National forest reference emission level proposal México

Contents

Acronyms

BUR: Biennial Update Report

UNFCCC: United Nations Framework Convention on Climate Change

CTC: Technical Advisory Committee on REDD+

CONAF: National Forestry Council (Consejo Nacional Forestal in Spanish)

CONAFOR: National Forestry Commission (Comisión Nacional Forestal in Spanish)

AD: Activity Data

ENAREDD+: REDD+ National Strategy (Estrategia Nacional REDD+ in Spanish)

ENCC: National Climate Change Strategy (Estrategia Nacional de Cambio Climático in Spanish).

FAO: Food and Agriculture Organization of the United Nations

EF: Emission Factors

FRA: Global Forest Resources Assessment

FCC: Fuel Condition Class

GHG: Greenhouse Gases

WG: Working Groups

INECC: National Institute of Ecology and Climate Change (Instituto Nacional de Ecología y Cambio Climático in Spanish).

INEGEI: National Inventory of Greenhouse Gas Emissions (Inventario Nacional de Emisiones de Gases de Efecto Invernadero in Spanish).

INEGI: National Statistics and Geography Institute (Instituto Nacional de Estadística y Geografía in Spanish).

INFyS: National Forest and Soils Inventory (Inventario Nacional Forestal y de Suelos in Spanish).

LGCC: General Climate Change Law (Ley General de Cambio Climático in Spanish).

LGDFS: General Law for the Sustainable Development of Forests (Ley General de Desarrollo Forestal Sustentable in Spanish).

MRV: Measurement, Reporting, and Verification System.

MASL: Meters Above Sea Level.

NFREL: National Forest Reference Emission Level

IPCC: Intergovernmental Panel on Climate Change

LULUCF: Land Use, Land Use Change and Forestry

REDD+: Reducing Emissions from Deforestation and Forest Degradation, and the role of Conservation, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks.

PSU: Primary Sampling Units.

SSU: Secondary Sampling Units.

1. Introduction

In response to the invitation of the United Nations Framework Convention on Climate Change (UNFCCC), Mexico voluntarily presents a proposal for its National Forest Reference Emission Level in accordance with decision 1/CP.16, paragraph 71(b), as part of the country's adoption of the measures mentioned in paragraph 70 of the same decision (UNFCCC, 2011), for its technical assessment in accordance with the guidelines and procedures adopted in decision 13/CP.19 (UNFCCC, 2014), where the National Forest Reference Emission Level (NFREL) may be technically assessed in the context of results-based finance.

This proposal was prepared in adherence to the guidelines for presenting information on National Forest Reference Emission Levels as indicated in the Annex to 12/CP.17 (UNFCCC, 2012). The information provided follows the guidelines of the Intergovernmental Panel on Climate Change (IPCC), and it includes:

(a) Information used to construct the NFREL;
(b) Transparent, complete, consistent, and accurate information, including methodological information used in constructing the NFREL;
(c) Pools and gases, and activities listed in decision 1/CP.16, paragraph 70, of which were included in the NFREL;
(d) The definition of forest used in the construction of the NFREL.

2. National Context

a) Legal Framework

Mexico has a solid legal framework providing novel tools and structures to meet national objectives on climate change, including those relevant to REDD+. This framework includes the General Law for the Sustainable Development of Forests (DOF, 2003) and the General Climate Change Law (DOF, 2012).

The General Climate Change Law (LGCC, for its acronym in Spanish), published in June of 2012, constitutes the main legal instrument establishing the foundations for implementing the mechanisms that will regulate mitigation and adaptation actions in the long term.

Regarding mitigation, the LGCC mandates the National Forestry Commission (CONAFOR, for its acronym in Spanish) to design strategies, policies, measures, and actions to transition to a rate of zero-percent carbon loss in original ecosystems, and to integrate them into forest policy planning, taking into account sustainable development and community forest management[1].

1 Third Transitory Article of the LGCC

As a planning instrument, the LGCC commands the development of the National Climate Change Strategy (ENCC, for its acronym in Spanish), which provides a road map for medium- and long-term national policy to address the effects of climate change and advance toward a sustainable and competitive low-carbon economy (DOF, 2013). Additionally, it establishes a 40-year vision and sets progressive ten-year objectives to realize it.

To increase and maintain forest carbon stocks, the ENCC promotes the expansion of improved agricultural and forestry practices through the design and implementation of plans, programs, and policies oriented towards reducing deforestation and forest degradation under a REDD+ strategy.

b) Forest Land Cover

Mexico's territory has a total land area of 1,964,375 square kilometers (km²), which include a continental area of 1,959,248 km² and an insular area of 5,127 km².[2] According to CONAFOR (2014), around 45% of the forested area of the country is under a common property regime.

Mexico is considered a megadiverse country, as it is among the 12 states whose territories contain about 70% of the world's biodiversity.

The following paragraphs describe the different plant ecosystem groups found in Mexico according to the classification system proposed by Rzedowski (1978). This grouping is based on the ecological affinities of the different types of vegetation (INEGI, 2009) that are included in the NFREL:

- Coniferous Forest: Plant formations in humid, sub-humid, and temperate zones composed of perennial gymnosperms. In Mexico, they are found from sea level to the timber line (3,000 MASL).
- Oak Forest: Plant communities composed of the genus *Quercus* (oaks). They are found almost from sea level to 2,800 MASL, except in very arid lands. They are highly linked to pine forests, forming a series of mixed forests with species of both genera.
- Mountain Cloud Forest: This plant ecosystem is characterized by the presence of dense arboreal vegetation, epiphytes and ferns. It is located mainly in mountains, cliffs, and places with favorable moisture conditions and fog. In Mexico, it is located at an altitude between 600 and 3,200 MASL.
- Evergreen Forest: It groups tropical plant formations in which more than 75% of their elements retain leaves during the driest period of the year.
- Semi-Deciduous Forest: Plant formations in which 50% to 75% of their components lose their leaves during the driest period of the year.
- Deciduous Forest: These are plant formations of arid and tropical origin in which more than 75% of the species that inhabit them lose their leaves during the dry period of the year.

2 www.inegi.org.mx

- Grasslands: These ecosystems are composed of herbaceous communities in which the graminoids and graminae predominate. In some cases, they are of natural origin, but in others, their existence is due to overgrazing.
- Xeric Shrublands: This plant ecosystem is characteristic of the arid and semiarid zones of Mexico and is composed of microphyllous and spiny shrub communities.
- Hydrophilous Vegetation: This ecosystem is composed of plant communities that inhabit swamplands and floodlands with shallow brackish or fresh water.
- Planted forests: This group includes tree populations that are not native and have been introduced by humans due to different causes (for example, the establishment of tree plantations).

3. Information Used

This NFREL was constructed using information from official sources, mainly the Land Use and Vegetation Series issued by the National Institute of Statistics and Geography (INEGI, 1996, 2005, 2010, and 2013) and the National Forest and Soils Inventory (INFyS, for its acronym in Spanish) produced by the National Forestry Commission (CONAFOR, 2012).

a) INEGI's Land Use and Vegetation Series

The INEGI is in charge of providing official statistical and cartographic data at the national level, including Land Use and Vegetation Maps (also known as Series)[3]. These maps show the distribution of the different types of vegetation and of land areas used for agriculture, livestock production, and forestry. They include accurate information on the botanical species representative of the vegetation cover and allow experts to identify the state of the vegetation cover throughout the national territory. They are issued on a 1:250,000 scale with a minimum mappable unit of 50 hectares. To date, INEGI has issued 5 Series[4], whose characteristics are shown in Box 1.

Table 1. Main characteristics of the INEGI Series.

	SERIES II	SERIES III	SERIES IV	SERIES V
Editorial Reference Dates	1990s	2002-2005	2007-2010	2011-2014
Field Data Dates	1993-1998	2002-2003	2007-2008	2012-2013
Scale	1:250,000	1:250,000	1:250,000	1:250,000

[3]Declared as information of national interest through an agreement published in the Official Gazette of the Federation (DOF). (http://dof.gob.mx/nota_detalle.php?codigo=5324032&fecha=02/12/2013)

[4]Series I was not analyzed for this REL because the vegetation and land use classes used in this series are not completely compatible with that used in subsequent series.

Resolution	50 m per pixel in origin, interpretation on printed image, 1:250,000 scale	27.5 m per Pixel	10 m per Pixel	27.5 m per Pixel
Data	Georeferenced Printed Maps	LANDSAT TM (30 m)	SPOT 5 (10 m)	LANDSAT TM (30 m)
Methodology	Analog Technology	Digital Technology	Digital Technology	Digital Technology
Information	5 Layers	14 Layers	13 Layers	14 Layers

b) CONAFOR's National Forest and Soils Inventory

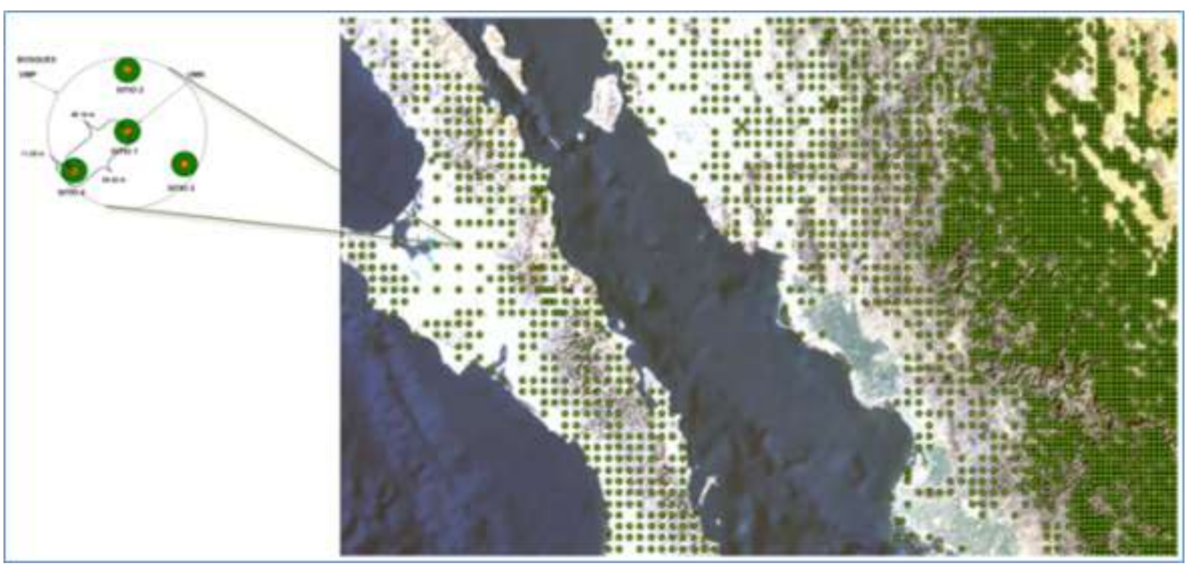
The National Forest and Soils Inventory (INFyS), issued by CONAFOR, is an instrument for forestry management mandated by the General Law for the Sustainable Development of Forests (LGDFS for its acronym in Spanish).

The INFyS is the main input for estimates in some categories of land use, especially those related to forestry. It comprises 26,220 plots distributed systematically throughout the country (Figure 1) in 5x5 km spacings in forests and jungles, 10x10 spacings in semiarid communities, and 20x20 km spacings in arid communities. Each plot consists of four sub-plots of an area of 0.04 hectares each in which the dasometric information is collected in the field (CONAFOR, 2012).

The INFyS has a five-year cycle for gathering field data. To this date, two cycles have been completed: the first from 2004 to 2007 and the second from 2009 to 2013.

For INFyS sampling and re-sampling, there is information available at the sub-plot level concerning the dasometric measurements of all trees.

Figure 1. Layout of INFyS plots and sub-plots and their systematic distribution



4. Estimation Methods

a) Activity Data (Consistent Representation of Lands)

The classification and hierarchical structure of INEGI's cartography was used to establish correspondence between the vegetation cover classes used in the country and the categories of the IPCC (2003) (INEGI, 2009).

Ensuring consistency with the inventory included in the Biennial Update Report (INECC-CONAFOR, 2014) to be submitted to the UNFCCC, the grouping proposal for the Land Use, Land Use Change, and Forestry (LULUCF) sector includes 19 groups in forest lands, 6 in grasslands, 2 in croplands, 1 in wetlands, 1 in settlements, and 1 in other lands. Figure 2 graphically represents how classes in the INEGI Series were grouped into IPCC categories.

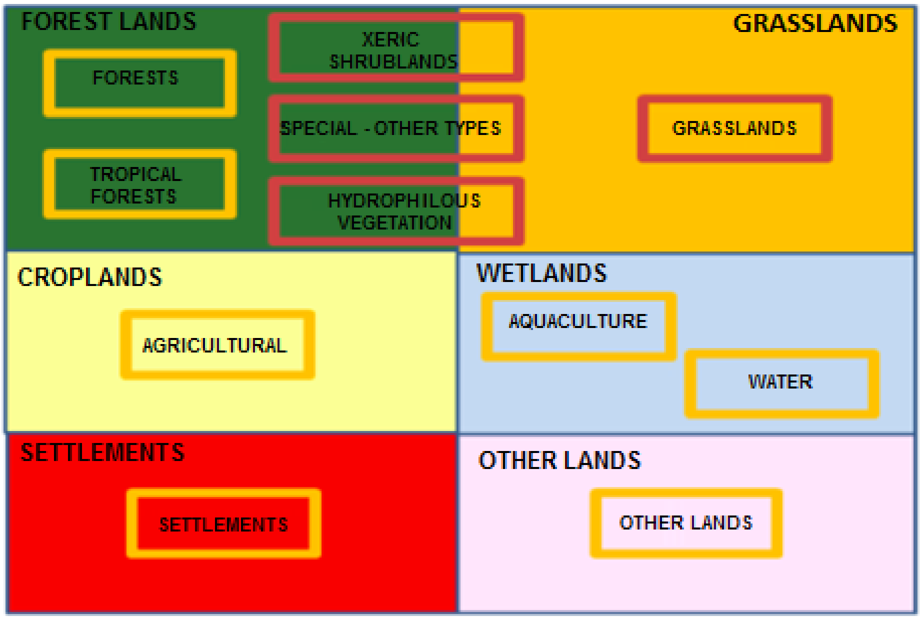


Figure 2. Graphic representation of the INEGI Series grouped into IPCC Categories.

The criteria to define the vegetation groups and types[5] that correspond to the category of forest land that were used in this report to estimate gross deforestation are:

[5] The description found in the Guide for Interpreting Land Use and Vegetation Cartography (INEGI, 2009) was considered.

- INEGI Vegetation Group, which refers to a hierarchical level above vegetation types and types of agroecosystems
- Stage (Primary and Secondary)
- INEGI Development Phase (arboreal, shrub and herbaceous)
- Separation of vegetation groups (according to INEGI) into subcategories that group vegetation types corresponding to a dominance of woody (arboreal and shrub) elements and non-woody (herbaceous) elements at different phases of development (IPCC-INEGI).
- IPCC Criteria (IPCC, 2003) for Land Use, Land Use Change, and Forestry (LULUCF) Categories

The forest land category includes all land with woody vegetation within the thresholds used to define forest land in the National Inventory of Greenhouse Gas Emissions (INEGEI). These vegetation systems are subdivided nationally into cultivated and uncultivated lands and by type of ecosystem, as specified in the IPCC guidelines. This category also comprises systems with woody vegetation currently below the forest land category threshold, including any land with the ecological capacity to reach this threshold. Table 2 shows the categories regarded as forest land.

Table 2. INEGI vegetation types arranged by vegetation groups and development stage included in the IPCC Forest Land category

Vegetation Group Proposal (INEGI-IPCC)	Vegetation Type (INEGI)
Coniferous Forest (Primary and Secondary Arboreal Vegetation)	Primary Oyamel (Sacred Fir) Forest, Arboreal Secondary Oyamel Forest, Primary Cypress Forest, Arboreal Secondary Cypress Forest, Primary Juniper Forest, Arboreal Secondary Juniper Forest, Primary Pine Forest, Arboreal Secondary Pine Forest, Primary Mixed Pine-Oak Forest, Arboreal Secondary Mixed Pine-Oak Forest, Primary Ayarín (Spruce-Fir) Forest, Arboreal Secondary Ayarín Forest, Primary Conifer Shrubland
Secondary Conifer Forest (Secondary Shrub and Herbaceous)	Secondary Oyamel Shrub Forest, Secondary Oyamel Herbaceous Forest, Secondary Cypress Shrub Forest, Secondary Cypress Herbaceous Forest, Secondary Juniper Shrub Forest, Secondary Juniper Herbaceous Forest, Primary Pine Forest, Arboreal Secondary Pine Forest, Primary Mixed Pine-Oak Forest, Arboreal Secondary Mixed Pine-Oak Forest, Primary Ayarín Forest, Arboreal Secondary Ayarín Forest, Primary Conifer Shrubland
Primary Oak Forest	Primary Oak Forest, Arboreal Secondary Oak Forest, Primary Mixed Oak-Pine Forest, Arboreal Secondary Mixed Oak-Pine Forest
Secondary Oak Forest	Herbaceous Secondary Oak Forest, Shrubby Secondary Oak Forest, Secondary Shrubby Mixed Oak-Pine Forest, Herbaceous Secondary Mixed Oak-Pine Forest
Primary Mountain Cloud Forest	Primary Mountain Cloud Forest, Arboreal Secondary Mountain Cloud Forest
Secondary Mountain Cloud Forest	Shrubby Secondary Mountain Cloud Forest, Herbaceous Secondary Mountain Cloud Forest
Primary Evergreen Tropical Forest	High-Stature Primary Evergreen Tropical Forest, High-Stature Secondary Evergreen Tropical Forest, High-Stature Primary Semi-Evergreen Tropical Forest, High-Stature Secondary Semi-Evergreen Tropical Forest Low-Stature Primary Evergreen Tropical Forest, Low-Stature Arboreal Secondary Evergreen Tropical Forest, Low-Stature Thorny Primary Semi-Evergreen Tropical Forest, Low-Stature Thorny Arboreal Secondary Semi-Evergreen Tropical Forest, Low-Stature Primary Semi-Evergreen Tropical Forest, Low-Stature Arboreal Secondary Semi-Evergreen Tropical Forest, Medium-Stature Primary Evergreen Tropical Forest, Medium-Stature Arboreal Secondary Evergreen Tropical Forest, Medium-Stature Primary Semi-Evergreen Tropical Forest, Medium-Stature Arboreal Secondary Semi-Evergreen Tropical Forest

Secondary Evergreen Tropical Forest	High-Stature Shrubby Secondary Evergreen Tropical Forest, High-Stature Herbaceous Secondary Evergreen Tropical Forest, High-Stature Shrubby Secondary Semi-Evergreen Tropical Forest, High-Stature Herbaceous Secondary Semi-Evergreen Tropical Forest, Low-Stature Shrubby Secondary Evergreen Tropical Forest, Low-Stature Herbaceous Secondary Evergreen Tropical Forest, Low-Stature Thorny Shrubby Secondary Semi-Evergreen Tropical Forest, Low-Stature Thorny Herbaceous Secondary Semi-Evergreen Tropical Forest, Low-Stature Shrubby Secondary Semi-Evergreen Tropical Forest, Low-Stature Herbaceous Secondary Semi-Evergreen Tropical Forest, Medium-Stature Shrubby Secondary Evergreen Tropical Forest, Medium-Stature Herbaceous Secondary Evergreen Tropical Forest, Medium-Stature Shrubby Secondary Semi-Evergreen Tropical Forest, Medium-Stature Herbaceous Secondary Semi-Evergreen Tropical Forest
Primary Semi-Deciduous Tropical Forest	Low-Stature Primary Semi-Deciduous Tropical Forest, Low-Stature Arboreal Secondary Semi-Deciduous Tropical Forest, Medium-Stature Primary Semi-Deciduous Tropical Forest, Medium-Stature Arboreal Secondary Semi-Deciduous Tropical Forest
Secondary Semi-Deciduous Tropical Forest	Low-Stature Shrubby Secondary Semi-Deciduous Tropical Forest, Low-Stature Herbaceous Secondary Semi-Deciduous Tropical Forest, Medium-Stature Shrubby Secondary Semi-Deciduous Tropical Forest, Medium-Stature Herbaceous Secondary Semi-Deciduous Tropical Forest
Primary Deciduous Tropical Forest	Primary Subtropical Shrubland, Low-Stature Primary Deciduous Tropical Forest, Low-Stature Arboreal Secondary Deciduous Tropical Forest, Low-Stature Thorny Primary Deciduous Tropical Forest, Low-Stature Thorny Secondary Deciduous Tropical Forest, Medium-Stature Primary Deciduous Tropical Forest, Medium-Stature Arboreal Secondary Deciduous Tropical Forest, Primary Tropical Mezquite Shrubland, Arboreal Secondary Tropical Mezquite Shrubland
Secondary Deciduous Tropical Forest	Low-Stature Shrubby Secondary Deciduous Tropical Forest, Low-Stature Herbaceous Secondary Deciduous Tropical Forest, Low-Stature Thorny Shrubby Secondary Deciduous Tropical Forest, Low-Stature Thorny Herbaceous Secondary Deciduous Tropical Forest, Medium-Stature Shrubby Secondary Deciduous Tropical Forest, Medium-Stature Herbaceous Secondary Deciduous Tropical Forest, Shrubby Secondary Tropical Mezquite Shrubland, Herbaceous Secondary Tropical Mezquite Shrubland, Shrubby Secondary Subtroptical Shrubland, Herbaceous Secondary Subtroptical Shrubland,
Primary Xeric Shrubland	Primary Succulent Shrubland, Primary Microphyllous Desert Shrubland, Rosette-Like Microphyllous Desert Shrubland, Primary Tamaulipan Thorny Shrubland, Primary Xeric Mezquite Shrubland, Chaparral, Primary Coastal Rosette-Like Desert Shrubland, Primary Sarcocaulous Shrubland, Primary Sarco-Succulent Shrubland, Primary Submountainous Shrubland, Arboreal Secondary Submountainous Shrubland, Primary Misty Sarco-Succulent Shrubland,
Secondary Xeric Shrubland	Shrubby Secondary Succulent Shrubland, Herbaceous Secondary Succulent Shrubland, Shrubby Secondary Microphyllous Desert Shrubland, Herbaceous Secondary Microphyllous Desert Shrubland, Shrubby Secondary Rosette-Like Desert Shrubland, Herbaceous Secondary Rosette-Like Desert Shrubland, Thorny Shrubby Secondary Tamaulipan Shrubland, Thorny Herbaceous Secondary Tamaulipan Shrubland, Shrubby Secondary Xeric Mezquite Shrubland, Herbaceous Secondary Mezquite Shrubland, Shrubby Secondary Chaparral, Shrubby Secondary Coastal Rosette-Like Shrubland, Herbaceous Secondary Coastal Rosette-Like Shrubland, Shrubby Secondary Sarcocaulous Shrubland, Herbaceous Secondary Sarcocaulous Shrubland, Shrubby Secondary Sarco-Succulent Shrubland, Herbaceous Secondary Sarco-Succulent Shrubland, Shrubby Secondary Submountainous Shrubland, Herbaceous Secondary Submountainous Shrubland, Shrubby Secondary Misty Sarco-Succulent Shrubland, Herbaceous Secondary Misty Sarco-Succulent Shrubland
Primary Hydrophilous Vegetation	Primary Gallery Vegetation, Primary Gallery Forest, Arboreal Secondary Gallery Forest, Primary Peten Vegetation, Arboreal Secondary Peten Vegetation, Primary Gallery Tropical Forest, Arboreal Secondary Gallery Tropical Forest, Primary Mangrove Forest, Arboreal Secondary Mangrove Forest
Secondary Hydrophilous Vegetation	Shrubby Secondary Gallery Forest, Herbaceous Secondary Gallery Forest, Shrubby Secondary Peten Vegetation, Herbaceous Secondary Peten Vegetation, Shrubby Secondary Gallery Tropical Forest, Herbaceous Secondary Gallery Tropical Forest, Shrubby Secondary Gallery Vegetation, Herbaceous Secondary Gallery Vegetation, Shrubby Secondary Mangrove Forest, Herbaceous Secondary Mangrove Forest,
Special - Other Primary Types	Primary Mezquite Forest, Arboreal Secondary Mezquite Forest, Primary Natural Palm-Tree Forest, Arboreal Secondary Natural Palm Tree Forest, Induced Tree Plantation
Special - Other Primary Secondary Types	Shrubby Secondary Mezquite Forest, Herbaceous Secondary Mezquite Forest, Induced Palm-Tree Forest, Herbaceous Secondary Natural Palm-Tree Forest, Shrubby Secondary Natural Palm-Tree Forest
Planted forest	Tree Plantation

The cartographic information contained in the Land Use and Vegetation maps at a scale of 1:250,000 in Series II, III, IV, and V prepared by the INEGI were originally issued and are currently distributed in vector format, where Land Use and Vegetation units are represented with polygons.

The process to analyze the cartographic products converted by INEGI from analog to digital format considered that the mechanisms for perception and analysis of digital data differ from those used for analog data, and even though they can be visualized on graphic monitors, their analysis was performed fundamentally through a combination of statistical and geometric methods and database inquiry.

Geospatial data was processed using the software ArcGIS 10.1© (ESRI©, 2012). The first step was to integrate the vector data from the Land Use and Vegetation Maps (scale 1:250,000) of Series II, III, IV, and V.

Fields were added to the database of each Series in order to assign the categories and subcategories of the national land system applicable to the six LULUCF categories of the IPCC. Subsequently, vector databases were restructured, leaving only the information of the national land classification system applicable to the six LULUCF categories of the IPCC. All the Series were joined spatially by geometrically overlaying and intersecting them through the command "UNION" in ArcGIS©.

After performing the analysis of data in vector format, it was determined that using a *raster* format with a cell size of 100x100 meters (one hectare) would eliminate most problems related to displacements between Series. Consequently, vector data was converted to raster format using a cell size of 100x100 meters and the IPCC categories as the main field. This analysis rendered the following land use and vegetation change matrix (Figure 3).

Count	inegi_s2	inegi_s3	inegi_s4	inegi_s5
28022445	PE	PE	PE	PE
108047764	H2O	H2O	H2O	H2O
2	H2O	H2O	H2O	H2O
273	H2O	H2O	H2O	H2O
1088213	ZU	ZU	ZU	ZU
8936	R	AH	AH	AH
4108725	R	R	R	R
13965	ML	VSaML	VSaML	ML
1770289	ML	ML	ML	ML
214114	VSaML	VSaML	VSaML	ML
113	VO	VO	VSaML	ML
195577	VO	VO	VO	VO
241	VSaML	VSaML	VO	VO
3229	VSaML	AH	AH	AH
874	VSaML	VSaML	RAP	RAP
12553556	TA	TA	TA	TA
12963	BJ	VSaBJ	VSaBJ	VSaBJ
613	ML	VSaML	R	R
1478	ML	AH	AH	AH
675	ML	ML	AH	AH
364	BJ	VSaBJ	R	R
1	R	PE	R	R
381	ZU	VSaML	VSaML	ML
18270068	MDM	MDM	MDM	MDM
69	MDM	MDM	PE	PE
4183	VSaML	VSaML	R	R
9968575	MDR	MDR	MDR	MDR
5879	ML	R	R	R
317011	RA	RAS	RAS	RAS
2	RA	PE	PE	PE
9309	MDM	MDM	MDM	DV
13365	RA	AH	AH	AH
1	ZU	PE	ZU	ZU
193	VSaML	RAP	RAP	RAP
9097	ML	ML	VSaML	ML
556	VSaML	VSaML	VSaML	AH

Figure 3. Image of the raster file and the attribute table of the combination of Series II to V

The results were presented in three change matrices, each describing a period of comparison between Series:

- Period 1. Comparison between Land Use and Vegetation of Series II and III
- Period 2. Comparison between Land Use and Vegetation of Series III and IV
- Period 3. Comparison between Land Use and Vegetation of Series IV and V

The database resulting from the integration of the Land Use and Vegetation Series II, III, IV, and V using the report categories in the National Greenhouse Gas Emissions Inventory (INEGEI) was exported to MS Excel, as this format and application allows for the use of dynamic tables to aggregate land use and vegetation changes between Series.

Figure 4 illustrates the matrix used to identify the surface area values for each category of change. The matrix identifies the areas whose primary condition changed to a secondary one, implying a loss of carbon on forest lands (degradation). It also identifies the different categories of forest lands that changed to non-forest lands due to the expansion of agriculture and human settlements, indicating deforestation.

In contrast to the previous processes, the matrix shows the areas whose secondary condition changed to a primary one, indicating processes of forest recovery. Moreover, it records the areas where non-forest lands changed to forest lands (primary or secondary) through reforestation processes.

Finally, this matrix shows the areas with no recorded changes in land use (cells in yellow).

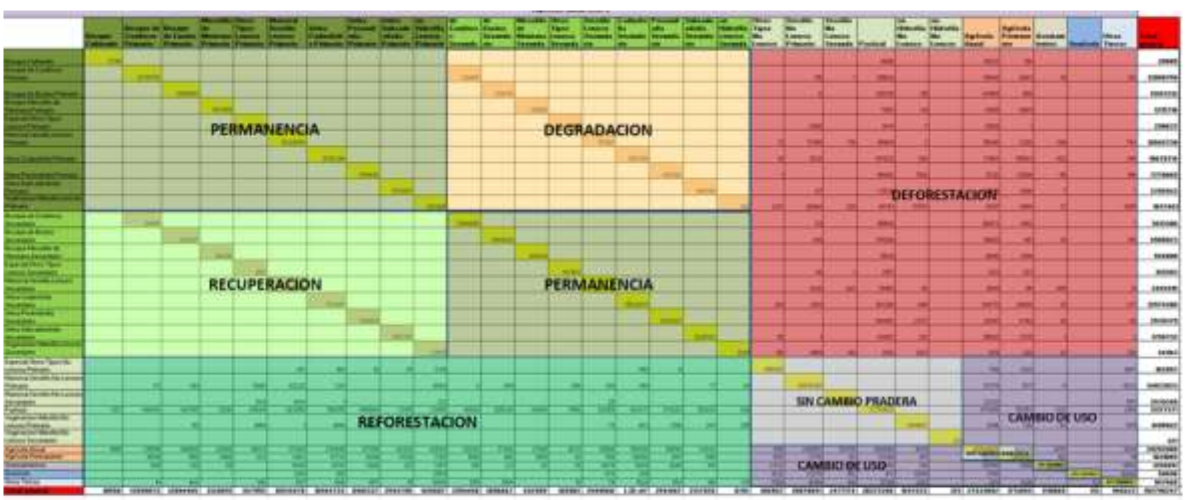


Figure 4. Example of the matrix used to identify the different conditions of change that can be observed

The methodology for the consistent representation of lands is documented in greater detail as part of the formulation of the INEGEI for the BUR (Reinforcing REDD+ Readiness in Mexico and Enabling South-South Cooperation, 2014a)

b) Emission Factors

The estimation process of emission factors (EF) included three stages: the first stage involved obtaining the carbon values of each tree measured by the INFyS; the second stage involved grouping INFyS plots into the land use and vegetation classes defined as forest lands; the third stage consisted in estimating the EF and their uncertainties (those associated with carbon in live biomass) for each of the classes defined as forest lands.

The content of carbon in live biomass at tree level was calculated using the stem measurements of woody plants (trees and shrubs) collected by INFyS field samplings between 2004 and 2007 (CONAFOR, 2012). The estimate used the dasometric data measured in 18,780 Primary Sampling Units (PSU), which included 70,868 Secondary Sampling Units (SSU) with dasometric data from 1,137,872 records of live woody plants (trees and shrubs) and 68,300 records of standing dead woody plants (trees and shrubs).

Prior to estimating tree-level carbon, a quality control protocol was applied to INFyS records of woody plants (tree and shrubs). This protocol included: a) reviewing the nomenclature of species, and b) debugging the dasometric information.

To estimate the biomass contained in each live woody plant, an algorithm was employed to assign allometric models (Figure 5). A total of 83 allometric models (available at the level of species, genera, or vegetation type) suitable for the country in ecological, statistical, and spatial terms were used (Reinforcing REDD+ Readiness in Mexico and Enabling South-South Cooperation, 2014b). The allometric model database used to perform biomass estimation is available for review at: http://www.mrv.mx/index.php/es/mrv-m/areas-de-trabajo/2013-09-17-22-03-45

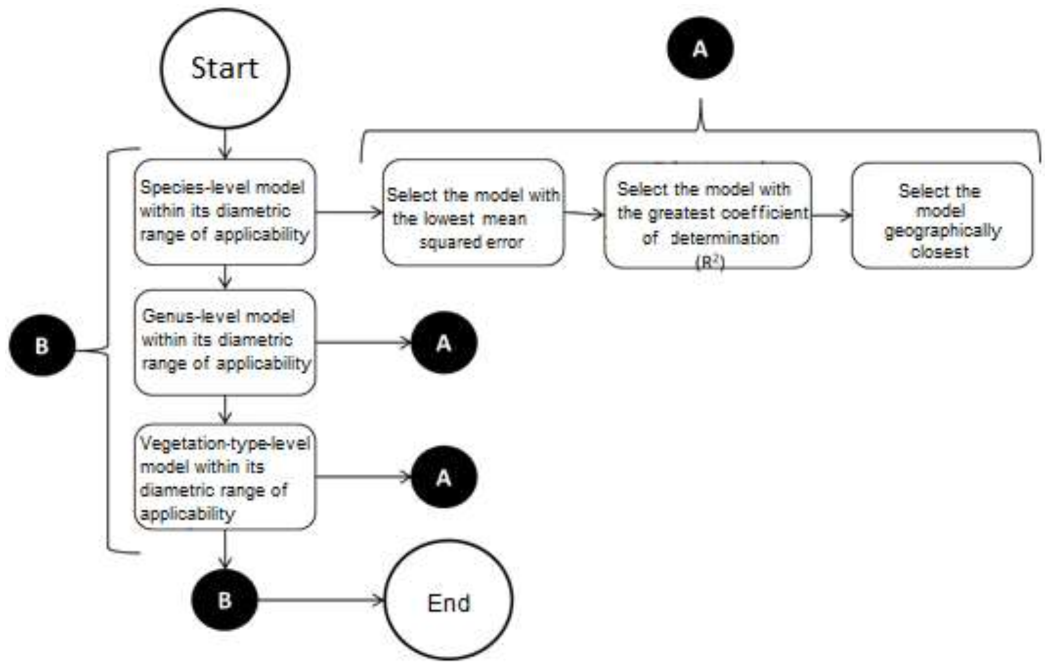


Figure 5. Decision tree algorithm used to assign allometric models to estimate tree-level biomass

To quantify below-ground biomass (roots), the allometric equations of Cains *et al* (1997) were employed as a function of above-ground woody biomass by type of ecosystem.

Using the biomass estimates obtained, a carbon fraction was assigned to each record (species, genus, and plant group) from the 56 carbon fractions found in the literature that are applicable to species in the country. When there was no carbon fraction available for a given record at the level of the species, genus, and/or vegetation type, an average fraction of 0.48% was assigned. This number was calculated from the data obtained from the records of carbon fractions found in literature at the national level[6].

Once aboveground woody biomass carbon was estimated at tree-level, the carbon of all the trees measured within each INFyS sub-plot was added to obtain the total aerial biomass at the sub-plot level (Figure 6). To estimate the total carbon (at the sub-plot level) in root biomass, a procedure analogous to the one used for above-ground woody biomass was followed.

[6] Protocol to Estimate Carbon Contents and Changes in Carbon Contents, Project to Strengthen REDD+ Capabilities and South-South Cooperation, CONAFOR 2014

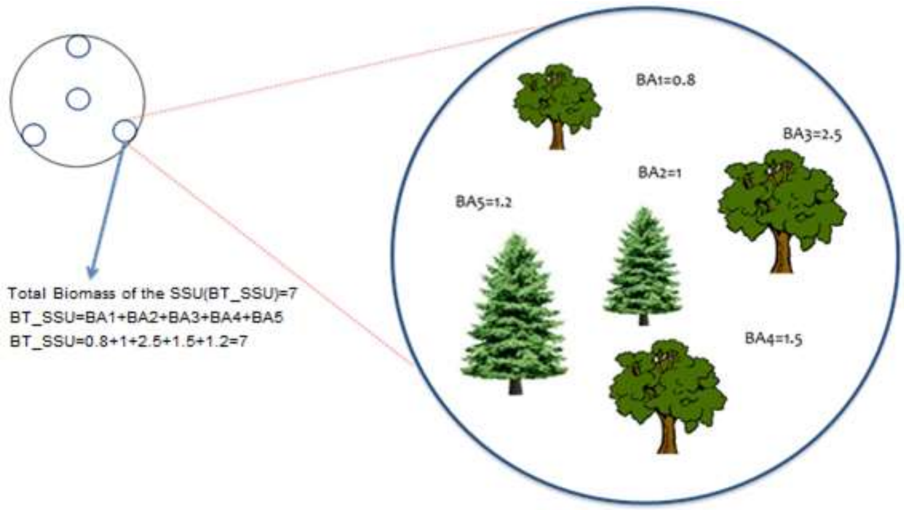


Figure 6. Estimate of total above-ground woody biomass at the sub-plot level

After estimating the total carbon at the sub-plot level for each carbon stock (above-ground woody biomass and roots), the INFyS plots were grouped according to their forest vegetation cover. Since the plots are georeferenced, it was possible to identify the vegetation cover subcategory to which each one belonged using INEGI Series IV. Table 3 shows the grouping of INFyS plots by subcategory of forest vegetation cover.

Table 3. Number of plots sampled for the National Forest and Soils Inventory (INFyS) with available information by forest vegetation cover subcategory

Subcategory	Sampling (2004-2007)
	Number of Plots
Planted Forest	8
Primary Conifer Forest	4404
Secondary Conifer Forest	1137
Primary Oak Forest	3365
Secondary Oak Forest	1466
Primary Cloud Forest	357
Secondary Cloud Forest	160
Special - Other Primary Woody Ecosystems	32
Special - Other Secondary Woody Ecosystems	31
Special - Other Primary Non-Woody Ecosystems	3
Primary Woody Xeric Shrublands	1484
Secondary Woody Xeric Shrublands	198

Primary Non-Woody Xeric Shrublands	864
Secondary Non-Woody Xeric Shrublands	81
Grasslands	1806
Primary Deciduous Tropical Forest	939
Secondary Deciduous Tropical Forest	613
Primary Evergreen Tropical Forest	2375
Secondary Evergreen Tropical Forest	585
Primary Semi-Deciduous Tropical Forest	993
Secondary Semi-Deciduous Tropical Forest	491
Primary Woody Hydrophilous Vegetation	246
Secondary Woody Hydrophilous Vegetation	17
Primary Non-Woody Hydrophilous Vegetation	156
Total	**21,811**

Source: Prepared by the author with data from the INFyS (2004-2007) and Series IV with INEGI vegetation types grouped into the subcategories of the National Greenhouse Gas Emissions Inventory.

The EF ratio estimators and their uncertainties were calculated for each carbon stock (above-ground woody biomass and roots biomass) in forest lands based on the grouping of INFyS sampling plots described above.

These EF were estimated for "Forest Lands" that changed to "Other Land Uses." Therefore, to obtain the estimators, it was assumed that the lands subject to such deforestation process lost all the carbon (from both above-ground woody biomass and roots) they stored. Accordingly, the average carbon densities (ton/ha) and their uncertainties were estimated for each subcategory and it was assumed that these values, calculated at the national level, represent local-level emissions in deforestation zones.

To obtain these estimates, carbon data at the sub-plot level from the first INFyS cycle (2004-2007) was used, having filtered beforehand the plots that do not belong to "Forest Lands" according to the IPCC (2003) classification of "Lands Uses". In this manner, the estimators were constructed using a total sample size of 21,811 plots out of the 26,220 present in the INFyS (Figure 6 and Table 3).

After identifying the subset of plots with which the estimation would be carried out, the estimators and their uncertainties were obtained.

The expression of this estimator is shown in the following equation:

$$\widehat{R}_k = \frac{\sum_{i=1}^{n_k} y_{ik}}{\sum_{i=1}^{n_k} a_{ik}} \qquad \text{Eq (1)}$$

In which:

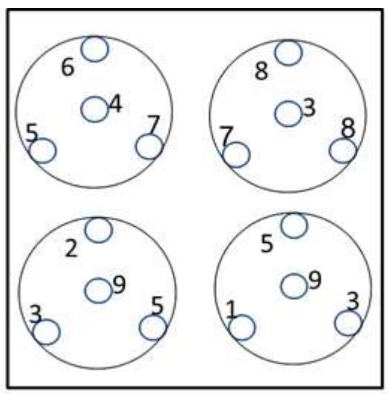
$\widehat{R}_k$ = Carbon estimator of stratum k.

y_{ik} =Total carbon in the sub-plot/site (or SSU) i of stratum k.

a_{ik} =Surface area sampled in the sub-plot/site (or SSU) i (400m2) of stratum k.

n_k =Total number of sites in stratum k.

The plot "ratio estimator" is directly used in calculating carbon content for each subcategory of forest land defined for the country. The procedure consists of using the group of plots belonging to each subcategory to determine the carbon content adjusted to their areas in order to obtain the emission and removal factors at the national level. Figure 7 illustrates a group of plots forming a stratum and how they are aggregated to quantify carbon using ratio estimators.



$$\hat{R} = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} a_i}$$

$$\hat{R} = \frac{5+6+4+7+7+8+3+8+3+2+9+5+1+5+9+3}{0.04 \times 16}$$

$$\hat{R} = \frac{85}{0.64} = 132.8$$

Figure 7. Example of the use of ratio estimators to calculate carbon in an INFyS subcategory

The 2006 IPCC Guidelines were followed to estimate the uncertainties of each EF. Accordingly, Equation 3 bellow shows the expression used to estimate them:

$$U_k = \frac{IC_k/_2}{\bar{R}_k} \times 100 \qquad \text{Eq (2)}$$

In which:

U_k: Uncertainty of the carbon estimator of subcategory k.
$\bar{x}_k$: Carbon estimator of subcategory k.
IC_k: Interval of the carbon estimator of subcategory k.

Where IC_k is in function of the variance of $\hat{R}_k$:

$$\hat{R}_k - 1.96\sqrt{\hat{V}(\hat{R}_k)} \leq R_k \leq \hat{R}_k + 1.96\sqrt{\hat{V}(\hat{R}_k)}$$

And $\hat{V}(\hat{R}_k)$ is defined as shown in Equation 3 (Velasco-Bautista *et al.*, 2003):

$$\hat{V}(\hat{R}_k) = \left(\frac{1}{n_k(n_k-1)\bar{a}^2}\right)\left(\sum_{i=1}^{n_k} y_{ik}^2 - 2\,\hat{R}_k \sum_{i=1}^{n_k} y_{ik} a_{ik} + \hat{R}_k^{\,2} \sum_{i=1}^{n_k} a_{ik}^2\right) \qquad \text{Eq (3)}$$

Where:

$\hat{R}_k$, y_{ik}, a_{ik} and n_k were defined previously.

$$\bar{a} = \frac{\sum_{i=1}^{n} a_i}{n}$$

The management of the databases and estimation processes was programmed and executed using the statistical software R.

Table 4 shows emission factor estimates and their respective uncertainties related to above-ground woody biomass and root carbon for the lands that changed from "Forest Lands" to "Other Uses." As observed, the estimates behave in a consistent manner between subcategories and within subcategories (primary/secondary). For example, the carbon content averages of coniferous forests are higher than averages found in oak forests; within the subcategory of oak forests, the average carbon in primary forests is greater than that of secondary forests. Additionally, Table 4 provides evidence of estimates being obtained from large sample sizes, rendering low uncertainties (Reinforcing REDD+ Readiness in Mexico and Enabling South-South Cooperation, 2014c).

Table 4. Emission factors and their uncertainties for carbon from above-ground woody biomass and roots from "Forest Lands" that changed to "Other Uses"

Subcategory	Carbon in Above-ground Woody Biomass (ton/ha)	Uncertainty (%)	Carbon in Roots (ton/ha)	Uncertainty (%)
Planted Forests	34.6	38	8.4	37
Primary Conifer Forest	33.6	2	8.0	2
Secondary Conifer Forest	22.1	5	5.4	5
Primary Oak Forest	20.7	3	5.6	3
Secondary Oak Forest	14.7	5	4.0	5
Primary Cloud Forest	37.7	10	9.4	9
Secondary Cloud Forest	18.1	19	4.7	18
Special - Other Primary Woody Ecosystems	3.5	95	0.8	92
Special - Other Secondary Woody Ecosystems	4.6	56	1.2	53
Primary Woody Xeric Shrublands	4.3	9	1.1	8
Secondary Woody Xeric Shrublands	3.2	29	0.8	27
Primary Deciduous Tropical Forest	17.4	5	4.3	5
Secondary Deciduous Tropical Forest	12.6	8	3.1	7
Primary Evergreen	40.4	3	9.5	3

Tropical Forest				
Secondary Evergreen Tropical Forest	19.7	9	4.8	9
Primary Semi-Deciduous Tropical Forest	30.2	5	7.3	4
Secondary Semi-Deciduous Tropical Forest	16.1	9	4.0	8
Primary Woody Hydrophilous Vegetation	13.3	22	3.2	21
Secondary Woody Hydrophilous Vegetation	8.1	66	2.0	64

To determine the value of carbon stocks in forest lands that changed to croplands, the 2003 IPCC Good Practice Guidance (GBP, per their Spanish initials) was followed, especially Table 3.3.8, page 3.95, Chapter 3 containing tier 1 default values since there is no data available for the country, as shown in Table 5.

Table 5. Default values of carbon stocks present in the biomass of lands converted to croplands in the year following their conversion

Type of crop by climate region	Change in carbon stocks in one year of cropland growth (tC/ha.)	Error range[7]
Annual cropland	5	±75%
Perennial cropland		
Temperate (All moisture regimes)	2.1	±75%
Tropical, dry	1.8	±75%
Tropical, humid	2.6	±75%

These values were used according to the type of agriculture. This means that for annual crops, the value for stock variation will always be 5. For perennial crops, values were used depending on climate type. This means that if change occurred in a forest, it is taken as temperate; if it occurs in a shrubland, it is dry; and if it occurs in a tropical forests, it is taken as humid tropical.

For forest land transitions to grasslands, settlements, wetlands, and other lands, the total loss of carbon in greenhouse gases (GHG) is inferred.

c) Propagation of Uncertainty

[7] This represents a nominal estimate of error equivalent to two times the standard deviation expressed as a percentage of the mean.

The propagation of uncertainty was developed from the combination of uncertainties of the annual variations in carbon for each transition grouped in the transition "Forest Lands" that changed to "Other Uses."

To combine the uncertainties of the annual carbon variations at the level of transition, first the uncertainties were estimated for each variations by subcategory (carbon in above-ground woody biomass and roots). To do this, the EF and their respective uncertainties (whose estimation is described in the Emission Factors section) were taken as an input. These EF and uncertainties are reported according to the vegetation types (classes) defined in the Activity Data (AD)section.

The propagation method used was the analytical method (*Method 1: Error Propagation)* of the IPCC (2006). It was chosen because it is easy to implement and suitable for the information related to EF available. It is worth mentioning that, currently, the uncertainties related to Activity Data are unavailable, this was another reason for choosing Method 1 of the IPCC. Consequently, the complete propagation of uncertainties for all levels was carried out by consecutively implementing the combination of uncertainties for addition and subtraction as indicated by IPCC in one of the combination options of Method 1.

Combination of Uncertainties at the Class Level in the Deforestation Transition

The estimate for carbon variations at the level of this transition was obtained by adding the variations in the above-ground woody biomass subcategory and in the subcategory of root biomass for each class. The variations in each of these subcategories resulted from weighting the EF of each class by their respective area (see Equation 4).

$$ABVA_{kij} = FA_{BVA_{kij}} \times A_{BVA_{kij}} \qquad \text{Eq (4)}$$

Where:

$ABVA_j$: Carbon variation in above-ground live biomass of class j of the transition analyzed
FA_{BVA_j}: Carbon Emission Factor of the live biomass of class j of the transition analyzed
A_{BVA_j}: Area of FA_{BVA_j} of subcategory j of the class analyzed

As observed in the equation above, the variation in carbon of the above-ground live biomass (ABVA) was the result of multiplying a variable (the EF) and a constant (the area). Therefore, the uncertainty of the ABVA directly inherits the properties of the EF's uncertainty, as the area is a constant. Additionally, the uncertainties are in function of the variance of the estimator, therefore, the properties of the variance for the EF were used to propagate the uncertainties. The EF for this IPCC transition were obtained from the ratio estimators (Velasco, 2003) and this estimator has the property that, when weighted by a constant, the product variance ($FA_{BVA_{ij}} \times A_{BVA_{ij}}$) is equal to the EF variance multiplied by the square of the constant (Velasco, 2003). This process is shown in Equation 5.

$$var(ABVA_j) = \left(A_{BVA_j}\right)^2 \times var\left(FA_{BVA_j}\right) \qquad \text{Eq (5)}$$

Where:

$Var(ABVA_j)$: Variance of $ABVA_j$.
$var\left(FA_{BVA_j}\right)$: Variance of FA_{BVA_j},, defined in the protocol for estimating emission factors and uncertainties (Reinforcing REDD+ Readiness in Mexico and Enabling South-South Cooperation, 2014c)

Once the variance of ABVA was obtained for each class, its uncertainties were estimated by following the IPCC Guidance (2003) as laid out in Equation 6.

$$U_{ABVA_j} = \frac{1.96 \times \sqrt{var(ABVA_j)}}{ABVA_j} \times 100 \qquad \text{Eq (6)}$$

Where:

U_{ABVA_j}: Uncertainty of ABVA of class j of the transition analyzed.
$var(ABVA_j)$ and $ABVA_j$: Previously defined.

It must be mentioned that, at the class level, uncertainties for variations in root biomass carbon (ABVR) were estimated in a manner analogous to what is displayed for ABVA.

To obtain live biomass by class, the above-ground woody biomass and the biomass in roots were added up. Therefore, after estimating the uncertainties of the ABVR and the ABVA, they were propagated by combining the uncertainties through addition, as indicated in Method 1 of the IPCC. In this manner, the uncertainties of ABV by subcategory were estimated as shown in Equation 7.

$$U_{ABV_j} = \frac{\sqrt{\left(U_{ABVA_j} \times ABVA_j\right)^2 + \left(U_{ABVR_j} \times ABVR_j\right)^2}}{\left|ABVA_j + ABVR_j\right|} \qquad \text{Eq (7)}$$

Where:

U_{ABV_j}: Uncertainty of carbon changes of live biomass of class j of the transition analyzed
$ABVR_j$: Carbon changes of biomass in roots of class j of the transition analyzed
U_{ABVR_j}: Uncertainty of $ABVR_j$.
U_{ABVA_j} and $ABVA_j$: Previously defined

In the case of "Forest Lands" that changed to "Croplands," the EF of "Croplands" was subtracted from the EF of the estimated live biomass at the subcategory level. Therefore, the EF used for this transition was the result of a subtraction, hence, the uncertainty of this subset of factors was obtained by propagating its respective uncertainties as shown in Equation 7, but for the subtraction.

Propagation of Uncertainty of Variations at the Transition Level due to Deforestation

The estimate of variations at the transition level results from the addition of the variations at the class level (see Equation 8).

$$ABV = \sum_{j=1}^{n_i} ABV_j \qquad \text{Eq (8)}$$

Where:

ABV: Total carbon change for live biomass of the transition analyzed
ABV_j: Carbon change of live biomass of class j of the transition analyzed
n_i: Number of classes in the transition analyzed

As observed in Equation 9, the ABV of the transition analyzed is the result of the addition of ABV of each one of its subcategories. Therefore, the uncertainty was propagated by combining the uncertainties through the addition shown in IPCC Method 1:

$$U_{ABV} = \frac{\sqrt{(U_{ABV_1} \times ABV_1)^2 + (U_{ABV_2} \times ABV_2)^2 + \cdots + (U_{ABV\,n_i} \times ABV_{n_i})^2}}{|ABV_1 + ABV_2 + \cdots + ABV_{n_i}|} \qquad \text{Eq (9)}$$

Where:

U_{ABV}: Uncertainty for total carbon change for live biomass of the transition analyzed
U_{ABV_1}: Uncertainty of the ABV of class 1 of the transition analyzed
U_{ABV_2}: Uncertainty of the ABV of class 2 of the transition analyzed
$U_{ABV_{n_i}}$: Uncertainty of the ABV of class n of the transition analyzed
ABV_1: Carbon variation of live biomass of class 1 of the transition analyzed
ABV_2: Carbon variation of live biomass of class 2 of the transition analyzed
ABV_{n_i}: Carbon variation of live biomass of class n of the transition analyzed

d) Forest Fires

The estimate for emissions due to forest fires is divided into two large groups. The first part of this section concerns CO_2 emissions from the loss of biomass due to fires on forest land. The second part consists of non-CO_2 gas emissions from *in situ* biomass combustion.

The general calculation of GHG emissions from forest fires (spontaneously caused) was made using the following general equation found in the guidance of the IPCC for LULUCF (IPCC, 2003):

$$Lfire = A \bullet B \bullet C \bullet D \bullet 10^{-6}$$

Where:

Lfire = Quantity of greenhouse gases due to forest fires, megagrams

A = Area burnt, hectares
B = Mass of “available” fuel, kg of dry matter ha^{-1}
C = Combustion factor (fraction of biomass consumed), dimension-less
D = Emission Factor

Area Burnt by Forest Fires (A)

The analysis of the area affected by fires was performed using official data from the CONAFOR for the period 1995-2013[8]. These reports record the areas affected by fires fought. These reports do not include fires were not fought, which may lead to an underestimation of this type of disturbance. The affected areas are disaggregated by federal state, year, and stratum of the vegetation affected; the latter are classified into arboreal, shrubs, and herbaceous (Table 6). Generally, fires are superficial, burning mainly dead matter, shrubs and grasses (Estrada, 2006).

Table 6. Example of the database report on fires that occurred in different dominant strata by federal state

	AREA IN HA			
	1998			
STATE	**Herbaceous**	**Shrub**	**Arboreal**	**Total**
Aguascalientes	5	99	63	167
Baja California	2,482	3,009	3	5,494
Baja California Sur	17	2	7	26
Campeche	182	0	5,271	5,453
Chiapas	85,335	47,590	65,883	198,808
Chihuahua	10,435	7,996	9,071	27,502
Coahuila	2,004	10,397	2,093	14,494
Colima	85	1,078	28	1,191
Federal District	4,705	714	316	5,735
Durango	24,191	24,347	20,422	68,960
Guanajuato	134	1,029	1,648	2,811
Guerrero	11,672	5,509	2,012	19,193
Hidalgo	5,984	5,222	3,351	14,557
Jalisco	8,208	6,121	3,867	18,196
State of Mexico	9,616	12,350	3,881	25,847
Michoacán	8,553	11,315	5,922	25,790
Morelos	336	1,778	246	2,360
Nayarit	231	276	1,777	2,284
Nuevo León	502	25,076	2,556	28,134
Oaxaca	144,704	61,803	35,143	241,650
Puebla	5,745	8,860	5,230	19,835
Querétaro	776	15,612	1,136	17,524
Quintana Roo	880	3,920	1,409	6,209

[8] http://www.conafor.gob.mx/web/temas-forestales/incendios/

San Luis Potosí	4,058	13,780	9,343	27,181
Sinaloa	2,757	859	4,595	8,211
Sonora	1,194	380	93	1,667
Tabasco	5,436	5,369	3,133	13,938
Tamaulipas	466	14,846	2,514	17,826
Tlaxcala	4,819	2,617	1,396	8,832
Veracruz	1,730	3,814	4,146	9,690
Yucatán	2,454	2,008	935	5,397
Zacatecas	2,546	1,127	997	4,670
Yearly Total	88,956	105,014	115,117	309,087

The reported area by state was related to the vegetation type which is or has been affected by fires in each state, as not all vegetation types are susceptible to burning. For this analysis, the phases related to dominant vegetation strata were disaggregated into arboreal, shrub, and herbaceous as described by the INEGI in order to link the INEGEI categories to the affected stratum surfaces reported by the CONAFOR. The aforementioned procedure was performed in order to infer the surface area by vegetation type at the state level, as geographical information (polygons) are not available for this activity data.

To select the subcategories historically affected by fires, the spatially explicit data issued by CONAFOR's Office for the Protection against Forest Fires were used as an indicator. A quality control was performed on the georeference data of fires registered between 2005 and 2013. This allowed us to locate 45,433 events (57%) out of the 79.465 recorded between 1995 and 2014. Such records were used as an indicator to weight the occurrence of fires for each subcategory by state where fires may occur (Figure 8). Once each subcategory of occurrence was located by state, it is possible to know upon what amount of surface area and in which affected vegetation strata we may proportionally assign the area affected by forest fires for the whole historical period.

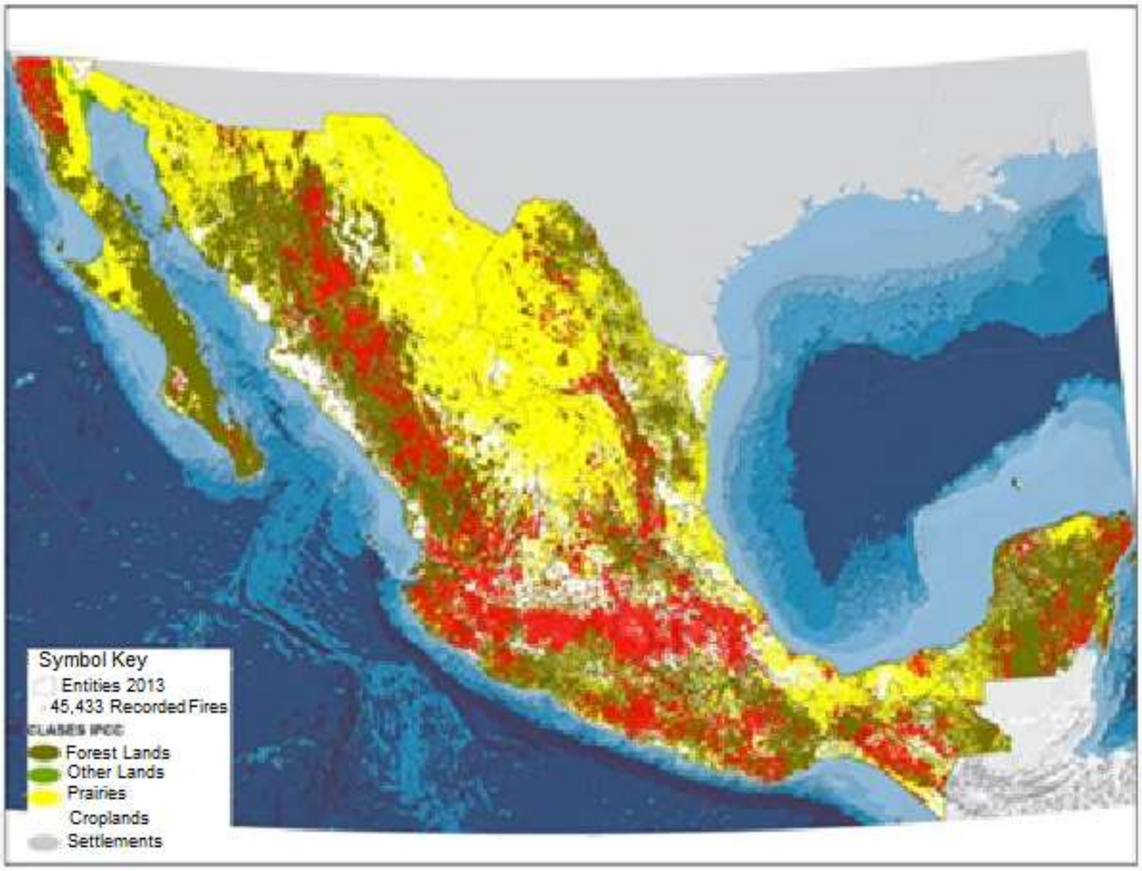


Figure 8. Georeferenced fires by state for the period 2005-2013 using IPCC classes

Using the Land Use and Vegetation data from each of the Series evaluated, the surface areas were quantified by INEGEI subcategory, development phase, and state with the objective of determining the contribution of each stratum affected by fire. The surfaces and their relative areas were obtained according to the time period corresponding to each INEGI Series. Consequently, the areas affected by fires in 1995-2002 were assigned to the relative surface area by state for each subcategory in Series II; the areas affected in 2003-2007 were assigned to Series III; the areas affected in 2008-2011 were assigned to Series IV; and the areas affected in 2012-2013 were assigned to Series III (Table 7).

Table 7. Example of the surface area calculated by state (Aguascalientes) and its relative area by affected stratum (arboreal, shrub, and herbaceous)

	1993	**2002**	**2007**	**2011**		**1993**	**2002**	**2007**	**2011**
COB	**SII**	**SIII**	**SIV**	**SV**		**SII**	**SIII**	**SIV**	**SV**
BE/S	882,957,518	478,462,589	514,287,541	508,007,967		46.24%	40.21%	43.44%	43.21%
MXL/P	303,340,556	300,773,069	190,146,461	188,469,733		15.89%	25.28%	16.06%	16.03%
MXL/S	95,830,915	88,558,123	181,431,851	181,431,851		5.02%	7.44%	15.32%	15.43%
SC/S	627,258,992	322,073,945	298,085,129	297,659,897		32.85%	27.07%	25.18%	25.32%
	1,909,387,981	1,189,867,726	1,183,950,982	1,175,569,448					

In order to distribute the annual surface area affected by fires in each subcategory and stratum by state, the relative area (%) was multiplied by the affected surface in each stratum affected annually for each INEGEI subcategory. The result is the annual proportional surface area affected by fires by subcategory (Figure 9) and state. To finish determining the surface areas affected by surface fires in each subcategory, the figures by state were added to obtain the national total per year.

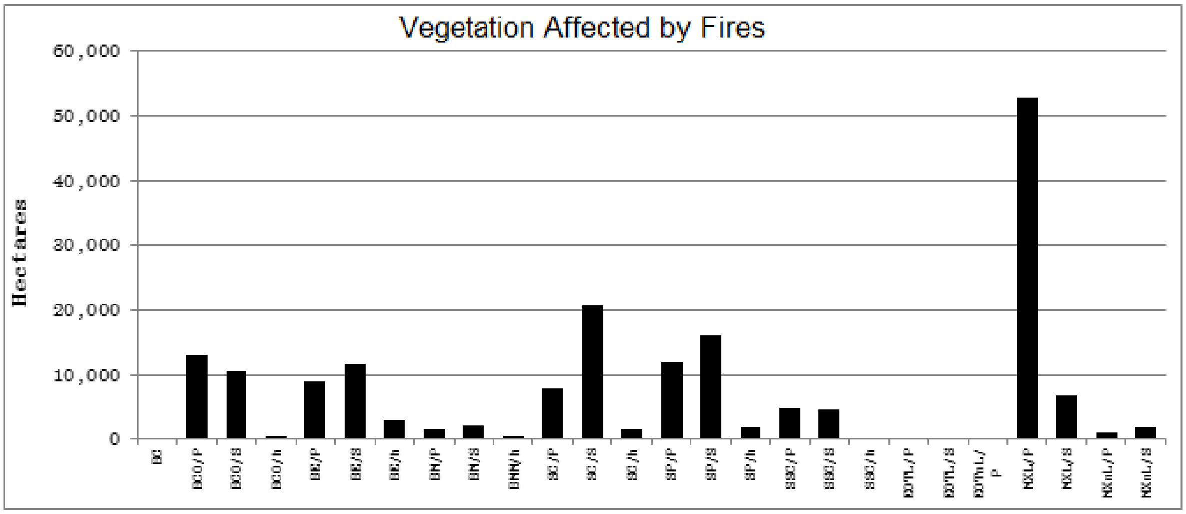


Figure 9. Surface area (ha) by INEGEI subcategory affected by fires

Mass of Available Fuel (B)

To quantify the available fuel, we will focus on the concept of "fuel bed," defined as a unit of vegetative material representing one or several combustion environments (Riccardi *et al.* 2007), for surface fires −which are the most common in Mexico−. It consists of the following strata: fermentation horizon, surface leaves, dead woody matter, vegetation of low height (herbaceous stratum), and shrubs.

Based on the above mentioned categories, the fuels (biomass and necromass) were quantified mainly using the photo series tool for quantifying forest fuels applicable to the ecosystems located in the Mexican territory (Alvarado *et al.* 2008, Ottmar *et al.* 2007, Ottmar *et al.* 2000), and which are used as a major source in the Fuel Characteristic Classification System (FCCS). Additionally, an exhaustive search was made in the scientific and gray literature (theses, reports, and conference proceedings) containing information on different types of vegetation and fuel components in various states of the Mexican Republic and the border states of the United States of America with which forest ecosystems are shared, so as to cover the maximum available information.

The literature review obtained 186 prototype fuel beds for different types of vegetation in Mexico (Table 8). With the aim of making generalizations at the national level, prototype fuel beds were aggregated according to the methods suggested by Hardy *et al.* 2000 to form fuel conditions representing each INEGEI subcategory.

Table 8. Vegetation types and the Fuel Condition Class (FCC) that represents it (N = Number of sites that represent the FCC).

INEGEI Subcategory (FCC)	INEGI Vegetation Type	Source	N
Conifer Forest	Pine Forest	Alvarado *et. al* 2008, Alvarado (unpublished data), Estrada 2006, Navarrete 2006, Ordoñez *et al.* 2008, Ottmar*et al.* 2000, Ottmar*et al.* 2007, Pérez 2005, Stephens 2004, Villers-Ruiz *et al.* 2001	36
	Mixed Pine-Oak Forest	Alvarado *et al.* 2008, Camp *et al.* 2006, Estrada 2006, Fulé and Covington 1994, Navarrete 2006, Ordoñez *et al.* 2008, Pérez 2005, Rodríguez and Sierra 1995, Villers-Ruiz *et al.* 2001	7
	Oyamel Forest	Alvarado *et al.* 2008, Estrada 2006, Navarrete 2006, Ordoñez *et al.* 2008, Pérez 2005, Rodríguez y Sierra 1995	19
	Juniper Forest	Ottmar *et al.* 2000	9
Oak Forest	Oak Forest	Alvarado *et al.* 2008, Estrada 2006, Fulé and Covington 1994, Morales *et al.* 2000, Navarrete 2006, Ordoñez *et al.* 2008, Ottmar*et al.* 2000, Ottmar*et al.* 2007, Pérez 2005, Rodríguez and Sierra 1995, Villers-Ruiz *et al.* 2001	14
	Mixed Oak-Pine Forest	Villers*et al.* 2001, Alvarado *et al.* 2008, Ottmar*et al.* 2007, Estrada 2006	16
Mountain Cloud Forest	Mountain Cloud Forest	Alvarado *et. al* 2008, Asbjornsen *et al.* 2005	5
Evergreen Tropical Forest	High-Stature Evergreen Tropical Forest	Hughes *et al.* 2000, Hughes *et al.* 1999	22
Semi-Deciduous Tropical Forest	Medium-Stature Semi-Deciduous Tropical Forest	CONAFOR-USFS 2006, Harmond *et al.* 1995, Jaramillo *et al.* 2003, Whigham *et al.* 1991,	14
	Low-Stature Semi-Deciduous Tropical Forest	CONAFOR-USFS 2006	2
Deciduous Tropical Forest and Other Special Types (Mezquite Forest)	Low-Stature Deciduous Tropical Forest	Jaramillo *et al.* 2003, Romero-Duque, 2008	13
	Subtropical Shrubland	Pérez 2005, Navarrete 2006, Ordoñez *et al.* 2008	1
Xeric Shrubland	Chaparral	Ottmar *et al.* 2000	16
	Submountainous	Alvarado *et. al* 2008, Rodríguez and	3

	Shrubland	Sierra 1995	
	Xeric Shrublands (Various)	INE, 2006	5

Since there are few works available to represent the heterogeneity of Mexican ecosystems and the number of observations is varied for each category per FCC (in some cases, there are more than 20 observations and in others, only 3), the quantity of available fuel was obtained using the median as the measure of the central trend. This is more appropriate when there is few data or non-normal distributions, as it allows to avoid very extreme values and, if there is a normal distribution, it must be similar to the mean (Zar, 1999) as shown in Table 9.

Table 9. Median of the quantity of biomass (Mg m. s. ha^{-1}) of each category by FCC and fuel category. F=Fermentation Layer, Fo & SDWM= Foliage and Small Dead Woody Matter, LDWM= Large Dead Woody Matter, Her= Herbacious Plants, Shr= Shrubs.

	Categories Mg m. s. ha^{-1}										
FCC	**F**	**N**	**Fo & SDWM**	**N**	**LDWM**	**N**	**Her**	**N**	**Shr**	**N**	**Total**
Conifer Forest	13.39	35	10.04	69	9.59	67	0.20	47	0.37	47	33.60
Shrubby Conifer Forest	13.39	35	10.04	69			0.20	47	0.37	47	24.00
Herbaceous Conifer Forest			10.04	69			0.20	47			10.24
Oak Forest	14.21	14	7.62	27	0.33	27	0.46	20	0.71	20	23.32
Shrubby Oak Forest	14.21	14	7.62	27			0.46	20	0.71	20	22.99
Herbaceous Oak Forest			7.62	27			0.46	20			8.08
Mountain Cloud Forest	11.93	5	2.02	5	6.94	1	0.15	1	0.19	1	21.23
Shrubby Mountain Cloud Forest	11.93	5	2.02	5			0.15	1	0.19	1	14.29
Herbaceous Mountain Cloud Forest			2.02	5			0.15	1			2.17
Evergreen Tropical Forest	ND		5.75	14	9.1	15	7.5	7	5	15	27.35
Shrubby Evergreen Tropical Forest	ND		5.75	14			7.5	7	5	15	18.25
Herbaceous Evergreen Tropical Forest			5.75	14			7.5	7			13.25
Semi-Deciduous Tropical Forest	ND		9.18	16	31.25	16	7.1	15	2.1	17	49.63
Shrubby Semi-Deciduous Tropical Forest	ND		9.18	16			7.1	15	2.1	17	18.38
Herbaceous Semi-Deciduous Tropical	ND		9.18	16			7.1	15			11.28

Forest											
Deciduous Tropical Forest/Special - Other Woody Types	ND		12.57	13	10.5	13	3.64	8	2.45	4	29.16
Deciduous Tropical Forest/Special - Other Shrubby Woody Types			12.57	13			3.64	8	2.45	4	18.66
Deciduous Tropical Forest/Special - Other Herbaceous Woody Types			12.57	13			3.64	8			
Xeric Shrubland - Woody and Non-Woody	2.97	2	5.78	6			1.44	3	26.34	24	36.53

Consumption Factors or Proportion of Consumed Biomass (C)

The Consumption Factors were taken by default from the values used in the software CONSUME 3, which were developed based on experimental empirical models in dry temperate forest ecosystems of the western United States that estimate the total consumption in the three combustion phases (Prichard *et al.* 2009).

The resulting Consumption Factors for each INEGEI subcategory of temperate forests are general and obtained by stratum and fuel category in order to be applied (where appropriate) to each INEGEI subcategory and its vegetation development phase as shown in Table 10.

Table 10. Consumption factors by INEGEI subcategory and fuel group obtained from CONSUME 3

INEGEI Subcategory	Fermentation Horizon	Leaves and DWM <7.62 cm	DWM >7.62cm	Grasses	Shrubs
Conifer Forest	0.79	0.93	0.55	0.93	0.89
Oak Forest	0.61	0.93	0.55	0.93	0.90
Mountain Cloud Forest	0.45	0.93	0.55	0.93	0.89
Xeric Shrubland	N/A	0.93	0.55	0.93	0.89

In tropical forests, information on consumption factors is rare or non-existent, and, for Mexico, only Kauffman *et al.* (2003) records values for the burning of low-stature deciduous tropical forests for land use conversion, which were used for dry tropical forests as they were the only source available. In the other groups of fuels from tropical forests, the values for proportion of biomass consumed provided by the IPCC guidelines in its LULUCF section (IPCC, 2003) were used, as shown in Table 11.

Table 11. Consumption factors by FCC and fuel group obtained from IPCC and Kauffman et al. 2003 for tropical forests and some types of shubland

Fuel Condition Class	Fermentation Horizon	Leaves and DWM<7.62 cm	DWM>7.62cm	Grasses	Shrubs
Evergreen Tropical Forest[9]	0.50	0.50	0.50	0.50	0.50
Semi-Deciduous Tropical Forest[7]	0.50	0.50	0.50	0.50	0.50
Semi-Deciduous Tropical Forest and Special / Other Lands[10]	N/A	0.89	0.71	1	0.78

The consumption factors were assigned to each surface of INEGI subcategories and their vegetation phase development according to the environment of combustion and its available mass (depending on the component).

Emission Factors (D)

Andreae and Merlet's EF (2001) were selected for this report as they comprise a thorough and up-to-date review of all publications about emission factors for CO_2 and CH_4, CO, N_2O and NO_x trace gases in forests, and provide general values in similar categories to those proposed by the IPCC for the LULUCF sector. Such categories include extratropical forests (temperate, boreal forests and temperate zone shrubs) and tropical forests (Table 12). Emission factors were applied to extratropical forests on the subcategories of coniferous, oak, cloud mountain forests and xeric shrubs; and the EF of tropical forests were applied to evergreen tropical forests, low semi-deciduous tropical forest and deciduous tropical forests.

Table 12.Emission factors by type of vegetation and chemical species (Andreae and Merlet 2001).

Type of vegetation	CO_2	CH_4	CO	N_2O	NO_x
Extratropical forests	1569	4.7	107	0.26	3
Tropical forests	1580	6.8	104	0.2	1.6

5. Activities, Pools and Gases

a) Activities

[9] IPCC 2003
[10]Kauffman *et al*. 2003

This NFREL includes the emissions associated with gross deforestation, as well as the emissions caused by fires in forest lands. Emissions from degradation are not included in this NFREL, but are estimated and presented in Appendix 1. For estimating degradation, the emissions associated with the losses of carbon in primary forest lands were calculated, based on the definition of degradation of the LGCC, which establishes that this occurs when there is a reduction in the carbon content in the natural vegetation due to human intervention.

It should be noted that an effort has been made to estimate emissions by degradation. It recognizes that it is a preliminary analysis whose methodological support will be improved as new data from the third cycle of the National Forest and Soils Inventory (INFyS) is obtained. Nevertheless, it demonstrates that a significant activity is not being excluded from the NFREL.

For other actions, such as those related to the enhancement of carbon stocks and the sustainable management of forests, according to the provision included in the decision 2/CP.17 on the step-wise approach, Mexico will improve its level of reference incorporating these activities as more cost-efficient methods become available for that purpose.

b) Pools

The treatment of carbon stocks is consistent with the national GHG emissions inventories submitted by Mexico in its national communications. The level of reference projected includes emissions and removals of the following stocks: above-ground woody biomass and biomass in roots for estimating deforestation; detritus and dead wood stocks for calculating emissions from forest fires (Table 13). Organic carbon in soils was not included since its emissions are not significant (INECC-CONAFOR, 2014).

Table 13. Carbon Reservoirs

Activity/ Disturbance	Reservoir	Description
Deforestation	Above-ground woody biomass	Trees and shrubs greater than 7.5 cm (normal diameter)
	Biomass of roots	Fine roots
Wildfires	Dead wood	Fallen woody material found in litter with a diameter larger than 7.5 cm
	Litter	Dead biomass that is not in an advanced state of decomposition; it includes needles, leaves, lichens and woody material of less than 7.5 cm lying above the mineral soil.
	Fermentation	Dead biomass that is in an advanced state of decomposition; it includes needles, leaves, lichens and woody material of less than 7.5 cm lying above the mineral soil

	Herbaceous	Herbaceous vegetation above ground, including grasses, herbs, and non-woody shrubs
	Shrubs	Low-height vegetation located above ground with a diameter of less than 7.5 cm

C) Gases

Emissions from Deforestation

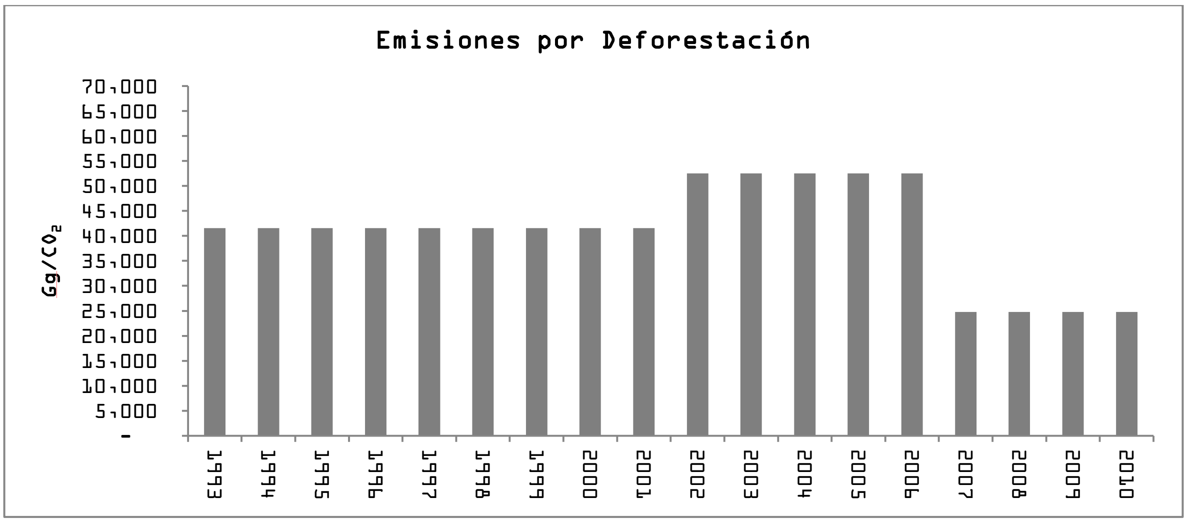


Figure 10. Emissions from deforestation

Emissions from Forest Fires

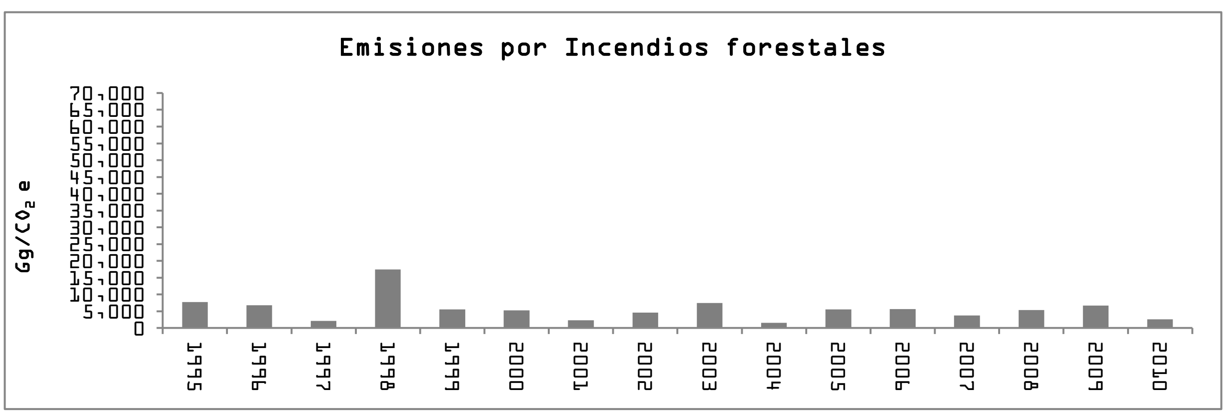


Figure 11. Emissions from forest fires

Total Emissions

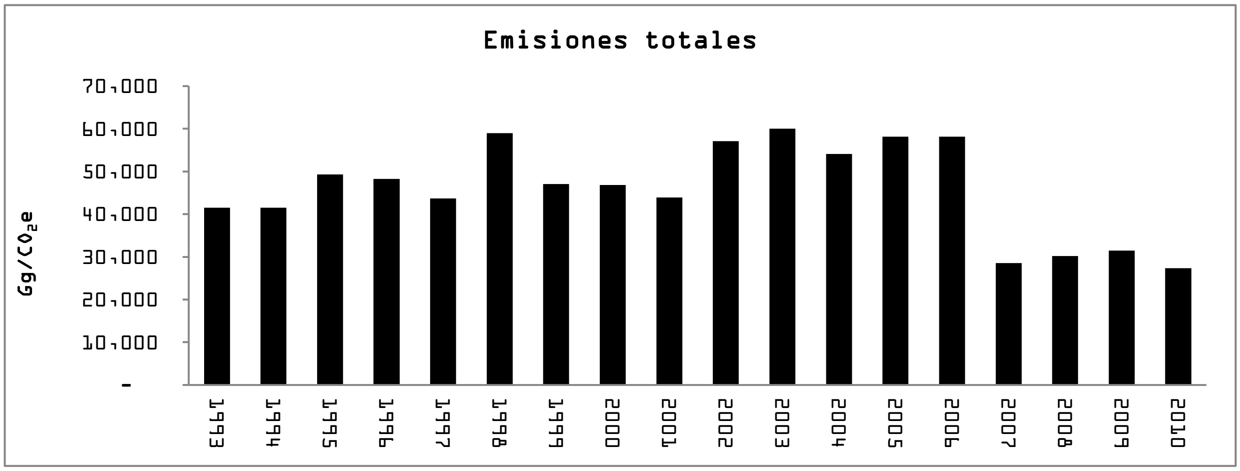


Figure 12. Total emissions

6. Definition of Forest

The definition of forest used in the construction of this report is consistent with that used in the INEGEI presented as part of the BUR, as well as the report of the Global Forest Resources Assessment (FRA) submitted to the Food and Agriculture Organization of the United Nations (FAO) and the minimum mapping unit from the Land Use and Vegetation Series of INEGI. To set the parameter of height (which cannot be established through remote sensing), INFyS data on tree height was analyzed in order to estimate the minimum height based on field data.

Therefore, the definition of forest used is "Lands with an area of more than 50 hectares with trees of more than 4 meters in height −or trees able to reach this height *in situ*− and a canopy cover of more than 10 percent. It does not include lands subject to a land use that is predominantly agricultural or urban."

The definition of "forest" is aligned with the definition of "forest land" in the LGDFS, which provides the framework for estimating GHG emissions for the category of "forest lands" in the BUR. In the LGDFS, the definition of “forest land” comprises all lands covered by forest vegetation, and “forest vegetation” is defined as "the set of plants and fungi that grow and develop naturally, forming forests, rain forests, arid and semi-arid areas, and other ecosystems."

The definition of forest is consistent with advancement in the national preparation for REDD+ and responds to commentaries issued by the various actors involved in this process (CTC, GT, CONAF, among others), who suggested using the broadest definition of forests to accomplish the objective of implementing REDD+ in an inclusive manner in Mexico (ENAREDD+, 2014).

7. Forest Reference Emission Level

a) Definition of the National Forest Reference Emission Level

Even when there is available data a longer period of time, this NFREL is constructed using the historical period of 2000 to 2010. This period is a benchmark for changes in policies in the forest sector as well as for the strengthening of the institutions implementing them nationwide. Hence, the NFREL to be used for results-based payments for the period 2011-2015 corresponds to the average emissions from gross deforestation for the period 2000-2010. This assumes that policies adopted and implemented in this period were the same as those implemented in the following years and that mitigation actions were undertaken under these policies.

One of Mexico's largest developments in forest policy was the creation of CONAFOR in 2001 and the development of incentive programs aimed to improve the situation of the forestry sector in the country prioritizing the sustainable development of forests (Del Angel-Mobarak, 2012).

The incentive programs implemented by CONAFOR are based on supporting communities and ejidos (agrarian communities under a common property regime), who own the majority of Mexican forests.

The main legal framework of the country's forest policies is the LGDFS (General Law for the Sustainable Development of Forests), issued on February, 2003. Since its inception, the sustainable development of forests has been considered a high-priority area in the national development agenda.

The main objective of the sustainable development of forests is to achieve a sustainable management of forest ecosystems through promoting a more eco-efficient system of production and the conservation of forests, improving social wellbeing −particularly in rural areas−, and maintaining the capacity of timber and non-timber production, as well as environmental services.

On the other hand, the year taken as the end of the historical period for this NFREL was marked by several events. Firstly, the 16th session of the Conference of the Parties (COP) of the UNFCCC, which conclude with the signing of the Cancun Agreements, took place in Mexico. During this international meeting, Mexico announced its “Vision of Mexico on REDD+” (CONAFOR, 2010), thereby expressing its firm interest in implementing mitigation actions in the forestry sector under a REDD+ mechanism. In addition, a series of projects began on that year to support Mexico’s preparation process for REDD+ and for the implementation of mitigation actions in the forestry sector. These projects include: the Local Governance Project for the Implementation of REDD+ Early Actions Areas, financed the European Commission through the Latin American Investment

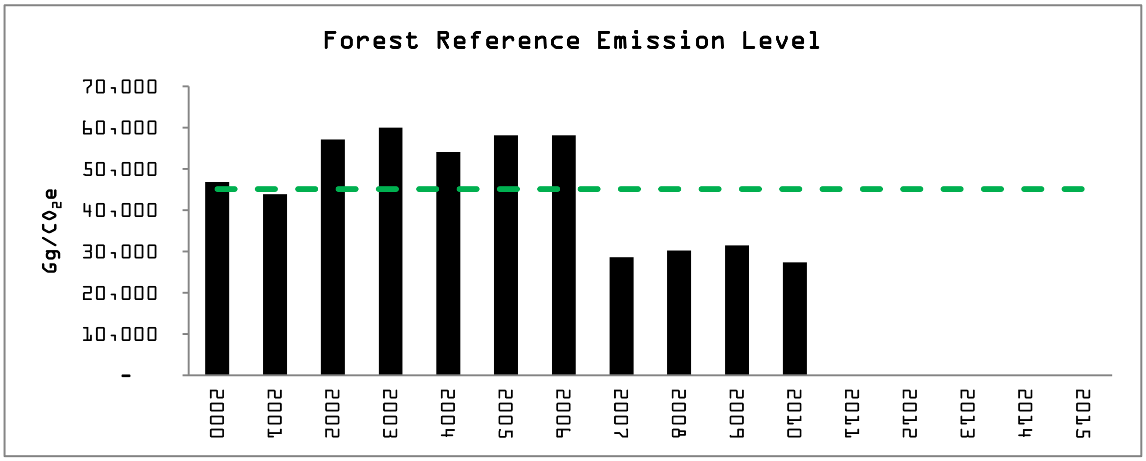
Facility (LAIF); the Forests and Climate Change Project, funded by the World Bank; the Forest Investment Program; and the Reinforcing REDD+ Readiness in Mexico and Enabling South-South Cooperation project, funded by the Government of Norway; among others.[11]

b) National Forest Reference Emission Level

The NFREL of Mexico for gross deforestation activities, including perturbations caused by forest fires, derived from the historical average for the period 2000-2010 is of 45,073 GgCO_2e/year for the period of 2011-2015, as shown in Table 13 and Figure 14.

Table 13. Total annual emissions due to deforestation and forest fires and the average representing the forest reference emission level

Year	Emissions GgCO_2e
2000	46,792.70
2001	43,881.55
2002	57,101.37
2003	60,012.41
2004	54,127.95
2005	58,115.62
2006	58,146.21
2007	28,563.15
2008	30,202.90
2009	31,486.21
2010	27,367.61
Average	**45,072.52**



[11] http://www.conafor.gob.mx/web/temas-forestales/bycc/

Figure 14. Total annual emissions due from deforestation and forest fires and the average representing the forest reference emission level

8. Short Term Methodological Improvements

a) Monitoring Activity Data for Mexico (MAD-Mex)

As part Mexico's REDD+ readiness process, capacities are being built for the development and implementation of the National Forest Monitoring System (NFMS). As a part of this process, a system for the semi-automatic classification of satellite images is being developed, and it is expected to render cartographic products similar to the INEGI's Series but with greater spatial and temporal resolution. A description of its methodology and preliminary results can be found at Gebhardt, *et al* 2014.

Additionally, this system has an algorithm to detect forest cover changes directly from the images, which is expected to improve information on forest cover change at a national level. This process is being documented, and a technical report will be issued upon completion.

b) National Forest and Soils Inventory (INFyS)

The second INFyS cycle for information gathering ended in 2013. However, a constant loss of samples due to inaccessibility was identified when analyzing the data. Therefore, in 2014, additional information was collected these sites to complete the original sample size of the INFyS.

Moreover, the third INFyS cycle (2015-2019) is about to begin. All carbon stocks have been incorporated in this cycle and, when completed, these data may be used for the estimation of EF.

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10. Annexes

a) Degradation

Measuring forest degradation depends upon the definition chosen to describe this phenomenon. The General Law for the Sustainable Development of Forests indicates that deforestation refers to "the process of reducing the capacity of ecosystems to provide environmental services and to produce goods." In the context climate change mitigation in Mexico, forests are considered a regulator of the carbon cycle and degradation, according to the General Climate Change Law, refers to the "reduction of the carbon content in the natural vegetation, ecosystems or soils due to human intervention, in relation to that of same vegetation, ecosystem or soils in the absence of such intervention."

Focusing on these perspectives, the calculation of degradation estimates at the national level considered two elements. Firstly, the primary stage (defined as vegetation phase that is predominantly arboreal) comprised both primary and secondary vegetation groups in arboreal phase as indicated at in the INEGI Series; and the secondary stage comprised the categories of vegetation development which are currently undergoing a shrub and herbaceous stage. The subcategories pertaining primary and secondary forest lands are described in the section on coherent representation of lands and the change matrix presented therein. In this manner, a criterion was developed to identify degradation based on what the cartographers of the INEGI Series visually detected as an area presenting a loss in tree cover density. This allows us to know that a loss of biomass and carbon occurred in a certain area as recorded by each change matrix for the forest land category, as presented in the diagonal cells where degradation was detected (Figure 15).

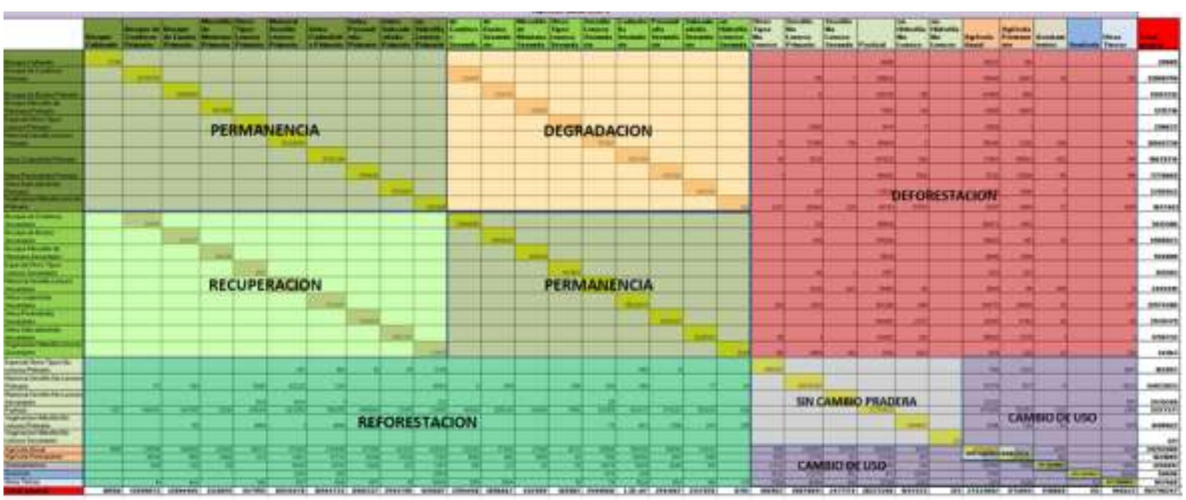

Figure 15. Matrix of change where degradation is identified

Secondly, the data from INFyS plots with categories of primary forest lands that lost biomass was used to build a model for forest degradation, as described in the following paragraphs.

The INFyS has very few plots available to robust estimate EF for "Forest Lands" that changed to "Degraded Forest Lands" (that is, for those lands that changed from a primary to a secondary condition). Therefore, Proxy Lineal Models for Losses (MLPP, for its acronym in Spanish) were developed to obtain these estimates. These models are adjustments of the mean of the variable *gross decrease of carbon* at the plot level reclassified according to the re-measurement periods. The variable *gross decrease of carbon* at a plot level was constructed using only the negative cases for the variable *gross carbon change at the plot level* (for each plot, *gross carbon change at the sub-plot level* were averaged, and those averages were expanded to the hectare), as shown in Figure 16.

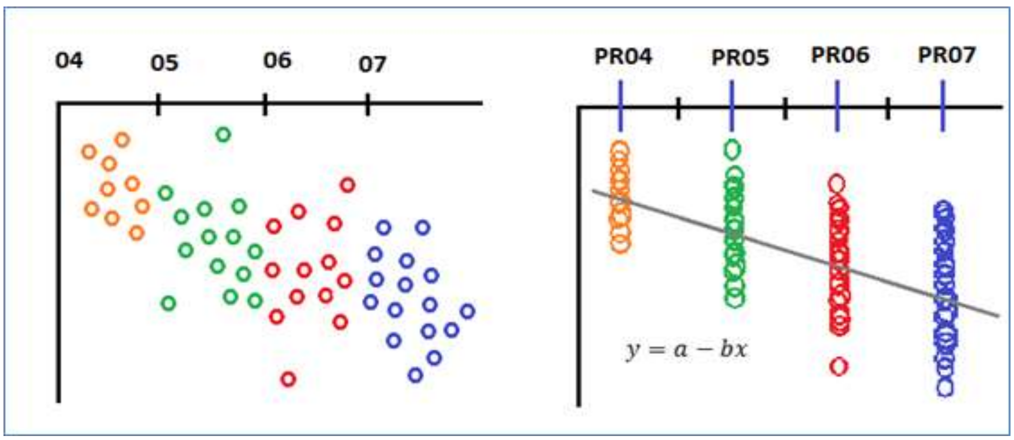

Figure 16. Process to develop the linear models for losses. (a) Diagram of dispersion of gross carbon decrease at plot level (negative cases of gross carbon change at plot level). (b) Graph of values of gross carbon decrease grouped at plot level by categories of re-measurements (absolute time difference between the measuring/remeasuring events) and linear adjustment of its averages.

Subsequently, the plots were categorized into "re-measurement periods”, which means that each plot was categorized according to the lapsed time between re-measurements (1 to 7 years). This continuous variable was converted into a categorical variable, as shown in Figure 16. Then, a linear model was adjusted in each subcategory for the *gross carbon decrease* averages, Figure 16. The slope parameter of the model is the rate of loss, and this value was used as a proxy for the EF of "Forest land" that became "Degraded forest lands."

Table 14 shows the emission factors for degradation assigned for each year in the areas where lands changed categories from primary to secondary forest lands in the matrix of change.

Table 15. EF used to estimate emissions due to degradation.

Subcategory	N	Carbon in above-ground	Carbon in roots

		woody biomass (tonC/ha/year)	(tonC/ha/year)
Coniferous forest – Primary	292	-0.09	-0.02
Oak Forest – Primary	818	-0.24	-0.06
Mountainous cloud Forest – Primary	67	-0.26	-0.06
Special - Other Woody Vegetation Types – Primary	ND	ND	ND
Wood Xeric Shrublands – Primary	501	-0.47	-0.12
Deciduous Tropical Forest – Primary*	169	-2.21	-0.54
Evergreen Tropical Forest – Primary	577	-1.94	-0.43
Semi-Deciduous Tropical Forest – Primary	169	-2.21	-0.54
Hydrophilous Woody Vegetation – Primary	43	-1.58	-0.36

* The slope of the model originally used for data in this subcategory displayed a carbon increase and this was not consistent with the carbon loss assumed for degradation. Hence, the factor obtained for primary semi-deciduous tropical forest was assigned to this subcategory, considering that it is the most similar vegetation class in terms of composition and structure.

The annual rates of loss of carbon (in tons) were assigned to the area values obtained from the space analysis of matrices where a change in categories from primary to secondary forest was observed. The emissions in carbon dioxide were calculated for the matrices related to the three comparison periods, resulting in annual emissions of 19,872 Gg for the period 1993-2001; 8,696 Gg for the period 2002-2006; and 1,812 Gg for 2007-2010. This denotes a trend of decreasing emissions from degradation as the carbon dioxide emissions due to a degradation processes related to changes in the density of tree-dominated vegetation have been reduced in the last two periods analyzed.

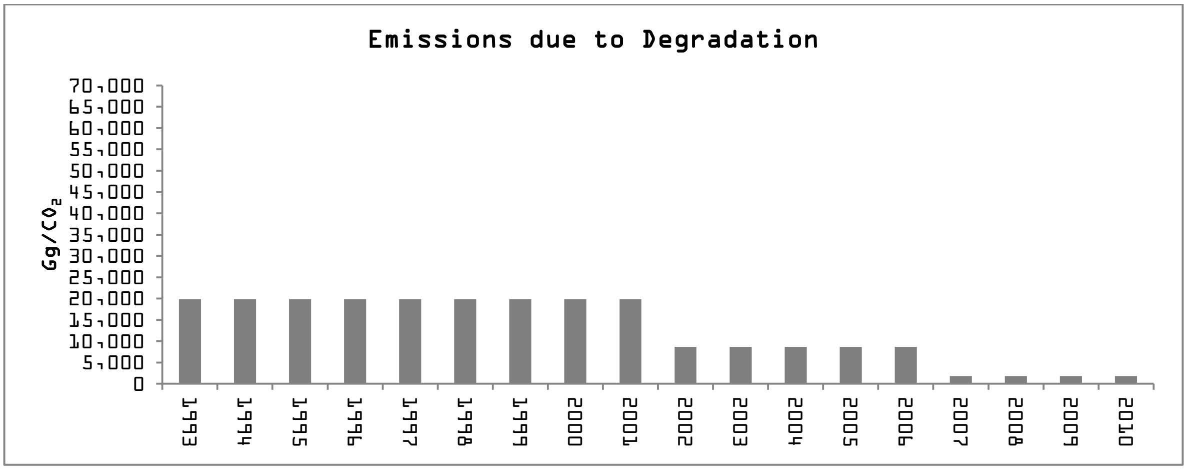

Figure 13. Historical emissions due to forest degradation

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