CARBON EMISSIONS FROM MEXICAN FORESTS: CURRENT SITUATION AND LONG-TERM SCENARIOS

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Abstract. Estimates of carbon emissions from the forest sector in Mexico are derived for the year 1985 and for two contrasting scenarios in 2025. The analysis covers both tropical and temperate closed forests. In the mid-1980s, approximately 804,000 ha/year of closed forests suffered major perturbations, of which 668,000 ha was deforestation. Seventy-five percent of total deforestation is concentrated in tropical forests. The resulting annual carbon balance from land-use change is estimated at 67.0×10^6 tons/year, which lead to net emissions of 52.3×10^6 tons/year accounting for the carbon uptake in restoration plantations and degraded forest lands. This last figure represents approximately 40% of the country's estimated annual total carbon emissions for 1985–1987. The annual carbon balance from the forest sector in 2025 is expected to decline to 28.0×10^6 t in the reference scenario and to become negative (i.e., a carbon sink), 62.0×10^6 t in the policy scenario. A number of policy changes are identified that would help achieve the carbon sequestration potential identified in this last scenario.

1. Introduction

Deforestation and logging of primary forests constitute a major source of global carbon emissions to the atmosphere (Houghton, 1990; IPCC, 1992). Estimates for the late-1980s suggest that from 0.6 to 3.6 metric gigatons of carbon (Gt C=10^9 t C), or about 11% to 39% of total CO_2 emissions from human origin, come from the forest sector (Hao et al., 1990; Houghton, 1990; IPCC, 1992). A recent analysis by Dixon et al. (1994) calculates a best estimate of 1.4 Gt C of net emissions from deforestation (Dixon et al., 1994).

Most forest-related emissions are concentrated in developing countries.

While presently important net sources of greenhouse gas emissions to the atmosphere, forests hold the potential to become large carbon sinks, helping sequester from 1 to 3 Gt C/yr for about a century (Trexler and Haugen, 1993; Dixon et al., 1994).

The wide range of existing estimates of global carbon emissions from the forest sector reflects the difficulties in obtaining accurate information regarding deforestation rates, forest conversion activities, and the relevant carbon-related parameters of forests. In addition, there is not always complete consistency in the definitions of deforestation, forest types, and which forests are included in the deforestation figures.

Country estimates present the same or even larger problems. In the case of Mexico, the currently available estimates for carbon emissions from deforestation

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in the mid-1980s to early-1990s differ by a factor of five, ranging from 13.7×10^6 t C (WRI, 1994), 56×10^6 t C (Subak et al., 1993, cited in Cairns et al., 1995) to $64–71 \times 10^6$ t C (Cairns et al., 1995). Most of the variation stems from divergences in the estimates of deforestation rates, of the forest types included in calculations, and in the procedure used to estimate annual carbon emissions. Until recently, most attention was paid to assessing deforestation rates in Mexico's tropical evergreen forests (i.e., Myers, 1989), neglecting about 80% of Mexico's closed forest coverage which is tropical deciduous and temperate forest.

Detailed country studies on carbon emissions from the forest sector are therefore urgently needed in order to provide improved estimates which can serve to better assess global carbon emissions from deforestation. From a policy perspective, a more accurate determination of carbon emissions at the country level is an important step in the efforts towards the limitation of global emissions of greenhouse gases. The examination of future long-term emission and sequestration scenarios will also help in assessing the amount of potential carbon savings, as well as the possibilities and constraints for achieving those savings.

Forests provide key services to Mexico and to its local residents as sources of diverse wood and non-wood products for local consumption and trade, biodiversity, climate regulation, recreational sites, etc. 'Carbon storage' is only one and, at least for local peoples, not the most important function of forest resources. The analysis of potential carbon savings should thus take into account the multiplicity of possible uses for forest resources, making carbon-saving strategies the by-product (as opposed to the starting point) of more general strategies aimed at sustainable management of forest resources.

This article begins with a section on the study methodology. The second section shows the major ecological characteristics and a simplified classification of Mexican forests and briefly discusses the current situation of Mexico's forest sector. In the third section, deforestation rates are estimated within closed forests. Current estimates are reviewed and the leading factors of deforestation by type of forest are discussed. The fourth section is devoted to a detailed analysis of current carbon emissions from deforestation. The fifth section shows two contrasting scenarios for carbon emissions and sequestration from land-use change in the year 2025, and a comparison of carbon emissions from the forest sector with those from energy use and cement production. A discussion on different policy options for promoting the sustainable management of forest resources in Mexico concludes this article.

2. Methods

Carbon emissions from deforestation were estimated through an in-depth review of the existing information on Mexico's forest cover and deforestation rates for the decade of the 1980s as well as on carbon-related biological parameters of the forests. The methodology used is based mainly on the CO-PATH model (Makundi et al., 1991), although several additions and modifications were incorporated into the model. Also, we updated and improved earlier estimates (Masera et al., 1992) for current and future carbon emissions from land-use change using the stated model. We relied on local information – both from official sources and from case-studies – as extensively as possible, using estimates from other regions only when local data were not available. The study covers all closed forest types in the country.

Deforestation rates were estimated through a review of official statistics (Castillo et al., 1989; FAO, 1988, 1990; SARH, 1984 cited by FSV, 1990; SARH, 1990) and of detailed case studies (Caro, 1987, 1990; Cortez-Ortiz, 1990; Cuarón, 1991; De Ita et al., 1991; Dirzo and Garcia, 1991). Relatively accurate information was available only for tropical evergreen forests; for the remaining forest types, and especially for deciduous and broadleaf forests, only partial information was obtained. Available state-level data on forest perturbation rates (SARH, 1990) and five-year averages of forest fires by forest type (SARH, 1989) provided the basis for estimating deforestation rates. For tropical forests, adjustments were done using data from case studies and recent estimates from satellite images. No explicit account was taken for deforestation from energy projects (construction of dams and oil exploration/ extraction activities) and road construction. However, part of the deforestation caused by these activities is already implicit in the estimates derived from satellite images of tropical forests.

Detailed information on both carbon content of vegetation and soils only was available for tropical deciduous forests. For the remaining forest types, basal area, mean tree height and wood density were also taken from primary sources. Above-ground biomass inventories were calculated using Cannell's (1984) formula:

$$WT = F * H * G * D \tag{1}$$

where WT = total above-ground woody biomass per hectare of stems and branches, including bark, of forest of woodlands; F = volume factor; H = mean tree height; G = basal area at breast height; and D = mean basic wood density (dry weight/green volume).

Data on burning efficiencies and carbon releases both from vegetation and from soil disturbances were entirely drawn from the literature. Detailed case studies and personal experience in the field provided the basis to estimate the assumed 'permanent' composition of the deforested area in the reference year. Determining the long-term or 'permanent' composition of the deforested area (e.g., how much of the forest cleared will end up as pasture, will be devoted to annual or permanent agriculture, will undergo natural regeneration or will be eroded) is very difficult for two reasons: (i) available estimates on deforestation rates give only the amount of land deforested but do not indicate the conversion activity; and (ii) there is usually a sequence in the deforestation process: for example, the forest is first cleared for agriculture from which it turns into pasture; also in many cases, pasture cannot be sustained and erosion takes place; in temperate forests, areas cleared are often simply abandoned – in these cases, the extent to which they are able to regenerate or become completely eroded is also difficult to estimate.

For tropical evergreen forests, estimates of changes in land-use patterns from satellite images for two different years were used (Cuarón, 1991). Secondary vegetation, which accounts for an important share of the deforested area within tropical forests, was partitioned between pasture and agriculture; a small fraction was considered to remain as such over the long term. Based on recent findings (Masera et al., 1995) a first rough estimate of carbon uptake from vegetation regrowth in degraded forest lands is also provided. Because of the large uncertainties about and inconsistencies among some of the primary sources of information, values for carbon emissions should be taken as first estimates to be improved through more detailed studies. Readers are referred to the authors' research report (Masera et al., 1992) for a more detailed discussion of the study methodology.

Future carbon emissions from the forest sector were estimated using a business as usual or reference scenario and a carbon sequestration or policy scenario. In the reference scenario we assume that current deforestation rates (as percentage of area cleared) and the structure of carbon emissions by forest type will continue in the future. Accordingly, future net emissions may be estimated as (Masera, 1995):

$$C_t = \sum_{1}^{N} [c_i * D_i * e^{-d_i t} - S_i * R_i * t] \tag{2}$$

where C_t is the net carbon emissions at year 't', c_i the carbon emission intensity, D_i the forest area in the base year ($t = 0$) and d_i the assumed future deforestation rate, s_i the carbon uptake intensity (in t C/ha/yr), and R_i the area annually reforested, by forest type 'i'.

The policy scenario was designed through a careful examination of promising forest options to save carbon emissions from deforestation (i.e., options that would help conserve existing forests) and to increase carbon sequestration (i.e., options that involve afforesting the land). Total carbon sequestration by forest option is the product of its projected future area times its associated unit carbon sequestration. The future area by forest option was estimated using long-term projections for both traditional and commercial wood demand, plus assumptions about the plausible extent of future natural protected areas. The unit carbon sequestration estimates the net avoided emissions that would arise from stopping the conversion of existing forests to their most likely alternative use, or the net carbon uptake that would result from afforesting existing degraded forest or agriculture lands. Total net carbon sequestration by forest type is finally obtained by subtracting deforestation emissions from total carbon sequestration. High and low estimates of future carbon sequestration are derived, in order to account for uncertainties in soil and biomass carbon uptake. For brevity, only the average scenario values are presented in this paper. Refer to Masera (1995) for a more detailed discussion about the scenario assumptions and methodology.

Table I
Land-use patterns in Mexico

Land area (10^6 ha)	196.7
Closed forests	26.0%
Open forests[a]	33.6%
Degraded forest lands	11.0%
Agriculture and pasture	26.3%
Other uses	3.1%
Natural protected areas (10^6 ha)	5.7
Closed forests (10^6 ha)	51.1
Tropical evergreen	18.8%
Tropical deciduous	31.3%
Temperate coniferous	32.8%
Temperate broadleaf	17.1%

Source: Modified after Masera et al., 1992. The figures are approximate, given that large discrepancies exist among the different official sources about the exact magnitude of each forest type. Tropical forests include 6.8 million ha (Mha) of fragmented forests.
[a] Open forests include 28 Mha that are used as grazing lands for extensive cattle ranching in Northern Mexico. If these lands were included within Pasture, this last category would reach 27% of the total country area.

3. Mexico's Forest Sector

Mexico spans almost 2×10^6 km^2 and has a population of 81.1×10^6 (1990) with a 70/30 urban/rural split. The current population growth (2.1%/year) is mostly concentrated in the urban sector (INEGI, 1992) as the rural population has remained virtually constant since the 1970s.

There are several discrepancies among existing estimates of the distribution of the country area by land-use category in the 1980s (Castillo et al., 1989; Flores-Villela and Gerez, 1988; SARH, 1986; SPP, 1980; Toledo et al., 1989). Based on the best existing primary data, we estimate that, as of the mid-1980s, about 26.0% of Mexico's 196.7×10^6 ha of land was covered by closed forests (Table I). This estimate for closed forests is also very similar to that obtained in a remote sensing forest inventory conducted in Mexico in 1991 (SARH, 1991a).

Land devoted to livestock production, which has increased dramatically since the 1960s, already occupied over 27% of the total area of the country, including approximately 28 million ha of open forests that are used for extensive cattle ranching. In contrast, only 13.9% was used for agriculture (27.4×10^6 ha). The protected areas in the country amounted to 5.7×10^6 ha by the end of the 1980's. Of this total, about 5×10^6 ha were in relatively well-preserved areas. Thirty-four percent of all protected area is located in tropical evergreen forests, 2% in tropical deciduous forests, 7% in temperate forests, and the remainder in open forests

(in the last four years there has been a substantial increase in the protected area of open forests, primarily through the addition of two large reserves in Northern Mexico, Ordóñez and Flores-Villela, 1995). Additionally, there is a small area (0.7×10^6 ha), which is partly-to-largely altered, assigned as national parks, and a small (though not quantified) area of natural vegetation in good condition that is not formally protected.

3.1. ECOLOGICAL FEATURES

Mexico lies at the point where the holarctic and neotropical geographical regions converge. Mexico's location, together with its high climatic diversity, complex topography, and geological history, has resulted in a very rich and unique constellation of ecological situations within the national boundaries. It is estimated that approximately 10% of the world's biodiversity is concentrated in Mexico (Flores-Villela and Gerez, 1988). Mexico's forests show a very high proportion of endemism. These forests also represent a bank of germplasm for improving many agronomically important species (e.g., perennial maize), or for identifying new species with potential economic value as sources of drugs, biocides, timber, etc. (Dirzo and Raven, 1991).

We classified Mexican forests into five main forest types: tropical evergreen, tropical deciduous, temperate coniferous, temperate broadleaf, and open forests. The enormous altitudinal and climatological variability of Mexico makes Holdridge's life-zones classification difficult to apply (Holdridge, 1987). For this reason, Mexico has traditionally used its own local (national) systems in the past. In deriving our estimates we used the simplified system of Rzedowski (1978). The equivalence with Holdridge's system is as follows: Tropical evergreen (subtropical wet pre-montane, subtropical moist pre-montane moist); Tropical deciduous (subtropical dry pre-montane); Temperate broadleaf (subtropical pre-montane and low-montane, subtropical mountain wet); Temperate (subtropical montane dry); Open (subtropical desert, subtropical scrub desert, subtropical montane thorny).

Only the first four of the five forest types in our classification are incorporated into the analysis of carbon emissions. While open forests occupy a large fraction of the forested area, no reliable information exists on their deforestation rates. In addition, given their lower carbon content per hectare, the contribution of open forests to the country's carbon dioxide emissions from deforestation is small compared to that of closed forests.

Temperate forests comprise 50% of total closed forests. They are common at elevations above 1000 m and concentrate the highest diversity of *Pinus* (pine) and *Quercus* (oak) in the world (e.g., having more than 50 species of pines and 140 species of oak) (Rzedowski, 1991). *Coniferous forests* (16.9×10^6 ha) are dominated by *Pinus*, but also include *Abies*, *Cupressus*, and mixed *Pinus*-*Quercus* forests. Coniferous forests are located along the different mountain formations, at altitudes ranging from the lowlands to timberline. *Quercus* is the dominant genus in *broadleaf forests* (8.8×10^6 ha). These forests lie in the areas surrounding coniferous forests and are dominant at lower altitudes and/or in drier conditions. Aside from their importance in terms of biodiversity, these forests are crucial in the hydrological cycle and as sources of timber and fuelwood.

Tropical evergreen forests (9.7×10^6 ha) are concentrated at low elevations (< 1000 m) in the southern and southeastern areas of the country. In the present study they include both true evergreen (16.9% of the total tropical evergreen forests) and semi-evergreen tropical communities. Dominant species include *Brosimum alicastrum*, *Ceiba pentandra*, *Terminalia amazonia*, *Manilkara zapota*, and several *Leguminosae*. These forests include the largest number of woody species per unit area, which in turn determines the existence of a considerable diversity of other organisms (e.g., birds, mammals, insects). They are also important as potential new sources of economically useful resources.

Tropical deciduous forests (16.1×10^6 ha) are mostly located along the Pacific Coast, with patches in the Yucatan Peninsula and the Balsas watershed. Dominant species include *Bursera* spp., *Enterolobium cyclocarpum*, and several *Leguminosae*. They cover a wide range of ecological conditions in hot climates. A considerable portion of the open forest areas of Mexico are the result of the alteration and, sometimes, the eradication of tropical deciduous forests. In contrast to evergreen forests, tropical deciduous forests have received much less attention from the scientific community and management planners. Protected areas including deciduous forests are grossly under-represented, despite the fact that deforestation in absolute terms is the highest for tropical deciduous vegetation (see below).

3.2. THE FOREST SECTOR

Despite the country's large forest resources, the forest sector does not play an important role in the national economy (about 3% of the manufacturing GDP: CNIF, 1991) and is undergoing a severe crisis. While domestic demand for wood products has been constantly increasing, particularly during the last decade, the production of timber, and pulp and paper industries, decreased 24% and 32%, respectively, between 1985 to 1990. Imports have increased almost 90% since 1988, and there has been a reduction of 15% in the contribution of the forest sector to the GNP since 1987 (CNIF, 1992).

The total demand for wood products (production plus imports minus exports) is estimated in 47.6×10^6 m^3 for 1990. Fuelwood accounts for 78% of total demand, the rest being for industrial use (10.1×10^6 m^3). Fuelwood is extensively used in rural areas, where it is the most important source of energy for cooking and water heating (about 25×10^6 people still cook with fuelwood in the country) and is also burned in many rural industries (brick making, pottery kilns, etc.) (Masera, 1993). Sixty percent of industrial demand for wood products goes for timber and 40% for

Table II
Production and demand of forest products in Mexico in 1990 (10^6 m^3/year)

Product	Production	Exports	Imports	Total demand
Timber	5.7	0.7	1.0	6.0
Pulp	2.0	0.2	2.2	4.0
Fuelwood	37.9	0.3	$<$0.1	37.6
Commercial	0.4	0.3	$<$0.1	0.1
Rural[a]	37.5			37.5
Total	38.3	1.2	3.2	47.6
Industrial	8.1	1.2	3.2	10.1

Notes: From CNIF (1992) and Masera (1993). Not included in the estimates are demand for wood products for rural subsistence uses (fences, home construction, etc.) and clandestine logging (which may be large but is difficult to estimate).

pulp and paper (Table II). Imports supply more than 50% of the total demand for pulp and paper products (CNIF, 1991).

Commercial forest exploitation is concentrated on temperate forests (95% of total harvesting) and, within them, on coniferous forests. Harvesting by rural villagers for local consumption occurs in most forests in the country (Jardel, 1989). Only selective cutting is permitted within areas under management. Poor technical harvesting systems have led to very low productivity in managed forests (Jardel, 1989). Bellón et al. (1994) and Masera et al. (1995) provide a more detailed discussion of the characteristics and problems of the forest sector and of the current forest management systems used in Mexico.

The institutional framework of forest exploitation is very complex and largely responsible for the problems of the forest industry. Approximately 80% of the commercial forest lands are in *ejidos* (communal land grants) or are owned by local communities, and the remaining 20% is private property (Lara, 1992). The timber industry is, however, controlled by a few relatively large private enterprises. Traditionally, forest production has been structured as a supply source for industry and not as a development option for local communities. Government policies have contributed to the crisis in the forest sector through excessive and discretional regulation of all forestry activities, a lack of definition of property rights in forest lands, short-term contracts between industry and landowners, inadequate financing policies to promote the development of the forest sector, and subsidies to cattle ranching and agriculture. The disparity between those who own and those who economically benefit from the forests is at the root of the crisis within the sector and has led to severe environmental degradation within managed forests.

4. The Deforestation Process

Mexico has lost a large fraction of its original forest coverage (Figure 1). It is estimated that tropical evergreen forests, for example, currently have been reduced to 10% of their original area (Rzedowski, 1978).

The history of the deforestation process is long and complex in Mexico. It is estimated that the first large scale clearing of forests occurred early in the colonial period (XVI and XVII centuries), when indigenous communities were forced by the Spanish conquerors to abandon the best agricultural lands and had to settle in forested areas (González, 1992). The huge amounts of wood needed for the extensive mining activities undertaken during the colonial period also contributed to the elimination of large forest areas (González, 1992).

The deforestation process had another boost in the period comprised between the end of the nineteen century and the 1910s. During this period the Mexican government gave concessions of large forest tracts to foreign enterprises, which clear-cut existing forests moving along as the resources were exhausted (González, 1992). This process was particularly crude in the temperate forests of Central Mexico, and resulted in harvest bans that lasted until the late-’70s in some states.

The final and most extensive ‘push’ to the deforestation process in the country initiated in the 1940s and had their peak during the ’60s and ’70s. In this period, tropical forests were the most affected. ‘Development projects’ – many of them funded by multilateral lending agencies – and generous subsidies for cattle ranching provided the basis for extensive clearing of forested areas, especially in Southeast Mexico. (For example, from 1973 to 1977, the World Bank and the Inter-American Development Bank made loans for cattle production in Mexico totaling US\$ 527.4×10^6: this represented 48.7% of the total lending to cattle production in Latin America (Toledo, 1987).) Forests were also seen as an ideal target for colonization programs, as they avoided the politically more difficult undertaking of a land reform within existing agricultural lands (Paz, 1995). Deforestation continued during the 1980s, fostered by the country’s economic crisis, and a deepening of rural poverty.

A remarkable feature of the deforestation process in Mexico is that it is weakly correlated with population growth, as shown by a detailed analysis conducted by FAO in 1990 (FAO, 1990). This result confirms that in Mexico like in other regions of Latin-America (e.g., Brazil), socioeconomic factors such as a skewed and unstable structure of land ownership, an institutional context unfavorable to small land holders and rural development, and direct or indirect subsidies to cattle ranching have been the key driving forces of the process of land-use change (Janvry and García, 1988).

Statistics about current deforestation rates in Mexico are highly uncertain. Estimates range from 400,000 ha/year to 1.5×10^6 ha/year for the 1980s (Table III). Part of the discrepancy derives from the definitions of forest types used by each particular source. Some authors only include tropical forests, which have captured

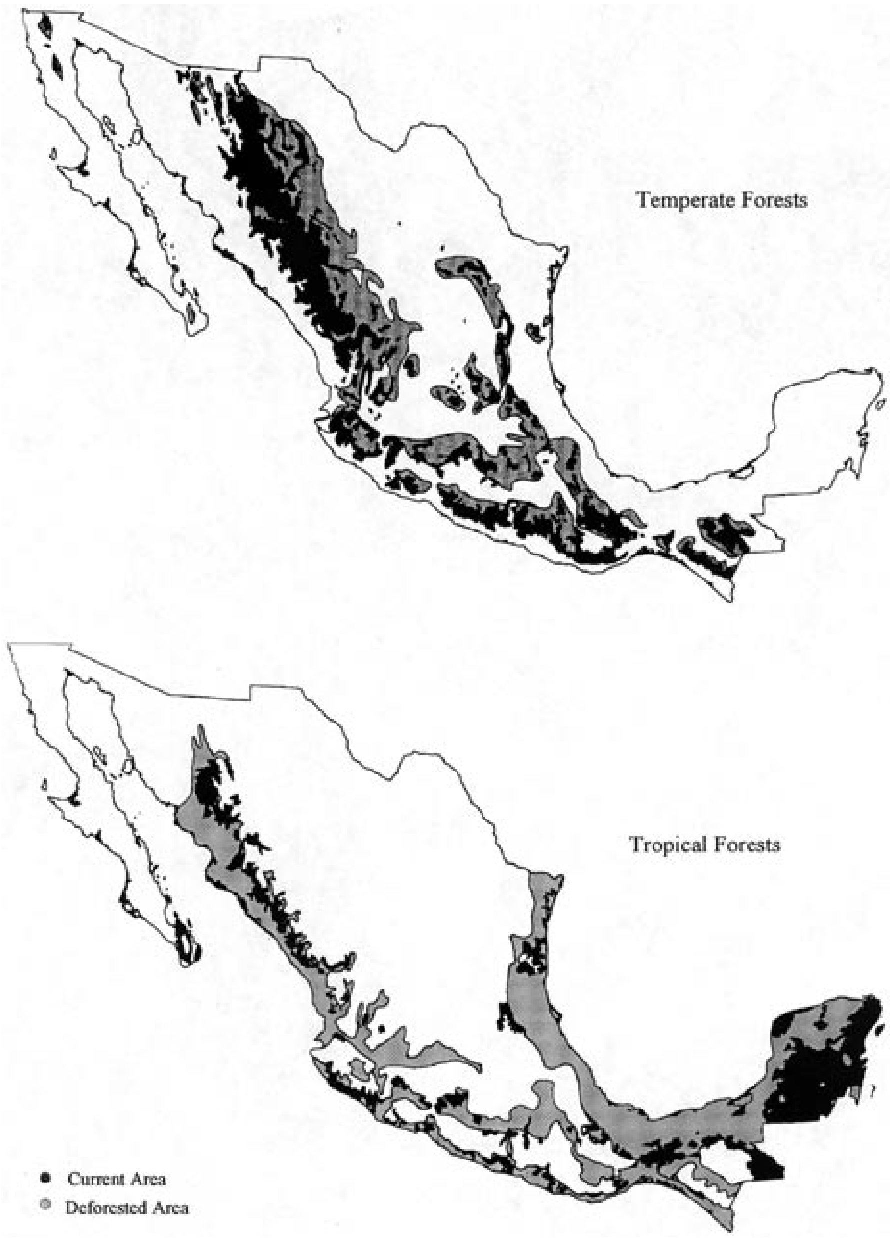

Figure 1. Deforestation in Mexico: original vs. current area for temperate and tropical closed forests. Original area taken from the map by Rzedowski and Reyna-Trujillo (1990), which estimates the potential distribution of the different forest types; current forest area taken from the latest national forest inventory (SARH, 1994). The following forest types are included: conifer, broadleaf, tropical evergreen and tropical deciduous.

Table III

Range of estimates of deforestation rates in Mexico's closed forests for the 1980s (10^3 ha/year)

Source	Temperate	Tropical	Total
Toledo et al., 1989[a]	n.a.	n.a.	1500
Repetto, 1988	n.a.	460	460
Myers, 1989	n.a.	700	700
FAO, 1988; WRI, 1990	125	470	595
SARH, 1990[b]	127	202	329
Castillo et al., 1989	272	473	746
This study[c]	167	501	668

[a] Values include deforestation in open forests.
[b] Adjusted to exclude open forets. The original value was 370,000 ha lost per year.
[c] Values correspond to annual averages for projected deforestation during the period 1988–1994.

the most international attention; others account for both open and closed forests (i.e., Toledo et al., 1989). Deforestation figures calculated for all forest types (FAO, 1988) have been erroneously assigned to tropical closed forests (Myers, 1989). Moreover, tropical deforestation has been largely estimated on the basis of measurements carried out in evergreen forests only (i.e., ignoring deforestation patterns in tropical deciduous vegetation). To make things worse, the latest national forest inventory (SARH, 1994) cannot be used to estimate historic deforestation rates because the inventory is based on a classification of forest types that does not match previous forest inventories.

Forest degradation is occurring in several harvested areas. Due to the lack of precise information about the total area harvested by forest type, harvesting extraction intensities and forest regeneration, a conservative fraction of the total deforested area was assigned to harvesting.

According to our results, approximately 668,000 ha were lost each year during the mid-1980s, leading to an overall deforestation rate of 1.29%/year of the original (early-1980s) forest area. Total forest losses are split into 167,000 ha of temperate and 501,000 ha of tropical forests. Deforestation rates are substantially higher for tropical forests (1.90% for deciduous forests and 2.00% for evergreen forests) than for temperate ones (0.64%/year for coniferous forests and 0.64%/year for broadleaf forests). It should be noted that the figures are well below those found for case studies covering the different forest types (Table IV; Figure 2 shows the geographical locations of the different case studies in Mexico).

Adding the area affected by forest fires predicted to regenerate to the deforestation figures above, a total of 804,000 ha underwent major perturbations in the mid-1980s in Mexico (Table V). Most of the area affected by forest fires regenerates. Only the fraction of the area burned not allowed (or not able) to regenerate is includ-

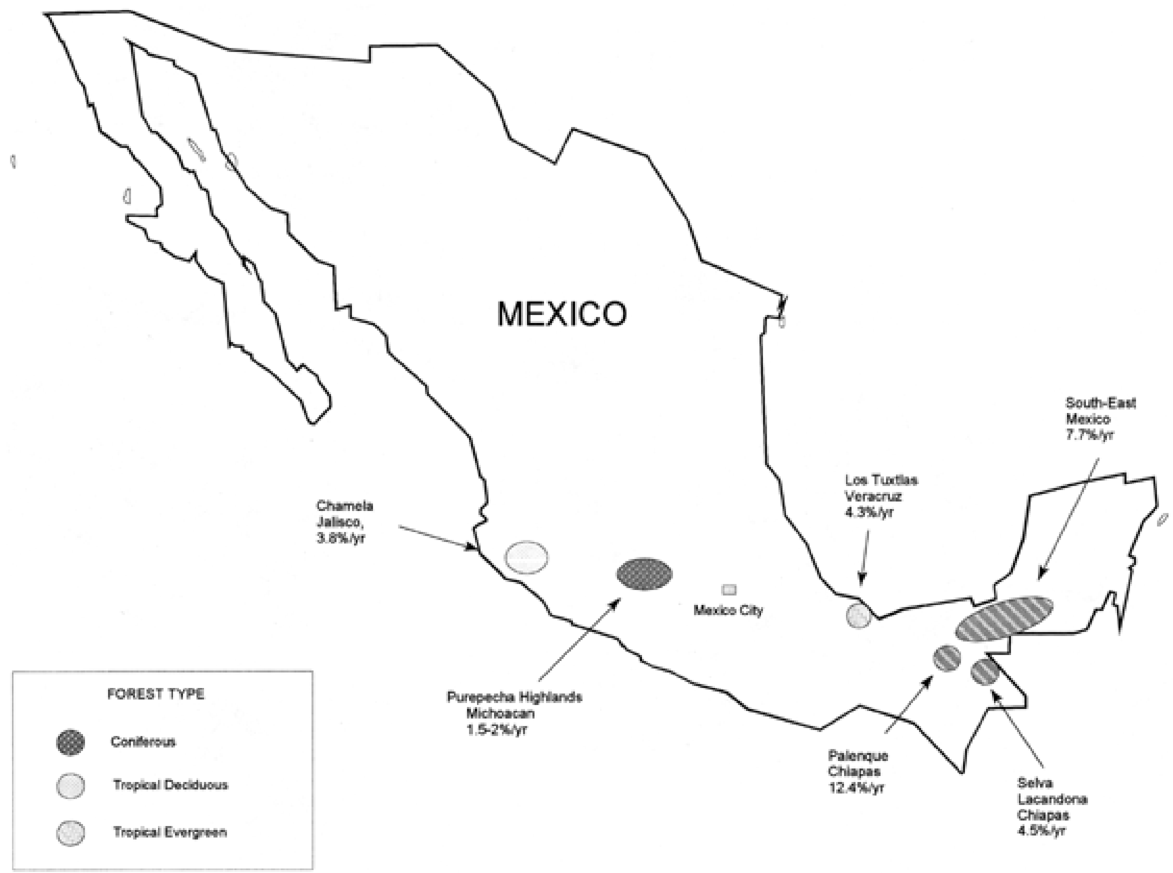

Figure 2. Geographical location and estimated deforestation rates in selected Mexican regions. Deforestation rates are for early- and mid-1980s.

Table IV
Deforestation rates and leading causes of deforestation in selected regions

Region	Ecological features	Deforestation rates (%/year)	Leading factors of deforestation
Lox Tuxtlas, Veracruz[a]	Tropical evergreen	750 ha/year (4.3%/year) 1976–1986	Cattle ranching
Selva Lacandona[b] (Usumacinta River)	Tropical evergreen	14,700 ha/year (4.5%/year) 1980–1988	Cattle ranching (200% increase), opening to agriculture (67%)
Southeast Mexico[c]	Tropical evergreen	∼40,000 ha/year (7.7%/year) 1974–1986	Cattle ranching (42% of deforested area), eroded (6.7%), shifting agriculture (3.7%); 45% on secondary vegetation
Palenque, Chiapas[d]	Tropical evergreen	9,500 ha/year (12.4%/year) 1973–1981	Cattle ranching, (no rainforest remains at present in this area)
Chamela, Jalisco[e]	Tropical deciduous	26,700 ha/year (3.8%/year) 1982	Cattle ranching, shifting agriculture
Purepecha Highlands, Michoacan[f]	Temperate coniferous	1,800 ha/year (1.5–2%/year) 1985–1987	Clandestine logging, unsettled land tenure conflicts among villages, crisis peasant economy

[a] Dirzo and García (1991).
[b] Cortez-Ortiz (1990) (using satellite imagery).
[c] Cuarón (1991) (using satellite imagery to include SW of Campeche, E of Tabasco and NE of Chiapas).
[d] SARH (1984, cited by FSV, 1990).
[e] De Ita et al. (1991).
[f] Caro (1987, 1990).

ed in our estimates for deforestation. The following fractions of areas affected by forest fires are assumed not to regenerate: temperate coniferous (30%); temperate broadleaf (40%); tropical evergreen (20%); and tropical deciduous (30%).

The main activities causing deforestation and major perturbations vary according to forest type. Deforestation is, however, ultimately rooted in the overall rural development strategy followed by the government during the last four decades. Expansion of cattle ranching has been by far the leading factor encouraging deforestation in the tropical forests (Dirzo and Garcia, 1991; Synnott, 1988; Toledo,

Table V
Estimates of deforestation and forest fires shares by conversion activity (10^3 ha/year)

Activity	Temperate coniferous	Temperate broadleaf	Tropical evergreen	Tropical deciduous	Total
Deforestation and forest fires	163	82	237	322	804
Pasture	28%	28%	58%	57%	49%
Agriculture	16%	17%	10%	14%	13%
Harvesting	5%	5%	2%	5%	4%
Forest fires	49%	47%	22%	7%	24%
Other[a]	3%	3%	7%	16%	10%

Notes: From Masera et al. (1992).
[a] Other hand uses include forest losses through erosion, road building, etc. Here the whole area affected by forest fires is included.

1990; Tudela, 1990), and it has also affected temperate forests (Table V and Figure 3).

A typical sequence in the deforestation process of tropical forests begins with timber extraction. This activity provides the first roads to the forest, from which spontaneous or directed colonization by poor settlers is facilitated. The harvested forest is usually dedicated for the first few years to annual agriculture, from which it subsequently moves into permanent pasture. The many comparative advantages of livestock production with respect to traditional crops (specifically maize), and the absence of markets for other rainforest products induce the ultimate conversion of forests to pasture (Janvry and García, 1988).

Forest clearing for shifting agriculture also adds to the deforestation process, particularly when the fallow period is shortened. The impact of oil extraction (which was not possible to quantify in this study) has also been very large in specific areas (e.g., the state of Tabasco) (Tudela, 1990). Anthropogenic fires have increased substantially during the 1980s, becoming the leading factor of deforestation and forest degradation in temperate forests (Table V). Fires are set to burn the forest understory to increase pasture production and to allow people to claim timber as 'dead wood' in areas without harvesting permits. Clandestine forest clear-cutting and opening of clearings for agriculture are other major causes of deforestation within these forests.

4.1. AFFORESTATION

At present, afforestation programs include restoration plantations and commercial plantations. The area afforested has increased substantially during the last few years, but the results of these programs are still modest in the country. Approximately 50,000 ha were reforested annually between 1985 and 1990 for restoration purposes, for a gross total of 432,000 ha reforested since 1960 or a net of 146,000

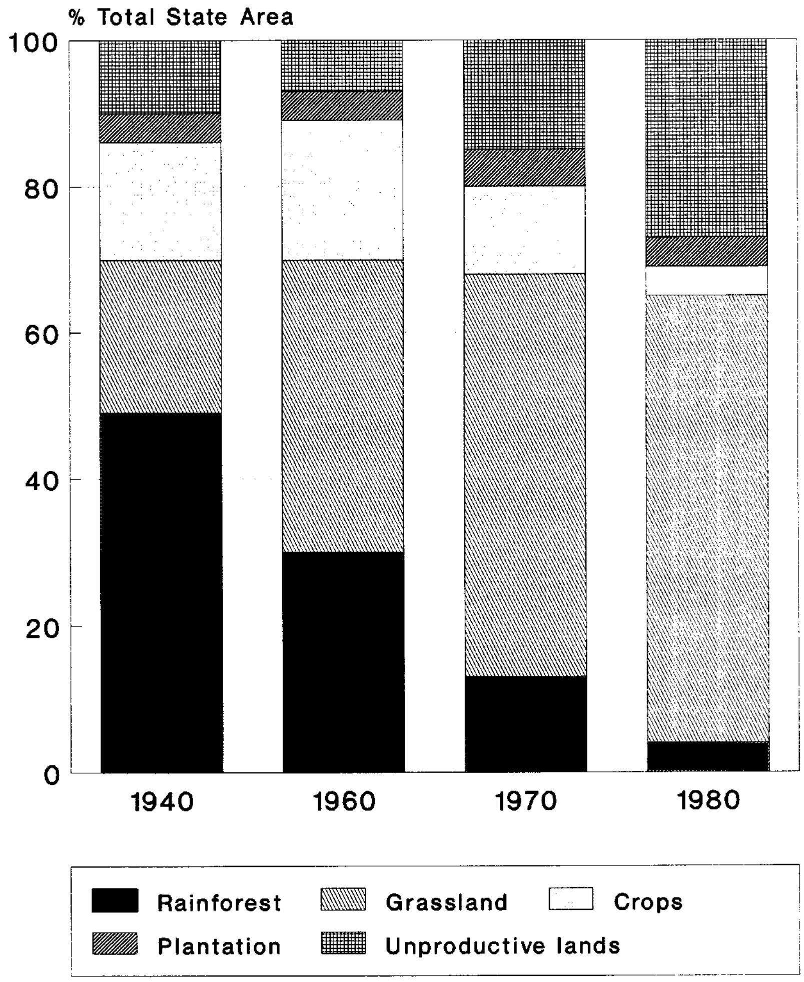

Figure 3. Evergreen forest conversion in the state of Tabasco, Mexico. Adapted from Tudela (1990); total state area is 2.5×10^6 ha.

ha, including a 34% of seed survival rates (SARH, 1991b). Eighty percent of total restoration plantations is concentrated on areas previously vegetated by coniferous forests. The low success rate of most restoration plantations is associated with the limited duration of the projects and inability to create incentives among land owners to manage and conserve the plantations. Restoration projects are mainly limited to planting and monitoring the establishment of seedlings during the first five years and do not contemplate the long-term costs and benefits to maintain and manage the plantation. These types of plantations also have not offered alternative benefits for land owners, leading to a lack of interest in protecting and managing the forests. In order to capture the large potential for establishment of restoration plantations and to ensure their sustainability, it is important to design restoration projects that contemplate the supply of goods and services to land owners and local inhabitants (Bellón et al., 1994).

The national government is currently encouraging the large-scale establishment of commercial plantations in Mexico (SARH, 1991b). While official targets are optimistic, the series of biophysical, financial, and institutional conditions needed for the successful implementation of these types of plantations might limit their widespread dissemination in the country (Bellón et al., 1994).

Two additional promising afforestation options that have not been promoted or developed to the scale needed in the country are agroforestry systems and energy plantations (Masera, 1995). By providing tangible benefits to local users, agroforestry systems may become a good alternative to the clearing of tropical evergreen and tropical deciduous forests. There is already a long experience with these systems in Mexico (indigenous groups have used several agroforestry systems for centuries, i.e., Barrera-Marín et al., 1977), which needs to be rescued and used for launching larger programs at the national level. Energy plantations, particularly those aimed at electricity generation, offer a good alternative for making the restoration of degraded forest lands cost-effective. Adequately established, these plantations offer local benefits such as employment opportunities in rural areas. They are also a good option for carbon sequestration, given that a large fraction of Mexican electricity generation comes from fossil fuels (SEMIP, 1994).

5. Current Carbon Emissions from Deforestation and Forest Fires

Carbon emissions were calculated separately for each forest type and conversion activity. Estimates on deforestation rates, were combined with the area affected by forest fires, forest conversion activities, and biological data. The whole area affected by forest fires, as opposed to only that area which will not regenerate, is included in our calculations. This is because for the purposes of determining current carbon emissions, any activity leading to an immediate or future change in the original forest carbon content must be accounted for. As with the rest of forest conversion activities, the ‘carbon uptake’ from the vegetation regenerating after the fires is taken into account separately, and subtracted from emissions. We also account for the carbon uptake in the reforested areas and the uptake in degraded forest lands undertaking secondary forest regrowth.

Total average carbon storage (vegetation plus soils) is estimated to range from 121 t C/ha for tropical deciduous forests to 232 t C/ha for tropical evergreen forests (Table VI). Other forest carbon relevant parameters (biomass combusted, soil disturbances, and forest fires re-conversion) are also presented in Table VI.

Two indexes are used for the calculation of carbon emissions from deforestation: annual carbon balance and net committed emissions. The *annual carbon balance* represents the balance between emissions and uptake originating from the deforested areas that occur in the base year. It thus includes both the prompt emissions

Table VI
Carbon-related parameters of Mexican forests used in emission estimate

Parameter	Temperate coniferous	Temperate broadleaf	Tropical evergreen	Tropical deciduous
General				
Dominant species	*Pinus* spp.	*Quercus* spp.	*Terminalia amazonia*	*Caesalpinia eristachys*
Wood basic density (t/m^3)	0.48[a]	0.60[b]	0.60[c]	0.50[d]
Biomass (t/ha)				
Total	156[e]	117[e]	360[e]	135[f]
Aboveground	120	90	300	85
Total/aboveground	1.30	1.30	1.20	1.59
Carbon				
Content (%)[g]	45	45	45	45
Total (t C/ha)	179	153	232	121
Vegetation	70	53	162	61
Soils[h]	109	100	70	60
Combustion release[g]				
Biomass carbonized	0.1	0.1	0.1	0.1
Slash-and-burn agriculture	0.6	0.6	0.5	0.4
pasture	0.6	0.6	0.5	0.4
Soil disturbance[i] agriculture	0.3	0.3	0.3	0.3
pasture	0.3	0.2	0.2	0.2
Uptake[g]				
% Fires reconverted	70	60	80	70

[a] Wood basic densities (dry weight/green volume) of the more than 50 species of pines in Mexico (Rzedowski, 1991) range from 0.41 to 0.55; the value chosen (0.48) corresponds to the average wood density for the most common species.
[b] Corresponds to the average wood basic density for broadleaf species estimated by Cannell (1984).
[c] Mexican tropical evergreen forests do not have a definite dominant species: there are several tree species that share the dominance; for that we use the average wood density of the most common species reported by Sarukhan (1968) and Bongers and Popma (1988).
[d] Dominant species reported by Martínez-Yrizar (1992), we use an average of the most common species reported.
[e] Aboveground biomass was estimated applying Cannell's formula (1984) (see text) to data drawn from the National Forest Inventory of 1991-1992 (SARH, 1992) and from different case studies (San Rafael (1985) and SARH (1985) for temperate forests; and Sarukhan (1968) and Bongers and Popma (1988) for tropical evergreen forests). Cannell (1984), suggests F (stand form) values of: 0.4-0.5, 0.5-0.6, 0.6-0.7, for stands having an average of 5%, 15%, and 25% branches, respectively. In this study we have used the following values: conifer 0.55 (14% branches); broadleaf 0.7 (23% branches); and tropical evergreen 0.6 (19% branches). Estimates only

Table VI
(Continued)

include aboveground biomass of tree species. There is a large difference between the values otained from the National Forest Inventory (low end) and those derived from the case studies (high end), which may be partly due to the fact that sites with good local forest inventories are those with higher biomass densities. In absence of more detailed information, we have used conservative estimates, particularly for temperate forests. For example, preliminary data from destructive inventories in the state of Chiapas indicates aboveground biomass values of 140-160 t/ha for pine forests, and of 200 to 320 t/ha for broadleaf forests (B. de Jong, pers. comm.).

[f] Data reported by Martínez-Yrizar (1992).

[g] Assumed, based on estimates for comparable forest types in other countries (Makundi et al., 1991 and default values suggested by IPCC (1995).

[h] Currently there is no data available about average soil carbon content for the different forest types in Mexico. In the absence of local information we have used conservative estimates, based on data for similar forest types located in other parts of the world. Estimates for the soil carbon content of temperate forests (conifer and broadleaf) are consistenly over 100 t C/ha (Zinke et al., 1984; Ravindranath et al., 1992; IPCC, 1995). Ravindranath et al. (1992) estimated 57 t C/ha as the average carbon content for tropical deciduous forests in India, which appears to be similar to very rough estimates derived for Mexico (V. Jaramillo, pers. comm.). Soil carbon content estimates for tropical evergreen forests are more uncertain, as they range from 24 t C/ha in the Brazilian Amazon (Fearnside, 1992), to 130 t C/ha or more in India (Ravindranath et al., 1992).

[i] Currently there is no consensus about the magnitude of soil carbon losses after the clearing of tropical forests (IPCC, 1995). Lugo et al. (1986) found that conversion of tropical forests to pasture may even increase the soil carbon content. In this study we have assumed that tropical soils are net sources of carbon when forests are converted to other land uses.

from deforestation and forest fires in the base year plus the inherited emissions coming from historic deforestation (that is, emissions that occur in the base year because of decomposition of woody biomass produced by past deforestation). In the absence of data on historic deforestation trends in Mexico, this study assumes that current deforestation rates do not differ very much from past deforestation. Under these circumstances, delayed emissions from present deforestation can be assumed to be equal to inherited emissions from past deforestation; consequently the data obtained for the base year suffices for calculating the annual carbon balance. After estimating prompt and inherited emissions, the uptake from vegetation regrowth in the area deforested in the base year is subtracted to get the annual carbon balance (see Table VII).

Net committed emissions represent the net long-term change in carbon content between the original forest cover and the forest conversion activity (i.e., agriculture, pasture, etc.). It is calculated as prompt plus inherited emissions from current deforestation and forest fires minus prompt and delayed uptake from vegetation replacing the deforested area or the area affected by forest fires (see Table VII). This indicator is necessary in order to make our estimates comparable to those

Table VII
Carbon emissions and uptake from deforestation and forest fires in Mexico (*c.* 1985) (10^6 t C/year)

Indicator	Temperate coniferous	Temperate broadleaf	Tropical evergreen	Tropical deciduous	Total[a]
Emissions					
Prompt	7.2	2.6	15.8	10.5	36.1
Delayed	2.1	1.1	17.0	10.9	31.1
Committed[b]	9.3	3.7	32.8	21.4	67.2
Uptake					
Prompt	0.06	0.02	0.14	0.01	0.2
Delayed	2.0	0.6	2.7	0.7	6.0
Committed[b]	2.1	0.6	2.8	0.7	6.2
Annual carbon balance[c] (10^6 t C/year)	9.2	3.7	32.7	21.4	67.0
Net committed emissions[d] (10^6 t C)	7.2	3.1	30.0	20.7	61.0

[a] Totals do not always add up to the first decimal point because of rounding.
[b] Committed emissions (uptake) are (is) the sum of prompt and delayed emissions (uptake).
[c] Committed emissions-Prompt uptake.
[d] Committed emissions-Committed uptake.

from other sources (e.g., Houghton, 1990; WRI, 1990) (see also Makundi et al., 1992, for a more detailed discussion of the two indicators).

Table VIII presents the annual carbon balance for each conversion activity and forest type. A ‘carbon intensity’ index (net emissions per hectare of land deforested) is estimated in order to illustrate the relative impact of each conversion activity and forest type on carbon emissions. The net committed emissions and *stored carbon* by forest type are also included in Table VIII. This last indicator helps illustrate the maximum potential cumulative releases of carbon dioxide to the atmosphere.

Also in Table VIII we show *the carbon balance of the forest sector* as whole. To do this we include the prompt carbon uptakefrom all growing vegetation in the base year (i.e., the growth of trees in afforestation programs, plus a rough estimate of the amount of vegetation regrowth in degraded forest lands) and subtract it to the annual carbon balance from deforestation.

Our results show that Mexican closed forests store about 8.6 gigatons of carbon (Gt C), from which 67.0×10^6 t of carbon were emitted because of land-use changes in the base year. Conversion to pasture is responsible for over 60% of the total annual carbon balance. On average, 83 t C were emitted per hectare, with the

Table VIII
Net carbon emissions from Mexican closed forests (*C.* 1985)

Emissions	Temperate coniferous	Temperate broadleaf	Tropical evergreen	Tropical deciduous	Total	(%)
Annual carbon balance from deforestation (10^6 t C/year) (1)	9.2	3.7	32.7	21.4	67.0	100%
Intensity (t/ha)	57	44	138	66	83	
Agriculture	2.5	1.1	4.3	3.4	11.3	17%
Intensity (t/ha)	97	78	166	75	114	
Pasture	4.4	1.6	22.3	12.7	41	61%
Intensity (t/ha)	97	68	162	69	66	
Other	2.4	1.0	6.2	5.3	14.8	23%
Intensity (t/ha)	27	21	85	56	58	
Prompt carbon uptake (10^6 t C/year)	<0.1	<0.1	<0.1	<0.1	0.2	1%
Intensity (t/ha)	0.7	0.3	0.7	0.1	0.2	
Net committed emissions (10^6 t C)	7.2	3.1	29.9	20.6	60.9	100%
Intensity (t/ha)	44	37	126	64	76	
Stored carbon (Gt C)	3	1.3	2.2	1.9	8.6	
Intensity (t/ha)	178	152	231	121	166	

Prompt carbon uptake in afforested and degraded forest lands (2)	Temperate forests	Tropical forests	Total
	1.8	12.9	14.7
Restoration plantations	0.2	0.1	0.3
Degraded forest lands	1.6	12.8	14.4
Annual carbon balance forest sector (1)–(2)	11.1	41.2	52.3

[a] From Masera et al. (1995). Carbon uptake in degraded forest lands accounts for vegetation regrowth in abandoned lands created during the last 20 years (i.e., forest lands cleared for agriculture or pasture in the past where secondary forests are currently regrowing).

highest value for conversion to agriculture (166 t C/ha). While accounting for only one-fourth of the area affected by deforestation and forest fires, tropical evergreen forests were responsible for 49% of total annual carbon balance. Eighty-one percent of total emissions comes from tropical forests.

Carbon releases per hectare differ markedly by forest type, ranging from 44 t C/ha for temperate broadleaf to 138 t C/ha for tropical evergreen forests. The difference in intensities shows the importance of correctly assigning deforestation figures to the corresponding forest type. The prompt carbon uptake is very low because most deforested area is converted to annual agriculture and pasture, which are characterized by low carbon storage per hectare. Net committed emissions reach 61.0×10^6 t C (or 76 t C/ha). Using this indicator, the contribution of

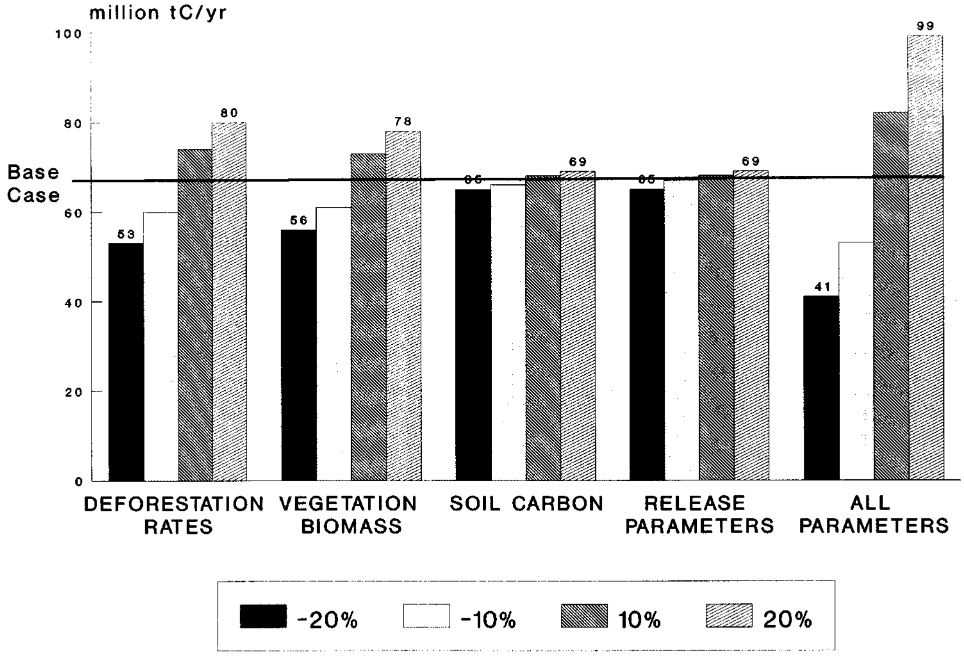

Figure 4. Sensitivity analysis annual carbon balance from deforestation and forest fires.

temperate forests decreases, mainly because of delayed uptake from the growing forests regenerating after fire.

We estimate a carbon uptake of approximately 14.7×10^6 t C in afforested and degraded forest lands (12.9×10^6 t C in tropical forests and 1.8×10^6 t C in temperate forests). Therefore, the annual carbon balance for Mexican closed forests reaches 52.3×10^6 t C.

A sensitivity analysis was performed on the annual carbon balance from deforestation. A set of key parameters (deforestation rates, biomass, soil carbon and carbon release parameters) were selected and given values from –20% to +20% of the current estimate. Deforestation rates proved the most sensitive, with a close-to-linear response in carbon emissions. Total biomass showed less sensitivity. Soil carbon content carbon release parameters were found to be the least sensitive (–5% to +2% variation in emissions for a –20% to +20% variation in the parameter). When all key parameters are simultaneously varied from –20% to +20%, the annual carbon balance ranges from 41.0×10^6 t C/year to 99.1×10^6 t C/year (Figure 4).

6. Long-Term Carbon Emission Scenarios

Future carbon emissions from the forest sector are very difficult to estimate given the linkages among the economic, technological and social factors involved in the deforestation process. The current economic panorama and the institutional framework regulating access to forest resources are changing rapidly in Mexico, making it difficult to predict future trends in basic economic activities within the country.

Two contrasting scenarios were developed on future carbon emissions from deforestation: ‘reference’ and ‘policy’. The scenarios are intended to provide the most likely range of emissions given contrasting long-term policies on land-use patterns within the country. The year 2025 was chosen as the final year in order to make the scenarios compatible with those developed for emissions from energy use (Mendoza et al., 1991).

6.1. REFERENCE SCENARIO FOR THE FOREST SECTOR

Table IX illustrates the basic assumptions of the reference scenario. This scenario visualizes a future with little concern for forest conservation. We assume that current deforestation rates (as percentage of the remaining forests) will continue in the future. Carbon intensities are kept the same as in the base year (in other words, it is assumed that the present structure of carbon emissions and uptake will continue in the future).

By 2025, the annual carbon balance reaches 28×10^6 t C/year. (Table X). The reduction in forest cover is responsible for the reduction of carbon emissions with respect to the base year (66.7×10^6 t C/year, without including uptake in degraded forest lands).

6.2. POLICY SCENARIO FOR THE FOREST SECTOR

A sustainable forest management should maintain or increase the forest stocks and their productivity, while contributing both to a good standard of living for the forest owners, as well as providing goods and services to the rest of society, such as wood products and environmental services. In the policy scenario we tried to combine options that accomplish these objectives, at the same time being consistent with limitations in budget and government policies.

The scenario assumes that there will be strong efforts to revitalize the Mexican forest sector, allowing Mexico to satisfy its domestic demand for subsistence and industrial forest products by 2000. Also, it is assumed that future land for food production can be accommodated on existing agricultural lands through intensification and improved yields.

Seven options to both conserve existing forests and to increase the current forested area were considered. These options include, within conservation of existing forests, natural protected areas, management of native forests and dissemination of improved woodburning cookstoves; within afforestation, restoration plantations, pulpwood plantations, energy plantations, and agroforestry systems. Refer to Masera (1995) and Masera et al. (1995a) for a detailed description of the different mitigation options.

Table IX
Main assumptions for carbon emission and sequestration scenarios in Mexico

Indicator	Base year (*c*. 1985)	Reference (2025)	Policy (2025)
Forested area (10^6 ha)	51.7	28.2	51.8
Native forests	51.5	27.2	46.3
Afforested area	0.2	1.0	5.5
Deforestation rate (%/year)	2.44%	2.44%	0.19%[a]
Evergreen	2.02%	2.02%	0.20%
Deciduous	0.96%	0.96%	0.13%
Coniferous	0.94%	0.94%	0.13%
Broadleaf			
Conversion activity shares & carbon release parameters		Same as base year	Same as base year
Carbon uptake			
Afforestation	0.2 Mha (million ha) restoration plantations	1 Mha restoration plantations	2.5 Mha restoration plantations, 1.6 Mha pulpwood plantations, 0.8 Mha energy plantations, 0.6 Mha agroforestry systems
Conservation of native forests	6.8 Mha poorly managed and 2.6 Mha protected	Most managed forests and protected areas are degraded and deforested	Programs for sustainable forest management in 13.2 Mha, 4.9 Mha of natural protected areas

Notes: Refer to Masera (1995) for a complete discussion about the procedure used to construct the policy scenario.
[a] The figure represents the target for the year 2025. The average deforestation rate during the period 1985–2025 is higher because it is assumed that the rate will diminish gradually from the current level to the value targeted for the year 2025.

Contrasting with a 46% reduction of the base-year forested area in the reference scenario, the policy scenario shows a slight gain in the country's forested area. Native forests are estimated to diminish 11%, mainly because of the existing inertia in the deforestation process, however, this area loss is counterbalanced by

Table X
Long-term carbon emissions from deforestation in Mexico

Indicator	Base year (1985)	Reference (2025)	Policy (2025)
Annual carbon balance (10^6 t C/year)[a]	66.7	29.0	–62.0
Emissions (10^6 t C/year)	67.0	29.8	6.0
Prompt uptake (10^6 t C/year)	0.3	0.8	68.0

Notes: Refer to Masera (1995) for a complete discussion about the method used to estimate the carbon uptake in the policy scenario.
[a] We have left the uptake in degraded forest lands out of the analysis because the large uncertainty in the current estimates made it impossible to project the figures to the future.

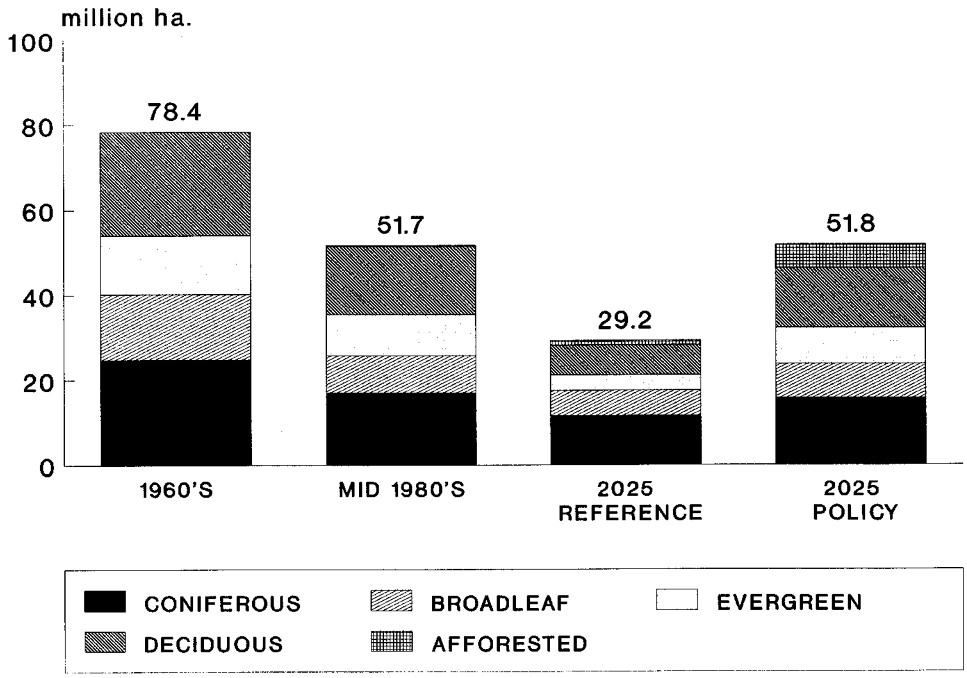

Figure 5. Historic and future estimated evolution of closed forests in Mexico.

afforestation programs. The different forestry options undertaken make Mexican forests become a large net carbon sink, with an uptake of 62×10^6 t C/yr.

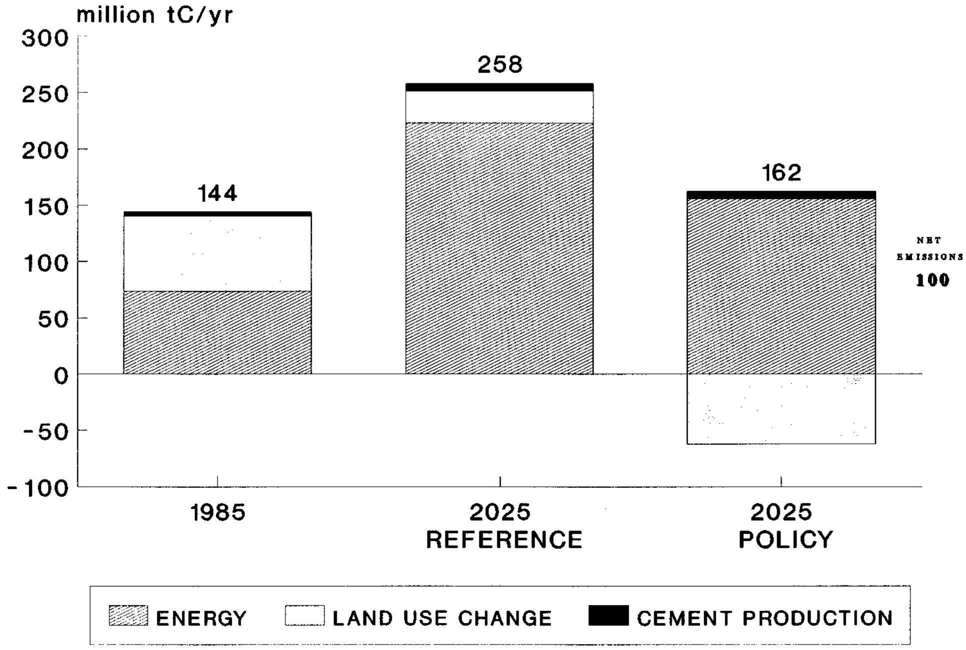

Figure 6. Overall carbon emissions in Mexico. Emissions from deforestation correspond to annual carbon balance without including the uptake from degraded forest lands.

6.3. OVERALL CO_2 EMISSIONS: LINKING ENERGY, INDUSTRY AND THE FOREST SECTOR

Adding forestry emissions to those estimated from energy use (Mendoza et al., 1991) and cement manufacturing (Ketoff et al., 1990), annual carbon emissions increase from 144×10^6 t C/year in 1985 (including the uptake of degraded forest lands the figure is 126×10^6 t C) to 258 in the reference scenario, and *decrease* to 100 in the policy scenario (Figure 6).

The current annual carbon balance per capita (1.7 t C/year) *decreases* by 70% in the policy scenario and increases by 6% in the reference scenario. Carbon emissions from energy use grow substantially in both scenarios while emissions from deforestation decrease, leading to an important drop in the share of deforestation in total emissions. In the policy scenario forests help offset 39% of country emissions from energy use. Emissions from cement manufacturing increase by a factor of two in both scenarios, but this activity's share in total emissions remains low.

Implementation of policies to reduce carbon emissions in the policy scenario leads to 158×10^6 t C/year savings by 2025 relative to the reference scenario (cumulative carbon sequestration in the forest sector alone is estimated to reach 2.4 Gt C by 2025). It should be noted that further savings are technically possible, both through increasing carbon sequestration in the forest sector (Masera, 1995), and through a more intensive utilization of renewable sources of energy.

7. Conclusions: Reducing Carbon Emissions through the Sustainable Management of Forest Resources

This study suggests that about 67.0×10^6 t C/year were emitted in Mexico from deforestation and forest fires in closed (temperate and tropical) forests in the mid-1980s. Emissions arise from major perturbations affecting 804,000 ha of forest annually, which, after subtracting the area that regenerates from forest fires, leads to a net deforestation rate of 668,000 ha/year, or an annual loss of approximately 1.3% of the total closed forests present in the early-1980s. Subtracting the carbon uptake in existing restoration plantations and degraded forest lands, the annual carbon balance of closed forests reaches approximately 52.3×10^6 t C.

Overall net carbon dioxide emissions for Mexico, from forestry, energy, and industry amount to 126×10^6 t C/year (1.6 t C/capita). This figure, both in absolute and per capita terms, indicates that Mexico's contribution to global carbon emissions is among the highest for the developing countries (WRI, 1992). Emissions are, however, still well below those from industrialized countries, especially if cumulative emissions are accounted for.

The examination of future scenarios about the forest sector shows two divergent paths for Mexico. Under a 'business as usual' future, forests will still constitute large net sources of carbon emissions forty years from now. However, if effective policies to reduce deforestation rates and increase afforestation are implemented, the potential exists for converting Mexican forests into large carbon sinks. This last path also offers two important advantages. First, carbon savings in the forest sector will help buy time for the large scale deployment of renewables in the energy sector, which are expected to be competitive with fossil fuels early in the next century.

Second, and more important for Mexico, following the path suggested in the policy scenario should result in tangible benefits for local inhabitants. It is not advisable for Mexico to follow a narrow 'carbon reduction maximization' strategy for its forest resources. Addressing global warming concerns may bring about substantial benefits for the country both in the short- and long-run. But critical to actually accruing these benefits is undertaking a strategy that strikes a balance among the different uses for forest resources: wood, fuel and food for local needs, products for urban areas, biodiversity, climate regulation, watershed protection, education, recreation and others.

The best strategy for reducing carbon emissions (i.e., the strategy that maximizes the probability of long-term success and is economically realistic) is one that builds upon the solution of the more immediate needs that forest resources provide to local people and to the country. Fortunately, it appears that no intrinsic obstacles hinder the sustainable management of forest resources in the country. Population growth is not the leading factor in the deforestation process and food needs can be largely accommodated within the existing area open to cultivation through a better crop mix. As shown in the policy scenario, at least in principle, a large land area shows potential for forest use without impinging on other economic activities. Success in conserving the country's forest resource base and in afforesting the land, however, will largely depend on a thorough revision of current rural development and forest sector policies. Basic elements for an alternative long-term strategy supporting the sustainable management of the country's forests include:

(i) *Eliminate the disparity between those who own and those who economically benefit from forests*. Given the social appropriation of most forest resources in the country, programs should be promoted which allow local residents to benefit from conservation of forest resources (e.g., through social forestry and agroforestry programs, among other options).

(ii) *Incorporate ecological principles into forest management activities and strengthen basic and applied research on forest ecosystems*. Management methods adequate to the diversity of forest conditions within the country which also increase productivity of wood with commercial value, should be developed. Harvesting activities should keep the balance between forest resources for local consumption (i.e., fences and other construction materials, fuelwood, food, medicinal plants, etc.) and for external demand (timber, paper pulp, etc.).

(iii) *Diversify forest production through development of new markets for sustainably produced non-precious woods and non-wood products, and increasing the value added of forest products at the harvesting site*. Currently, about 60% of timber extracted from villages is sold 'standing' (Jardel, 1989). Wood extraction is also heavily concentrated on wood from conifer species. Alternatives to be considered include local furniture production and other processing of forest resources; promoting the use of oak and non-precious tropical woods; in some places promotion of eco-tourism might provide incentives for stopping deforestation. Quite clearly, the success of such programs depend on simultaneously assuring peasants fair competition with large producers and control over the production and commercialization of the extracted products.

(iv) *Eliminate direct and indirect subsidies to livestock production and reduce its comparative advantages against other less environmentally damaging economic activities*.

(v) *Promote research and development on alternative bio-energy systems*. Currently, most demand for wood products is in the form of fuelwood. The large amount of fuelwood consumed is leading to forest degradation in certain regions. A sustainable bio-energy strategy should include: (a) improving fuelwood supply through integrated forestry and agroforestry management systems; (b) disseminating more efficient wood-burning stoves in rural and peri-urban areas; (c) improving the efficiency of fuelwood/charcoal combustion in rural industries; and (d) increasing support for research and development of new bio-energy systems (e.g., biomass gasification).

Industrialized countries, largely through multilateral lending institutions, also bear a responsibility for the deforestation process, for example, by encouraging large development and cattle-ranching projects during the 1970s and 1980s.

Because it is also in the best interests of these countries to help maintain existing forest resources, they have the obligation to contribute to the solution of the problem. Needed actions include facilitating the economic recovery of Third World countries, increasing funds for basic and applied research on alternative forest management systems, and helping to establish or to improve international markets for sustainably produced non-precious woods and non-wood forest products.

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