation options and future emission reduction paths that simultaneously contribute to advance the country's own development priorities.

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The case of Mexico is relevant for several reasons. First, Mexico is among the 20 countries with the highest greenhouse gas emissions in the world. Second, since 1994, Mexico became a member of both the OECD and the North American Free Trade Agreement (NAFTA), and has been subject to pressures to put a cap on future GHG emissions or emissions growth. Also, Mexico is an oil exporting country with a heavy dependency on fossil fuels for satisfying its domestic energy needs. At the same time, however, Mexico is clearly a developing country in terms of its average income per capita, the lack of basic services in a very important portion of its population, and the amount of emissions per capita. Finally, the country does not have the necessary capital to make incremental investment in mitigation options to reduce GHG emissions. Under this framework, it is particularly important to analyze potential trends in GHG emissions, identify the forces that have driven GHG emission changes, and evaluate mitigation options that help advance the country's own development priorities.

In this paper we examine future carbon emission mitigation scenarios for a set of selected energy and forestry options in Mexico. The forestry options are compatible with the three options accepted in the Kyoto protocol, that is: deforestation, afforestation and reforestation. The exercise is directed mainly to illustrate the range of options available to the country in the short (2000) and medium terms (2010), and their associated costs. Specifically, we have left out of the analysis a more comprehensive coverage of the transportation sector because of lack of detailed technical and financial data. We only consider passenger transportation mitigation options in the Mexico City Metropolitan Area (MCMA), which represents approximately 15% of carbon emissions of the whole transportation sector.

We first summarize the measures and policies that Mexico is currently undertaking that address climate change concerns. We then describe the methods used to construct future mitigation scenarios, estimate the carbon mitigation potential to the year 2010 and calculate the costs of the different options analyzed. The methodology utilized to evaluate different energy and forestry scenarios is based on a 'bottom up' model developed at the Engineering and Ecology Institutes at the National University of Mexico (UNAM). We finish the paper with a discussion of the scenarios and a set of recommendations.

1.1. CURRENT SITUATION AND EFFORTS

As an oil exporting country, Mexico depends heavily on fossil fuels for satisfying its energy needs. About 86% of primary energy comes from these energy sources. CO_2 emissions related to energy use have grown from 150 Tg of CO_2 in 1975 to 297 Tg CO_2 in 1990, to 340 in 1996 (Sheinbaum et al., 1999; IEA, 1998). Deforestation and forest degradation have also been severe in the country in the past two decades, with an estimated loss of 670,000 ha per year in the early nineties (Masera et al., 1997). Approximately 185 to 229 TgCO_2 are emitted each year as a result of land use changes, the range coming from uncertainties in the carbon uptake in abandoned lands (Masera et al., 1997). Total carbon emissions reached approximately 520 TgCO_2/yr (143 TgC/yr) in 1990.

Mexico has been active in the climate change arena, fulfilling the commitments established in the climate convention such as conducting national greenhouse gas inventories and the examination of options to mitigate the expected growth of future GHG emissions. It has already presented its first national communication to the United Nations Framework Convention on Climate Change (UNFCC) and has signed the Kyoto protocol. A comprehensive National Climate Action Plan is currently under public review in order to be submitted to the UNFCCC.

There are several activities currently conducted in the country that address national development priorities while simultaneously helping to reduce the current rate of GHG emissions growth. These activities include, within the energy sector, increases in energy efficiency in the industrial, transportation, commercial, and residential sectors, switching to less carbon-intensive fuels, and the establishment of standards for new equipment. Within the forest sector, the adequate conservation and management of native forests as alternatives to deforestation, afforestation of degraded and deforested lands, and promoting agroforestry systems are also actions that mitigate GHG emissions. Below we summarize these options.

1.1.1. *Energy Sector*

Since 1989, Mexico has created institutions in charge of promoting energy efficiency, such as the National Commission for Energy Savings (CONAE), Electric Sectorïs Energy Saving Program (PAESE) and FIDE, which is a revolving-loan trust fund to save electricity (Friedmann and Sheinbaum, 1998). These institutions have developed several energy efficiency programs that are listed below.

Energy Efficiency Standards. Several standards are already in effect, including those for domestic refrigerators and coolers, room and central air conditioners, three phase electric motors, and non-residential lighting. According to CONAE, energy standards save 2000 GWh of electricity per year (CONAE, 1996).

DSM Programs. (a) Residential Lighting: In the residential sector, between 1989 and 1996 twelve projects to promote Compact Fluorescent Lamps (CFLs) in Mexican homes were implemented by the Comisión Federal de Electricidad (CFE, the main state-owned national utility). By September 1996 these projects were responsible for the adoption of about 1.2 million CFLs by Mexican homes and energy savings of 160 GWH/yr (Friedmann et al., 1993, 1995). (b) Incentives: The incentive program, started in early 1998, plans to achieve energy savings of 3,250 MWh in the year 2000 by promoting the introduction of efficient technologies for residential lighting, commercial lighting, industrial motors and compressors, and municipal pumping (FIDE, 1996). (c) Roof Insulation: Since 1991 CFE has been promoting insulation of the roofs of homes in northern Mexico by providing financing to homes using more than one MWh/month in the summer. Over seventy-five thousand homes in northern Mexico (mostly in Mexicali) have been insulated to reduce cooling loads, with electric savings of up to 35% reported (De Buen, 1993).

(d) Daylight Savings: Summer daylight savings time was carried out in 1996. Evaluations of its success claim a national savings of 0.7% of national electric consumption (1.3 Twh) and reduction of peak load of 500 MW (FIDE, 1997).

Industry. Specific work in this sector has included promoting the use of new high-efficiency burners, improving current systems and encouraging fuel switching. Additional programs include instrumentation and control of boilers and burners and the promotion of energy management systems. Work in the public sector includes strengthening the relationship with PEMEX and undertaking studies for heat recovery in rigs and platforms and the use of turbo compressors at terminal stations. Energy savings related to these programs are estimated in 480 GWh/yr (CONAE, 1995; FIDE, 1995a).

Buildings. Demonstration projects have been done in buildings, educational facilities, commercial malls, department stores, restaurants, hotels, self-service stores, hospitals, and other establishments. Savings obtained varied between 20 and 37%, with investments with a maximum payback of three years, and a total energy savings of 24 GWh/yr (FIDE, 1995b).

Cogeneration. As of 1994, Mexico has installed nearly 3 GW of industrial cogeneration, mostly in PEMEX refineries and petrochemicals. In recent years, the Regulatory Energy Commission has authorized nearly 20 permits of cogeneration which represent an installed capacity of around 600 MW. However, most of this installed cogeneration capacity was used exclusively for on-site energy demand due to some barriers related to power wheeling costs (Sheinbaum et al., 1997–1998).

Renewable Energy. (a) Rural Electrification: In 1994, a rural photovoltaic electrification program covered around 35,000 household small systems for communities that do not have access to the electricity grid (SE, 1997). (b) Solar Thermal Systems: There are a variety of applications of water heating solar systems working for commercial and household services that include one of the main public hospitals in Mexico City. (c) Wind Power Generation: The main wind power generation system is in the south-east of the country (La Venta-Oaxaca). It is connected to the national interconnected grid system with a power capacity of 1575 kW and a capacity factor of nearly 40%. There are plans to expand wind projects to reach a power capacity of 56 MW in year 2005 (CFE, 1997).

Fuel Switching. Most of the expansion in the electric power sector to the year 2005 will take place adding natural gas fired (combined cycle) power plants (9,500 MW from 1996 to 2005) instead of the traditional thermal (fuel-oil fired) power plants. Also, most of the industries in the regions with high local pollution indexes have switched from fuel oil to natural gas, especially in the main cities of the country.

1.1.2. *Forest Sector*

Mexico has 49 million ha of native forests, half of them are temperate and half tropical (Masera et al., 1997). In addition, there are 21 million ha classified as degraded forest lands. About 80% of total forest lands is socially owned by rural communities. Aproximately 95% of total timber harvesting is conducted in native forests, mainly on temperate forests (SEMARNAP, 1996). Several programs are in place to reduce deforestation and forest degradation in the country. The main actions that will result in a reduction in GHG emissions are:

Promotion of Sustainable Forestry in Native Forests. The Government plans to support the establishment of sustainable forest harvesting systems in more than 3 million ha of native tropical and temperate forests currently mismanaged by the year 2000. Most of these forests are socially owned by rural communities and currently unmanaged or have been managed using inadequate methods that have favored degradation and conversion to other land uses. Several incentives are in place that will help achieve the stated objectives, including a government program (PRODEFOR) that allocates between 9 million and 13 million dollars/yr (SEMARNAP, 1996). Through PRODEFOR a subsidy is given directly to forest owners (mostly rural communities and 'ejidos') to prepare integrated forest management plans for timber and non timber forest products, conduct forest inventories, improve the current timber and non-timber products harvesting systems, and build infrastructure to better protect the forests from fires and other natural hazards.

Commercial Plantations. Aproximately 25,000 ha of commercial plantations will be established by the year 2000. Most of these plantations are from fast growth species and will be devoted to cellulose production. A new recently approved legislation, places several constraints on the establishment of the plantations to assure that they will not cause major environmental and social disruptions (Alvarez-Icaza and Viveros, 1996). A subsidy of 30 million dollars/yr and several fiscal incentives are given to encourage the establishment of the plantations (SEMARNAP, 1996).

Agroforestry Systems. These systems combine the production of crops and trees in the same area for the purpose of obtaining both, agricultural and forest products. There are currently 0.86 million ha under shade agroforestry systems in Mexico (about 0.8 million ha with shade coffee and 0.06 million with cacao plantations) (Masera and Ordóñez, 1997). A large, but currently unknown area of fallow lands are also managed as agroforestry systems. Agroforestry systems offer a promising economic alternative, especially for tropical deciduous and tropical evergreen forests, to conversion of forests to pasture and agriculture. There are currently some large governmental programs planned for implementation in different tropical regions of Mexico. Specifically, in the humid tropics, the program 'Desarrollo Sustentable del Trópico Húmedo' plans to reduce the extent of slash and burn agriculture by intensifying corn production and by establishing soil conservation practices and by promoting different types of agroforestry systems.

Restoration Plantations (Afforestation). This option involves planting trees in both deforested and degraded lands. The objective is to regenerate vegetation, recovering degraded areas, protecting basins and reducing soil erosion. The afforested area has increased substantially during the last few years, but the results of these programs are still modest in the country (0.2 million ha). Government plans are for reforesting 200,000 ha per year from 1995 to the year 2000, for a total of 1 million ha in the period (SEMARNAP, 1996). However this area should be adjusted by the trees' survival rate (currently 34%) giving a net of 0.46 million ha by 2000.

Other Programs. Mexico has currently 111 Natural Protected Areas (NPAs) covering 11.9 million ha of tropical, temperate and semi-arid forests. Financial resources are not sufficient to protect adequately all the areas and the government has decided to give priority to the 10 most important NPAs. Two programs directed to slow the rate of conversion of forests to other land uses are: the UMAS and the Program for the Defense of the Forest Frontier (PDFS in Spanish). The former gives incentives to individuals or organizations to manage the fauna and vegetation for conservation purposes; it is currently applied in 7 million ha of semi-arid, temperate and tropical forests (Gobierno de Mexico, 1999). It is a voluntary agreement between land owners and the government. The PDFS is a program that incentives owners of land with marginal crop and pasture productivity to re-convert them to forests. The program covers currently 20,000 ha/yr. A recently approved program, PROLEÑA, will devote funds to encourage the sustainable use of fuelwood in the countryside, which currently accounts for 78% of total wood demand in Mexico (Gobierno de Mexico, 1999).

2. Methodology

There are a variety of methodologies to analyze the costs and feasibility of limiting GHG emissions at a national level, including a number of software packages that make forecasts in the energy sector and the forest sector (EAP, 1995). Most energy packages afford a comprehensive analysis of the energy system, as well as its relationship with other sectors of the economy. However, there are some disadvantages with pre-programmed packages. These are related to: (a) little control on the actual computational procedure, (b) the users depend on the packages programmers for any modification, (c) the form in which the data has to be entered may not coincide with that in which information is available, so that a certain amount of exogenous data-processing has to be completed before the package can be used, and (d) most packages impose major constraints in the planning process (Reddy, 1995).

There are also models that undertake an assessment of the role of the forestry and other land uses in a country's climate change mitigation effort. This is the case of COMAP (Sathaye et al., 1995) and CO-PATH (Makundi et al., 1995). However there are few efforts to combine energy and non-energy sectors in one model that allows evaluating and comparing the mitigation potential and costs of alternative options in both sectors. In this context, we developed a simulation bottom-up accounting model that integrates the energy and forest sectors for Mexico.

2.1. GHG MITIGATION MODEL FOR MEXICO

The model has three basic sections, which allows conducting estimates both for the base year and projected scenarios:

(a) Simulation of the Mexican energy system (end-use oriented) and its associated GHG emissions;
(b) Simulation of forestry options emissions and carbon sequestration,
(c) Financial module: estimation of CO_2 mitigation costs and incremental cost curve.

2.1.1. *Simulation of the Energy Sector: Mexican Energy-Emission Scenario Model (MEESM)*

The purpose of the MEESM is a simulation of the energy consumption and related GHG emissions through a bottom-up conception of the relations among energy services, technologies, transformation, and energy supply. This model has its origins on the STAIR model developed at the Lawrence Berkeley National Laboratory (Ketoff and Sathaye, 1991). In addition to the STAIR, the MEESM includes transformation, supply energy technologies and mitigation costs.

The MEESM has been utilized for several projections. The most important are the analysis of energy technology mitigation options for the Support National Action Plan for Mexico, revised by the National Institute of Ecology and USAID (Sheinbaum, 1997a), and estimations for the Mexican Ministry of Energy (Sheinbaum et al., 1999).

The MEESM is divided in four modules: energy demand, transformation, energy supply, and GHG emissions. The model evaluates the energy supply activities and links them with the end use sector activities through demand balance equations. As an end-use oriented model the energy supply requirements are determined from energy demand activities. The demand component considers seven sectors: agriculture, residential, commercial, services, industrial, transport and the energy sector. For each energy end-use sector an indicator of aggregate sector activity is defined. Depending on the sector, the activity parameters for energy demand are GDP growth, GDP structure, urban and rural dwellings, population, passenger-km and tonne-km. Projections are based on official data on the stated parameters. To each specific activity corresponds a measure of energy intensity, or energy use per unit of specific activity.

In formal terms, let A_{it} represent the aggregate activity level in sector i in year t; S_{ijtk} $(j = 1, 2, n;\ k = 1, 2, \ldots, m)$ represent the level of specific activity j per unit of aggregate activity, per unit of energy source k; and I_{jkt} represents the energy intensity of specific activity j of energy source k. Therefore the energy use of sector i in year t and fuel k is:

$$E_{it} = A_{it} \sum_{j=1}^{n} \sum_{k=1}^{m} S_{ijkt} I_{ijkt} \,. \tag{1}$$

And total energy demand in year t (ET_t), is the sum of the energy demand of the different sectors i ($i = 1, 2, \ldots, s$)

$$ET_t = \sum_{i=1}^{s} E_{it} \,. \tag{2}$$

The disaggregation of energy demand depends on the data availability. In the agricultural sector, unit consumption is considered as energy use per commercial value added, while the residential sector accounts unit consumption as energy use per dwelling for specific end use. In the services sector, according to the National Energy Balances, the model considers electricity use for public lighting and water pumping and unit consumption is calculated as electricity use per capita. In the industrial sector the model considers eight energy intensive industries, in which unit consumption is evaluated as energy use per physical production (GJ/tonnes). The rest of the industrial branches are treated as ‘other industries’ of which unit consumption is presented as energy use per value added. The energy sector considers energy consumption (different for energy production) by the main utilities: the stated owned petroleum industry (PEMEX) and the two main stated-owned power utilities (Comisión Federal de Electricidad-CFE and Luz y Fuerza del Centro-LyFC) and energy intensity is evaluated as energy use per sector value added. In the transportation sector, the model divides energy use into passenger and freight transport. Unit consumption is contemplated as energy use per passenger-kilometer and tonne-kilometer.

In the transformation module, the model incorporates oil refining, power plants and energy distribution. In the case of refining, the process is simulated as one big process of refinery due to lack of available costs data per refining plant. In the case of power plants, 15 options are included based on primary energy supply as well as technologies (e.g., combined cycle with gas and diesel, turbogas with gas and diesel, geothermal, etc.).

The supply component includes petroleum production and exportation, natural gas production and importation, coal production and importation, biomass, nuclear, geothermal and hydroelectricity. Each of the supply options includes different investment requirements and production costs.

Once the simulation of the energy system is modeled, the MEESM incorporates GHG emissions for each of the demand, transformation and supply activities. Electricity emissions are considered from the total electricity production and not for each end use. For the sake of simplicity, in this paper we limit the results to CO_2 emissions only. In formal terms, CO_2 emissions are calculated as:

$$\mathrm{CO}_2 = \sum_{i=1}^{s} \sum_{j=1}^{m} E_{ij} C_j \,. \tag{3}$$

The emission indexes associated to each activity are taken form national data sources in the case of the transportations sector. For all other activities, the emission indexes data sources are from IPCC.

2.1.2. *Simulation of the Forest Sector*

The forest sector is simulated using a demand – or end use – approach. First, the needs for forest products are determined, according to basic economic and demographic parameters. Separate estimates are made for timber, pulp and paper, and fuelwood. Trade for forest products is also allowed. The area required to cover the domestic plus export forest product needs is estimated according to the forest productivity associated with different management strategies (i.e., industrial plantations, selective cutting of native forests). The required area for restoration plantations is estimated using the expected plantation rates adjusted by the survival rates of the trees. The model covers a total of 9 generic mitigation options, divided into two main categories: forest conservation and afforestation (refer to Masera (1995), for a detailed description of the model). Estimates of forest loss and deforestation rates for the major forest types are also included in the model. In this paper, we examine in detail three options: sustainable management of native forests as an alternative to deforestation, restoration plantations, and agroforestry systems.

At this stage, only the carbon dioxide implications are estimated. The total carbon sequestered in the forest sector (St) is estimated as:

$$St = \sum Cnet_i * A_{it} , \tag{4}$$

where $Cnet_i$ is the average long-term unit net carbon mitigated (either sequestered or by avoiding emissions) (see below) and A_{it} the total area by mitigation option i at time t. *Cnet* represents the difference in the average total carbon sequestration between the proposed mitigation option and the alternative use of the land had the option not been put in place (e.g., agriculture, pasture). *Cnet* is estimated through a full carbon accounting, which includes estimation of carbon stored in vegetation (above and below ground), in decomposing matter, soils, wood products, and the carbon saved by burning wood for energy instead of fossil fuels. When appropriate, carbon accounting also represents the average over whole rotation cycles (i.e., planting, harvesting, forest regrowth). Long term averages are used because the different carbon pools increase and decrease over the rotation age (for example, in a plantation project, carbon stored in vegetation increases steadily during the rotation age, decreases abruptly with harvesting, and goes up again as trees are replanted).

The carbon sequestration is annualized, estimating the annual carbon balance (*Cbti*) for each mitigation option. *Cbti* represents the net carbon mitigation associated with each forestry option occurring at any given year, and is given in (tonC/yr). When deforestation occurs, only a fraction of total emissions occur in the base year (called ‘prompt’ emissions), while the rest is being emitted gradually through decomposition (called ‘delayed emissions’) (Makundi et al., 1992). In afforestation options a gradual buildup of carbon also occurs through time. In the calculation of *Cbti,* for forest convervation options, we thus include both the avoided prompt emissions from avoided deforestation in the selected year plus the avoided inherited emissions coming from historic deforestation (that is, emissions that would have occurred in the selected year because of decomposition of woody biomass produced by past deforestation). For options involving the increase in the forest area, we estimate *Cbti* as the net annual carbon uptake for all vegetation growing in the selected year. The annual carbon balance is similar to the land use change and forestry emissions estimated using the IPCC guidelines for national greenhouse gas inventories (IPCC, 1995). The annual carbon balance of the forest sector (*Cbt*) at year t is then the sum of the carbon balance associated to each mitigation option i:

$$Cbt = \sum Cbti\,. \tag{5}$$

2.1.3. *Mitigation Costs*

The costs calculated in the model include investment, operation and maintenance costs needed to achieve the energy and forest services for targetted years. In comparison to previous studies (Sheinbaum, 1997a; Sheinbaum et al., 1997, 1998), in this case fuel costs are considered. Projections of fuel prices are estimated from DOE (1998) and SE (1998).

The concept of levelised costs (*LC*) is recommended as a standard for the comparison of each flow which occurs at different points in time (UNEP, 1994). 'Levelisation' involves calculating a stream of equal cash flows whose net present value is equal to that of a given stream of variable cash flows (UNEP, 1994). Under this method,

$$LC_i = NPV_i * d/[1 - (1 + d)^{-n}]\,, \tag{6}$$

where LC_i is the levelized cost and NPV_i the net present value, calculated over the period from the first year of operation of the investment to the end of the scenario period (n years) for each mitigation option i, and d is the discount rate. For this exercise, we selected the discount rate used in official projections (9% in real terms, CFE 1994). The discount rate is assumed to be the same for all technology options.

The total abatement costs by mitigation option i 'TAC_i' is defined as:

$$TAC_i = [LC_{mi} - LC_{bl}]/[\mathrm{CO}_{2_{bl}} - \mathrm{CO}_{2_{mi}}]\,, \tag{7}$$

where $[LC_{mi} - LC_{bl}]$ is the difference in levelized costs between the cost of adding mitigation option i (LC_{mi}), and the cost of the baseline (LC_{bl}), and $[\mathrm{CO}_{2_{bl}} - \mathrm{CO}_{2_m}]$ is the total avoided emissions reached by adding option i to the reference scenario.

With the above results in hand, the model combines the different options in order to obtain the least cost 'path' of each carbon mitigation scenario. These results can be presented graphically in a figure that shows, for each scenario, the cumulative greenhouse gas emissions avoided (or sequestered) and the incremental costs of adding the mitigation options one by one. These curves, which are standard in engineering-economic studies of the mitigation potential of energy technologies (Krause, 1996), in our case allow determining the cheapest mix of energy

TABLE I
GDP and population growth projections (annual rate of growth)

	1990–1991	1991–1992	1992–1993	1993–1994	1995–2000	2000–2005	2005–2010
Population	1.97	1.93	1.87	1.82	1.60	1.34	1.14
GDP	3.63%	2.81%	0.68%	3.54%	4.00%	4.50%	4.50%

and forestry options that will meet the requirements for future GHG mitigation scenarios.

2.1.4. *Baseline and Mitigation Scenario*

In the energy sector, the baseline scenario assumes medium economic GDP growth, official projections for population growth (Table I; CONAPO, 1998), frozen intensities at its 1994 level, no fuel substitution, and new installed capacity for the power sector based on fuel oil plants. In the forestry sector, the baseline scenario assumes constant net deforestation rates in each of the four major forest types (as percentage of remaining forest area), that is deforestation minus afforestation. For comparative purposes CO_2 emissions are calculated for different GDP scenarios (low, medium and high economic growth).

The mitigation scenario considers specific rates of penetration of mitigation technologies by sector. Only a limited set of options were analyzed, thus the results presented should not be viewed as the total or maximum potential carbon mitigation for Mexico. This is particularly true for the energy sector, where data availability restrictions did not allow us to conduct an in-depth analysis of the transport sector. Table II shows the main assumptions for each scenario.

3. Results

3.1. BASELINE SCENARIO

Table III presents CO_2 emissions for different GDP growth scenarios for the year 2010. As shown, the total growth of CO_2 emissions between 1990 and 2010 varied from 55% to 85%. The baseline scenario considers the medium GDP growth.

Table IV shows the detailed projections of carbon emissions between 1994 and 1995 and the year 2010 for the baseline scenario divided into energy and forestry emissions. Total emissions reach 879 Tg/yr of CO_2 by 2010. Energy emissions are expected to grow 149% in the 15-year-time period. A net loss of 10.4 million ha

TABLE II

Basic assumptions baseline and mitigation scenarios

Sector	Baseline scenario	Mitigation scenario
General	Medium GDP growth scenario (nearly 4%/yr)	GDP and population growth as baseline scenario
	Reduction of population growth from 1.6% in 1995 to 1.1% in 2010	
	Frozen energy intensities at their 1994 value	Combined cycle plants based on natural gas as the dominant addition in installed capacity within the power sector
Energy	Fuel oil thermoelectric plants as the dominant addition in installed capacity within the power sector	Different penetration scenarios for the following mitigation alternatives: Industrial motors, commercial efficient lighting, efficient water pumping, public transportation in the MCMA, residential efficient lighting, industrial efficient boilers, metro increase coverage in the MCMA, wind power generation, industrial cogeneration
Forestry	Net deforestation rate – deforestation minus afforestation – at 1.5%/yr (early 1990s) levels from 1995 to 2010	361 Kha ha/yr of deforestation avoided by sustainable management of native forests in 2010
	Total deforested area reaches 10.4 million ha between 1995 and 2010	1.3 million ha under restoration plantations by 2010
		200 Kha under agroforestry systems by 2010

(20% of the existing forest area) of forests is expected in the baseline scenario. Because the net deforestation rate is considered to be proportional to the remaining forested area, the annual area deforested decline in the future; as a result, annual carbon emissions from forestry would decline 33% between 1995 and 2010.

TABLE III

CO_2 emissions for different GDP growth scenarios

Annual GDP growth (1990–2010)	2010 Tg of CO_2	Growth 1990–2010 (%)
Low (2.5%)	805.6	55%
Medium (4.5%)[a]	**878.9**	**69%**
High (6.0%)	960.3	85%

[a] Projection chosen as the baseline scenario.

TABLE IV

Energy and forestry emissions for the baseline scenario (Tg of CO_2)

	1990	1995	2000	2005	2010
Energy	292.1	333.4	397.9	546.3	726.0
Forestry	228.9	206.7	186.6	168.9	152.9
Total	520.0	540.1	584.5	715.2	878.9

3.2. MITIGATION SCENARIO

3.2.1. *Energy Sector*

The mitigation options related to energy use are: combined cycle plants, industrial efficient electric motors, industrial efficient boilers, industrial cogeneration, commercial and residential efficient lighting, efficient potable water pumping, passenger transportation in the Mexico City Metropolitan Area (MCMA) – inter-modal susbstitution (buses and metro) – and wind power generation.

Combined Cycle Plants. Assumes that the new installed capacity needed to fulfill the electricity demand will be based on natural gas combined cycle plants instead of fuel oil thermoelectric plants. For the year 2010, the required installed capacity will reach 51,464 MW, of which 43% will be combined cycle plants.

Industrial Efficient Motors. Assumes that all the motors sold from 1999 to 2010 will be high efficiency ones. Substitution is considered for motors between 5 and 125 hp, with energy savings of 15% per motor. This substitution implies cumulative energy savings of 754 GWh by the year 2010 (Rodríguez, 1997).

Industrial Cogeneration. Assumes that all new plants will use cogeneration in their industrial process. Energy needs are calculated assuming that the exhaust heat of a gas turbine will satisfy the thermal necessities of the industrial process. Under these conditions the cogeneration system will supply more power than what is needed for the industrial process. The cogeneration potential for new plants reaches 8664.3 MW for the year 2010 (Sheinbaum, 1997b).

Industrial Boilers. According to SELMEC (1994), 10,000 boilers are installed in the Mexican industrial sector with capacities between 10 and 2200 hp. Mitigation scenarios assume fuel switching (from diesel and fuel oil to natural gas), insulation and burners substitution for 20% of all industrial boilers in the year 2010 (Aguillón, 1997).

Efficient Lighting in Commercial Sector. Assumes that 5 million lighting arrangements will be installed in the year 2010 due to the expected increases in the electricity prices and the decrease in the costs of efficient lighting technology (Sheinbaum and Vázquez, 1997).

Compact Fluorescent Lamps (CFLs) in the Residential Sector. FIDE's incentive program estimates that 9.6 million lamps out of a stock of more than 150 millions of lamps will be replaced by CFLs in the year 2010. Our scenario assumes that for each lamp contemplated in the incentive program, another one will be installed, giving energy savings of 500 GWh in the year 2010 (Sheinbaum and Vázquez, 1997).

Efficient Water Pumping. It is estimated that corrective and maintenance measures can save approximately 35% of the national water pumping electricity consumption. Carmona (1997) estimates an energy savings potential for water pumping in 917.8 GWh per year, equivalent to an installed capacity of 106.2 MW (Carmona, 1997).

Inter-Modal Substitution in the MCMA. Substitution of small buses by large diesel buses and the increase of electric mass metro and ligh train lines are considered the most viable mitigation technologies for the MCMA. The mitigation scenario considers the substitution of 60,000 gasoline microbuses by 30,000 diesel buses and an increase of the metro and electric light train coverage (Dartois, 1997).

Large Scale Wind Electricity Generation. Based on different studies of the wind power generation potential for Mexico we assume that 5000 MW of large wind power plants will be installed in the country by the year 2010. Considering a capacity factor of 0.3, the generation capacity of these plants will be 1,314 GWh for each plant of 500 MW of installed capacity (Caldera, 1997).

3.2.2. *Forest Sector*

Three forestry mitigation options were analyzed in detail: management of native forests as an alternative to avoid deforestation, afforestation for forest restoration, and agroforestry systems.

Management of Native Forests. The sustainable management of native forests is one of the best Mexican options to avoid carbon dioxide emissions resulting from forest degradation and deforestation, offering simultaneously an important alternative to create local employment opportunities, increase wood and non wood production and conserve soil and biodiversity. As stated in the previous section, currently about 95% of all timber harvesting occur in native forests, wich are mostly socially owned by 10 million people grouped in several thousand communities and ejidos. Therefore, encouraging a sustainable management of native forests offers significant social and environmental benefits.

The area under native forest management used for the carbon mitigation scenario is estimated based on the expected deforestation rates, and adjusted by the area to be converted to improved management systems, according to the demand of wood products for year 2010 (based on population and economic growth) and reaches 4.4 million ha. Long-term unit carbon sequestration ranges between 618 and 763 t of CO_2/ha for temperate and tropical forests, respectively.

In estimating the annual carbon balance for this option, we assume that 40% of total avoided emissions occur in the same year – through biomass burning and soil disturbances – and 60% decay linearly over a 10-year-period. These assumptions are consistent with previous estimates on the subject (Masera et al., 1995). Because we are interested in examining the future effect of mitigation options that have been established since 1994–1995, in the base year we only account for prompt emissions – that is we do not track any emissions coming from past deforestation. In subsequent years, avoided emissions are the sum of prompt emissions occurring at each time period plus the sum of delayed emissions coming from the past – up to the base year or the decomposition period, whichever occurs first. The annual carbon balance grows from 47 Tg CO_2/yr in the year 2000 to 203 Tg CO_2/yr in 2010, 69% comes from temperate forests.

Afforestation. The scenario analyzed the planting of trees in both deforested and degraded lands. The penetration of the afforested areas is estimated considering governmental policies and goals for the year 2000, extrapolated to 2010 and corrected by the efficiency (living trees/planted trees) of reforestation and reaches 1.3 million ha. Unit carbon sequestration averages 476 t of CO_2/ha. For the annual carbon balance, we assume a linear unit carbon uptake of 9.5 t CO_2 over a period of 50 years. We then calculate the total area under tree growing as the cumulative forest area planted from the base year until any given year. The carbon balance is simply the unit carbon sequestration times the area of growing trees. Because our projection is less than 50 yr, the annual carbon balance for this option shows a steady increase from 2.8 Tg CO_2/yr in 2000 to 12.1 Tg CO_2/yr in 2010.

Agroforestry. The scenario analyzed different systems that combine trees and crops for the purpose of producing both agricultural and forest products. We assume a conservative figure of additional 0.2 million ha under these systems by the year 2010. Unit carbon sequestration has large variations depending on the particular system, but usually ranges between 73 and 440 t of CO_2/ha. The procedure used for estimating the carbon balance is similar to afforestation, but in this case we use a rotation period of 25 years. The annual carbon balance increases from 1.0 Tg CO_2/yr in 2000 to 2.0 Tg CO_2/yr in the year 2010.

Table V summarizes the avoided CO_2 emissions from energy and forestry options together – for the latter we use the annual carbon balance. The total mitigation

TABLE V

Avoided emissions of CO_2 in the mitigation scenario (Tg of CO_2

Mitigation option	2000	2005	2010
Combined cycle plants	13.9	21.2	70.0
Residential lighting	0.7	1.6	2.5
Commercial lighting	0.5	0.8	1.2
Water pumping	1	1.1	1.2
Industrial motors	0.2	0.6	0.9
Industrial boilers	1	1.8	2.7
Buses in the MCMA	1.2	1.1	1.0
Industrial cogeneration	0.4	17.9	35.4
Wind power	1	6.6	12.2
Metro in the MCMA	0	2.0	4.0
Total energy	19.9	54.7	131.2
Forest management (temperate)	33.3	74.7	141.1
Forest management (tropical)	13.2	31.4	62.0
Restoration plantations	2.8	8.0	12.0
Agroforestry	1.0	1.6	2.0
Total forestry	50.3	115.7	217.1
Total	70.2	170.4	348.3

potential for the options examined reaches 131.2 Tg of CO_2/yr in the energy sector and 217.1 Tg of CO_2/yr in the forest sector by 2010 (Figure 1).

3.3. MITIGATION COSTS

3.3.1. *Total Abatement Costs by Mitigation Option*

Table VI shows total abatement costs by mitigation option for the year 2010. Negative values mean that the levelised costs of the mitigation option is less expensive for the country than the baseline scenario, considering annual investment and maintenance costs in energy consumption, transformation and production, as well as actual management costs in forestry, including the benefits from timber extraction and other wood products and the opportunity costs of alternative land uses.

Unit annual costs range from \$–45.9/ton CO_2 for residential lighting to \$106.4 for industrial motors. The average costs for forestry options range from \$—3.5/ton

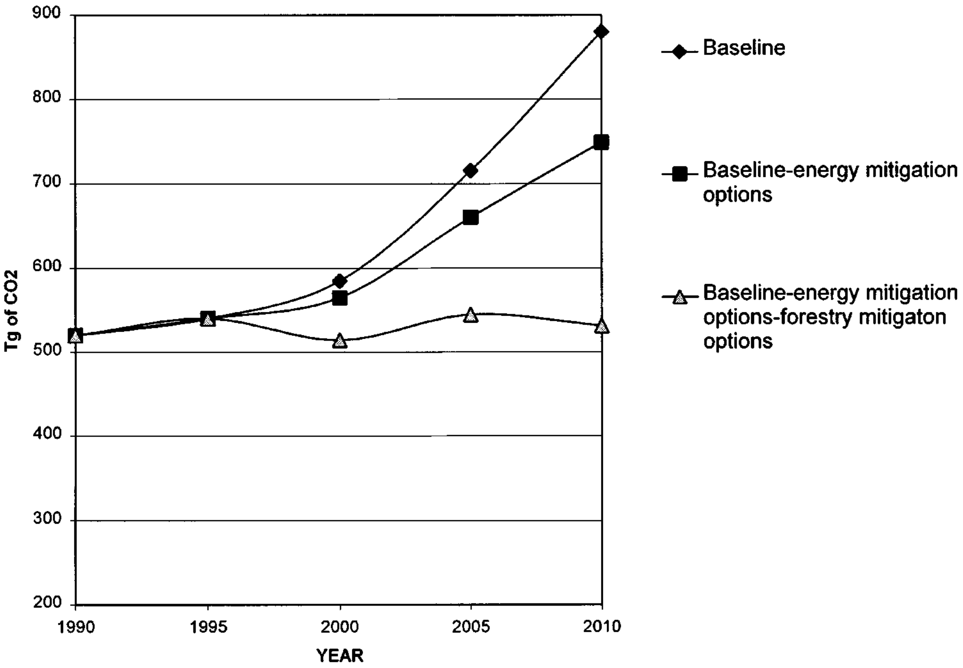

Figure 1. CO_2 emissions for baseline and mitigation scenarios.

CO_2 to \$5.4/ton CO_2, depending on the option. The mitigation options that resulted in higher costs than the baseline scenario are forest management in the tropical areas, restoration plantations, agroforestry systems, metro and light train in the MCMA, and efficient industrial motors. It should be noted that even cost-effective options, such as efficient lighting or, very specifically, the sustainable management of native temperate forests, usually require substantially higher investment costs than conventional technologies. Also, specifically in the case of forestry options, costs are extremely site dependent, thus the average values presented here might be much higher or lower for specific projects.

3.3.2. *Cost Abatement Curves*

Figure 2 shows the CO_2 abatement cost curve for the mitigation options for energy and forestry options combined. In the figure we present the incremental cost of adding options one by one, comparing them with the baseline case. As stated before, the figures for the management of native forests are rough averages; more detailed analysis will allow disaggregating the curve in several ‘steps’, according to site productivity, feasible area, etc. It is clear that the savings brought by cost-effective mitigation options help reduce substantially the net costs of undertaking the scenario. One of the most salient results of the financial analysis is that the mitigation scenario can be achieved at almost no net additional cost compared with the reference scenario.

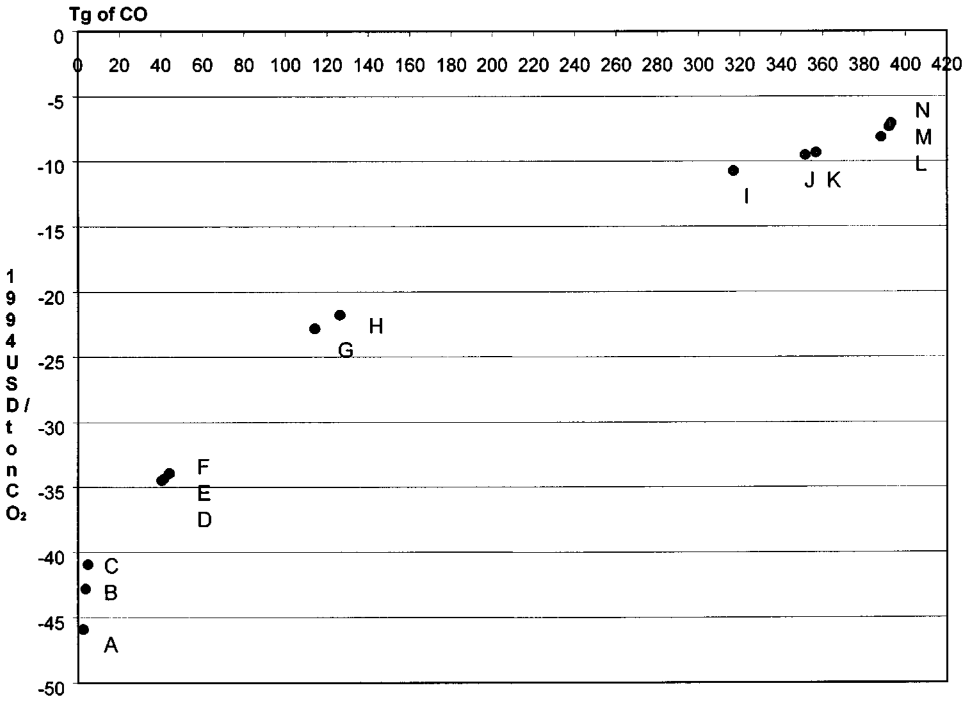

Figure 2. Incremental cost curve (energy and forestry mitigation scenarios for year 2010).

Data for the incremental cost curve

Mitigation option		Cumulative abatement costs 1994 USD/ton of CO_2
A	Residential lighting	–45.9
B	Water pumping	–42.8
C	Commercial lighting	–40.9
D	Industrial cogeneration	–34.5
E	Buses in the MCMA	–34.3
F	Industrial boilers	–33.9
G	Combined cycle plants	–22.8
H	Wind power	–21.8
I	Forest management (temperate)	–10.7
J	Forest management (tropical)	–9.5
K	Agroforestry	–9.3
L	Tropical	–8.1
M	Metro in the MCMA	–7.3
N	Industrial motors	–7.1

TABLE VI

Total abatement costs (1994 USD/tonne of CO_2) (difference between each mitigation option and the baseline scenario for the year 2010)

Mitigation option	Costs
Residential lighting	–45.9
Water pumping	–36.4
Commercial lighting	–35.0
Industrial cogeneration	–33.6
Buses in the MCMA	–29.2
Industrial boilers	–27.3
Combined cycle plants	–15.8
Wind power	–11.9
Forest management (temperate)	–3.5
Forest management (tropical)	1.6
Agroforestry	4.4
Restoration plantations	5.4
Metro in the MCMA	70.5
Industrial motors	106.4

4. Discussion

Through a detailed analysis of promising forestry and energy options we have identified a mitigation potential of 348.3 Tg of CO_2 for Mexico by the year 2010. If this potential were realized, Mexico would increase its total emissions by only 2% from 1990 to 2010 instead of increasing them by 69% (baseline scenario). Per capita emissions would drop by 30% in the same period of time (from 6.2 to 4.7 ton of CO_2/cap), instead of increase them by 26%. It should be noted that the analysis presented does not include the full range of mitigation options available to the country. Specifically, within the energy options, those belonging to the transportation sector, which is currently the largest source of CO_2 emissions in the country, have been addressed only partially. Further research needs to be conducted in order to quantify accurately the potential associated with other promising energy and forestry options.

Forestry options, particularly through the sustainable management of native forests as an alternative to deforestation, show the largest carbon mitigation potential in the short term. This potential is the combination of several factors. As discussed in section 1, the government is now giving strong emphasis to the conservation of existing forests and to the restoration of degraded areas – which currently account for approximately half of total closed forests (SARH, 1994). While financial resources for these programs are still well below those needed for effective implementation at the local level, at least there is a better institutional and regulatory framework in which to work for the advancement of mitigation options. The expected future increase in food demand can be largely accommodated by increasing the productivity of existing agricultural areas. Mexico has an extensive experience with community forestry (80% of total forest land is socially owned by communities in Mexico), with approximately 0.5 million ha of native forests under sustainable management (Sheinbaum and Masera, 1997). Forestry projects specifically aimed at carbon sequestration are already operating successfully (SCOLEL TE, 1997; Montoya et al., 1995) or are only waiting for the final approval of financial resources (UZACHI-IXETO, 1997).

It should be noted, however, that forestry options are ultimately limited by available area, and unless effective actions are taken in the energy sector, emissions will eventually continue to grow at a rapid pace (see Figure 1). While resulting in less carbon emission reductions in the short term, given Mexico’s strong dependence on relatively cheap oil resources, several energy options (like CFLs) are extremely cost effective. In this case, a consistent and strategic effort is needed that at the present time begins to assure that efficient technologies and renewable resources make a substantial penetration beyond 2010. As with forestry options, several carbon mitigation initiatives are already in place in the country. The ILUMEX case study, which avoids carbon emissions through the promotion of compact fluorescent lamps in the residential sector, has been highly successful and cited at the international level (De Buen and Masera, 1994).

5. Conclusions

By properly implementing a series of promising mitigation options in the energy and forest sector, Mexico has the opportunity to significantly advance national development priorities for the period 1995–2010, while keeping its per capita carbon emissions at a low level and having a very modest increase in total emissions. Therefore, in principle, there should be no contradiction between the local and global interests.

The mitigation options that result in gains in energy efficiency analyzed in this paper represent a small percentage of total avoided emissions. However, most of these options resulted cost effective, which provides an opportunity for the country to utilize the ‘saved’ economic resources obtained by energy efficiency and to develop mitigation options with larger potential such as renewable energy and forestry. On the other hand, the large amount of carbon that could be potentially captured by forestry options brings Mexico the opportunity to gain time for the development of a renewable energy path.

However, the mitigation potential identified will not be reached automatically. Strong, consistent, and durable efforts at the local, national, and global levels are needed. Locally there is the need to support activities, such as those identified in this paper, where climate change benefits are a byproduct of concrete economic, social, and environmental benefits. Achieving this objective involves an integrated strategy that combines institutional, financial and technical aspects. One of the main barriers to overcome is the increase in investment costs associated with carbon mitigation options. This is true for both energy and forestry options and even for those alternatives that result cost effective on a life-cycle basis, but require higher initial investment (e.g., cogeneration, sustainable management of native temperate forests). Innovative schemes are needed to reduce up-front costs so that users can afford to invest in GHG mitigation alternatives.

At the national level, the Government needs to be consistent in the type of cross-sectoral policies promoted. For example, directly or indirectly subsidizing cattle ranching or commercial agriculture while simultaneously promoting sustainable forestry is a contradiction. Energy and land use policies should also address long-term concerns, as opposed to the current six-year planning horizon. Finally, there should also be a clear commitment to reduce present inequities in resource allocation across social groups and to keep the role of state investment in strategic areas.

Internationally, industrialized countries need to acknowledge their dominant present and historical responsibility in the buildup of greenhouse gases in the atmosphere by increasing the transfer of funds and technology to the South. These funds, channeled for example through the CDM, could play a critical role in removing the ‘investment’ barrier associated with several energy and forestry mitigation options. Appropriately managed, new funds and better access to technology could also catalyze the ‘leap-frog’ from obsolete technology to state of the art systems. These actions should be accompanied by a much larger effort in capacity and institution building related to climate change. In this particular aspect, facilitating the resources for an increased South-South collaboration should be one of the key objectives.

To be successful, these transfers should be accompanied by a removal of the incentives brought about by the opening of the global economy favoring opportunistic, short-term behavior over conservation of natural resources. In this sense, the CDM must take into account the long-term national priorities in terms of environment and development, rather than provide incentives for opportunistic, short-term, behavior. For example, ‘social forestry’ enterprises in Mexico, which make significant investments to manage their forests in a sustainable way, are forced to compete with large timber enterprises from the United States and other countries that have lower costs partly because of lower social or environmental standards.

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