GREENHOUSE GAS EMISSIONS IN SONORA AND REFERENCE CASE PROJECTIONS 1990-2020

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Acronyms and Key Terms

bbls – Barrels

BOD – Biochemical Oxygen Demand

Btu – British Thermal Unit

C – Carbon

$CaCO_3$ – Calcium Carbonate

CCS – Center for Climate Strategies

CCT – Carbon Calculation Tool

CEDES – Comisión de Ecología y Desarrollo Sustentable del Estado de Sonora

CFCs – Chlorofluorocarbons

CH_4 – Methane

CHP – Combined Heat and Power

CO_2 – Carbon Dioxide

CO_2e – Carbon Dioxide equivalent

CONAFOR – Comisión Nacional Forestal

EAF – Electric Arc Furnace

EIIP – Emission Inventory Improvement Program

Gg – Gigagram

GHG – Greenhouse Gas

GWh – Gigawatt-hour

GWP – Global Warming Potential

H_2CO_3 – Carbonic Acid

HCFCs – Hydrochlorofluorocarbons

HFCs – Hydrofluorocarbons

HNO_3 – Nitric Acid

HWP – Harvested Wood Products

INEGI – Instituto Nacional de Estadísticas, Geografía, e Informática

IPCC – Intergovernmental Panel on Climate Change

kg – Kilogram

kWh – Kilowatt-hour

lb – Pound

LF – Landfill

LFGTE – Landfill Gas Collection System and Landfill-Gas-to-Energy

LPG – Liquefied Petroleum Gas

Mg – Megagrams

MMBtu – Million British thermal units

MMt – Million Metric tons

$MMtCO_2e$ – Million Metric tons Carbon Dioxide equivalent

MSW – Municipal Solid Waste

Mt – Metric ton (equivalent to 1.102 short tons)

N_2O – Nitrous Oxide

NEMS – National Energy Modeling System

NH_3 – Ammonia

ODS – Ozone-Depleting Substance

OEIDRUS - Oficina Estatal de Información para el Desarrollo Rural Sustentable

PFCs – Perfluorocarbons

ppb – Parts per billion

ppm – Parts per million

ppmv – Parts per million by volume

ppt – Parts per trillion

RCI – Residential, Commercial, and Industrial

SEMARNAT – Secretaría de Medio Ambiente y Recursos Naturales

SENER – Secretaría de Energía

SF_6 – Sulfur Hexafluoride

SIACON -- Sistema de Información Agropecuaria de Consulta

SIT – State Greenhouse Gas Inventory Tool

T&D – Transmission and Distribution

US – United States

US EPA – United States Environmental Protection Agency

WW – Wastewater

yr – Year

Executive Summary

The Center for Climate Strategies (CCS) prepared with the the Comisión de Ecología y Desarrollo Sustentable del Estado de Sonora (CEDES) a preliminary assessment of the State's greenhouse gas (GHG) emissions from 1990 to 2005 and a forecast of emissions through 2020. CEDES contributed with leadership, coordination, and technical input to the development of this report. The inventory and forecast estimates serve as a starting point to assist the State with an initial comprehensive understanding of Sonora's current and possible future GHG emissions.

Sonora's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the period from 1990 to 2020. Historical GHG emission estimates (1990 through 2005)[1] were developed using a set of generally accepted principles and guidelines for State GHG emission inventories, relying to the extent possible on Sonora-specific data and inputs when it was possible to do so. The initial reference case projections (2006-2020) are based on a compilation of various projections of electricity generation, fuel use, and other GHG-emitting activities for Sonora, along with a set of simple, transparent assumptions described in the appendices of this report.

The inventory and projections cover the six types of gases included in Mexico's national inventory and commonly reported in international reporting under the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalents (CO_2e), which indicates the relative contribution of each gas, per unit mass, to global average radiative forcing on a global warming potential-(GWP-) weighted basis.[2]

As shown in Table ES-1, activities in Sonora accounted for approximately 19.8 million metric tons (MMt) of *gross*[3] CO_2e emissions (production basis) in 2005, an amount equal to about 3.0% of Mexico's gross GHG emissions in 2005 excluding carbon sinks, such as carbon stock in forest land. Sonora's gross production-based GHG emissions increased by about 33% from 1990 to 2005, while national emissions rose by 31% from 1990 to 2005. The growth in Sonora's emissions from 1990 to 2005 is primarily associated with electricity consumption and transportation activities[4].

[1] The last year of available historical data varies by sector; ranging from 2000 to 2005.
[2] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC, 1996). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth), http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm.
[3] "Gross" emissions exclude GHG emissions removed (sequestered) due to forestry and other land uses and "consumption-based" emissions exclude GHG emissions associated with exported electricity.
[4] Comparison with national results were drawn from the official publication titled: *Mexico Tercera Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático.* Mexico: INE-SEMARNAT, 2006. Available at www.ine.gob.mx. Available annual emssions values were in the order of 498,747.57 and 618,071.73 gigagrams in 1990 and 2002 respectively. 2005 emissions were derived from these values at 655,476.60 gigagrams.

Initial estimates of carbon sinks within Sonora's forests have also been included in this report. However additional work is needed to gain an understanding of CO_2 emissions/sinks for urban forests, land use change, and cultivation practices leading to changes in agricultural soils. In addition, there is considerable need for additional work for the initial forestry sink estimates provided in this report (e.g. to account for losses/gains in forested area; see Appendix H). Additional work to improve the forest and agricultural carbon sink estimates could lead to substantial changes in the initial estimates provided in this report. The current estimates indicate that about 8.42 $MMtCO_2e$ were stored in Sonora forest biomass in 2005. Inclusion of this sink leads to *net* emissions of 11.4 $MMtCO_2e$ in Sonora for 2005.

Figure ES-1 compares the State's and Mexico's gross production based emissions per capita and per unit of economic output.[5] On a per capita basis, Sonora emitted about 7.98 metric tons (Mt) of gross CO_2e in 1995, higher than the1995 national average of 5.96 tCO_2e. Since 1995, Sonora's per capita emissions increased to 8.28 $MtCO_2e$ in 2005, while national per capita emissions for Mexico grew to 6.35 $MtCO_2e$ in 2005. Although Sonora's population has grown at the national rate, emissions have increased in the state at a higher rate, causing state emissions per capita to grow from 1995 to 2005. On the other hand, Sonora's economic growth exceeded emissions growth throughout the 1990-2005 period leading to declining estimates of GHG emissions per unit of state product. From 1995 to 2005, Sonora emissions per unit of gross product dropped by 21.7%.[6]

As illustrated in Figure ES-2 and shown numerically in Table ES-1, under the reference case projections, Sonora's gross consumption based GHG emissions continue to grow and are projected to reach 33.6 $MMtCO_2e$ by 2020. This would be an increase of 124% over 1990 levels. As shown in Figure ES-3, the electricity generation sector is projected to be the largest contributor to future emissions growth in Sonora, followed by emissions in the transportation sector (sum of all transportation subsectors).

Some data gaps exist in this analysis, particularly for the reference case projections. Key tasks in resolving the data gaps include review and revision of key emissions drivers that will be major determinants of Sonora's future GHG emissions (such as the growth rate assumptions for electricity generation and consumption, transportation fuel use, industrial processes, and RCI fuel use). Appendices A through H provide detailed methods, data sources, and assumptions made for each GHG sector. Also included are descriptions of significant uncertainties in emission estimates and/or methods and suggested next steps for refinement of the inventory and forecast.

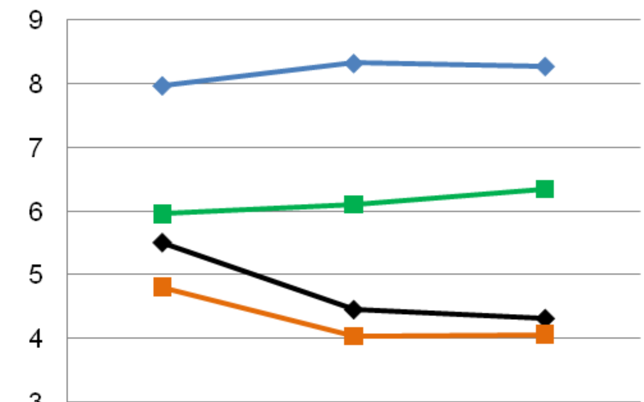
[5] Sonora population statistics were derived from information from the Instituto Nacional de Estadísticas Geografía e Informática (INEGI), and Tercera Comunicación Nacional ante la Convención de las Naciones Unidas.
[6] Based on domestic product at constant 2003 Mexican pesos values.

Table ES-1. Sonora Historical and Reference Case GHG Emissions, by Sector

(Millones de Toneladas Métricas de CO2e)	1990	1995	2000	2005	2010	2015	2020
Energy Consumption Based	**9.60**	**12.4**	**13.3**	**13.4**	**15.7**	**19.3**	**23.7**
Electricity Consumption Based	**4.03**	**5.50**	**7.03**	**6.84**	**7.58**	**9.76**	**12.2**
Fuel Oil	4.03	5.5	6.72	4.84	3.95	6.42	8.86
Natural Gas	0	0	0.30	2.00	3.63	3.34	3.32
Net Electricity Imports	1.20E-03	1.70E-03	2.30E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Electricity Production Based	*4.03*	*5.5*	*7.03*	*6.84*	*7.58*	*9.76*	*12.2*
Res/Com/Ind (RCI)	**1.58**	**2.56**	**1.27**	**1.06**	**1.43**	**1.78**	**2.30**
Liquefied Petroleum Gas	0.58	0.58	0.55	0.44	0.47	0.49	0.52
Natural Gas	0.24	0.27	0.28	0.33	0.37	0.41	0.46
Diesel	0.7	1.65	0.37	0.24	0.54	0.82	1.26
Wood	0.06	0.06	0.06	0.05	0.05	0.05	0.06
Transportation	**3.78**	**4.12**	**4.79**	**5.25**	**6.46**	**7.57**	**8.94**
Transportation - Gasoline	1.65	1.75	1.96	2.44	3.17	3.73	4.39
Transportation - Diesel	0.93	1.18	1.54	1.54	1.83	2.16	2.55
Marine Vessels	0.11	0.11	0.17	0.20	0.32	0.50	0.79
Aviation	0.26	0.28	0.32	0.26	0.29	0.30	0.31
Rail	0.17	0.14	0.14	0.15	0.20	0.22	0.24
Other	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Fossil Fuel Industry	**0.16**	**0.18**	**0.19**	**0.22**	**0.23**	**0.24**	**0.25**
Natural Gas Systems	0.16	0.18	0.19	0.22	0.23	0.24	0.25
Transmission	0.04	0.05	0.05	0.05	0.05	0.06	0.06
Distribution	0.12	0.14	0.14	0.15	0.16	0.16	0.17
Flared	0	0	0	0.02	0.02	0.02	0.02
Industrial Processes	**0.69**	**0.93**	**1.25**	**1.66**	**2.23**	**2.99**	**4.04**
Cement Production (CO2)	0.59	0.79	1.06	1.44	1.89	2.55	3.43
Lime Production (CO2)	0.03	0.04	0.05	0.07	0.09	0.12	0.16
Limestone & Dolomite Use (CO2)	0.03	0.04	0.05	0.07	0.09	0.12	0.16
ODS Substitutes (HFC, CFC)	0.03	0.04	0.05	0.02	0.09	0.10	0.15
Other (CO2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste Management	**0.95**	**1.09**	**1.18**	**1.34**	**1.43**	**1.52**	**1.61**
Open Burning	0.13	0.17	0.21	0.29	0.3	0.31	0.33
Landfills	0.34	0.38	0.42	0.46	0.51	0.56	0.61
Wastewater	0.48	0.55	0.56	0.6	0.62	0.65	0.68
Agriculture	**3.76**	**3.1**	**2.77**	**3.47**	**3.70**	**3.98**	**4.31**
Enteric Fermentation	1.98	1.57	1.36	1.83	1.97	2.13	2.3
Manure Management	0.18	0.16	0.16	0.18	0.18	0.19	0.2
Managed Soils	1.57	1.34	1.22	1.4	1.52	1.64	1.78
Rice Cultivation	0	0	0	0	0	0	0
Residue Burning	0.03	0.03	0.03	0.07	0.03	0.03	0.03
Forestry and Land Use	**-8.21**	**-9.12**	**-6.29**	**-8.42**	**-7.96**	**-7.96**	**-8.69**
Forest Land	-8.21	-9.12	-6.29	-8.42	-7.96	-7.96	-8.69
Forest Fires	1.80E-04	1.70E-04	3.40E-04	2.30E-04	2.50E-04	2.50E-04	2.10E-04
Gross Emissions Consumption Based	**15.0**	**17.5**	**18.5**	**19.8**	**23.1**	**27.8**	**33.6**
increase relative to 1990		*17%*	*23%*	*33%*	*54%*	*86%*	*124%*
Emission Sinks	**-8.21**	**-9.12**	**-6.29**	**-8.42**	**-7.96**	**-7.96**	**-8.69**
Net Emissions (incl. forestry*)	**6.74**	**8.36**	**12.2**	**11.4**	**15.1**	**19.9**	**24.9**
increase relative to 1990		*24%*	*81%*	*70%*	*124%*	*195%*	*270%*

(Millones de Toneladas Métricas de CO2e)	1990	1995	2000	2005	2010	2015	2020
Gross Emissions Production Based	**15.0**	**17.5**	**18.5**	**19.8**	**23.1**	**27.8**	**33.6**
increase relative to 1990		*17%*	*23%*	*33%*	*54%*	*86%*	*125%*
Net Emissions (incl. forestry*)	**6.7**	**8.3**	**12.1**	**11.4**	**15.0**	**19.8**	**24.8**
increase relative to 1990		*24%*	*81%*	*70%*	*124%*	*195%*	*270%*

Figure ES-1. Historical Sonora and National Gross GHG Emissions per Capita and per Unit of Economic Output



	1995	2000	2005
Sonora GHG/Capita (tCO2e/capita)	7.98	8.33	8.28
MX GHG/Capita (tCO2e/capita)	5.96	6.10	6.35
Sonora GHG/$ (kgCO2e/$)	5.50	4.45	4.31
MX GHG/$ (kgCO2e/$)	4.80	4.03	4.06

Figure ES-2. Sonora Gross Consumption-Based GHG Emissions by Sector, 1990-2020

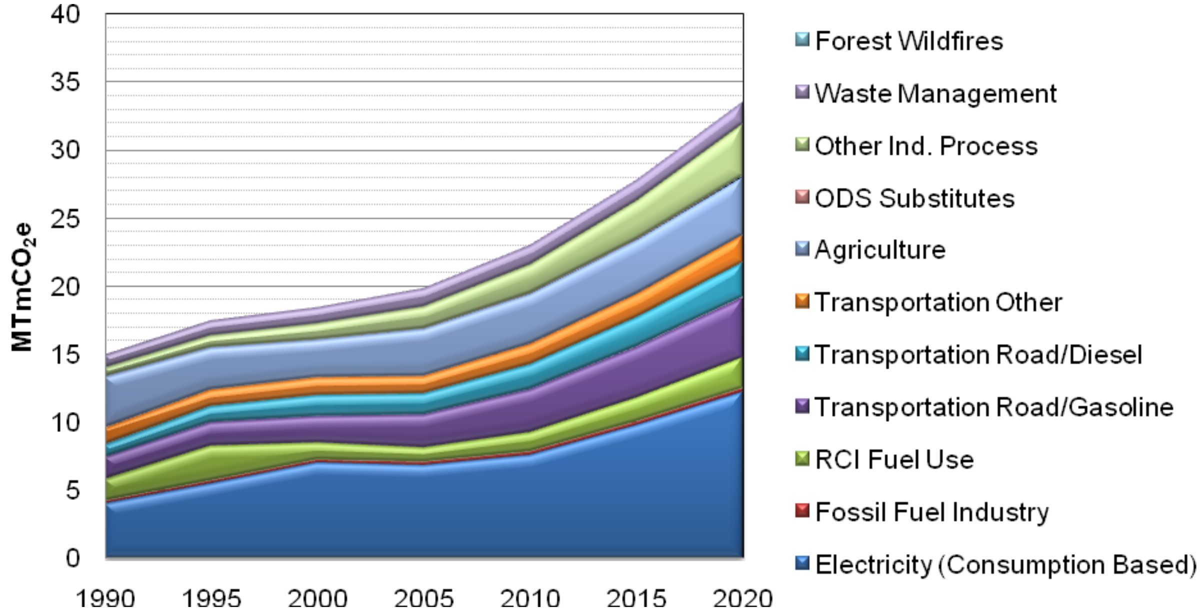
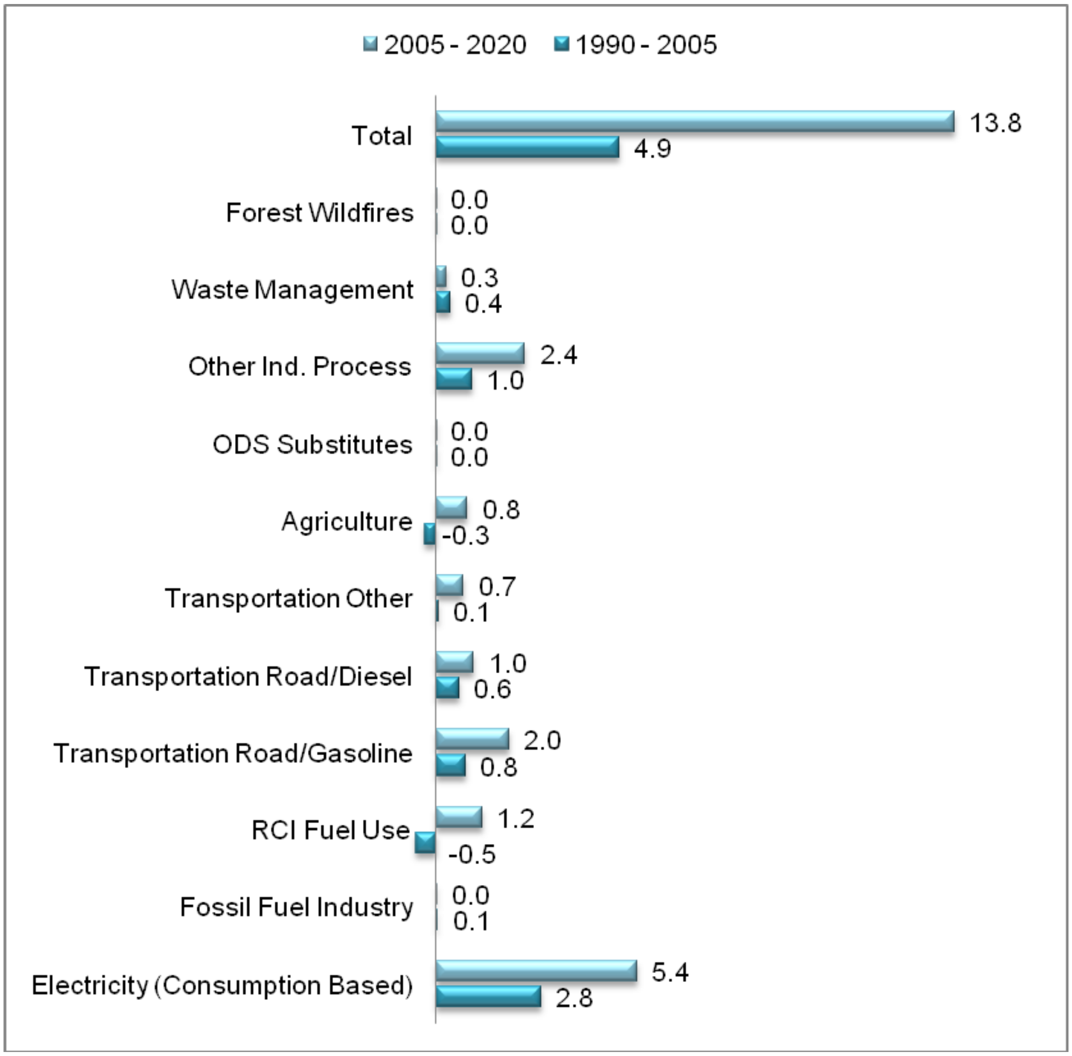


Figure ES-3. Sector Contributions to Gross Emissions Growth in Sonora, 1990-2020: Reference Case Projections (MMtCO_2e Basis)



Res/Comm – direct fuel use in residential and commercial sectors. ODS – ozone depleting substance. Emissions associated with other industrial processes include all of the industries identified in Appendix D except emissions associated with ODS substitutes which are shown separately in this graph. Data for US states indicates a high expected growth in emissions for ODS substitutes.

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Summary of Preliminary Findings

Introduction

The Center for Climate Strategies (CCS) prepared this report with the Comisión de Ecología y Desarrollo Sustentable del Estado de Sonora (CEDES). This report presents a preliminary assessment of the State's greenhouse gas (GHG) emissions and anthropogenic sinks (carbon storage) from 1990 to 2020. The inventory and forecast estimates serve as a starting point to assist the State with an initial comprehensive understanding of Sonora's current and possible future GHG emissions, and thereby can serve to inform the future identification and analysis of policy options for mitigating GHG emissions.

Historical GHG emission estimates (1990 through 2005) were developed using a set of generally accepted principles and guidelines for State GHG emissions inventories, as described in the "Approach" section below. These estimates rely to the extent possible on Sonora-specific data and inputs. The initial reference case projections (2006-2020) are based on a compilation of projections of electricity generation, fuel use, and other GHG-emitting activities for Sonora, along with a set of simple, transparent assumptions described in the appendices of this report.

This report covers the six gases included in the Mexico National GHG inventory and international GHG reporting under the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalence (CO_2e), which indicates the relative contribution of each gas, per unit mass, to global average radiative forcing on a global warming potential- (GWP-) weighted basis.[7]

It is important to note that the preliminary emissions estimates reflect the *GHG emissions associated with the electricity sources used to meet Sonora's demands,* corresponding to a consumption-based approach to emissions accounting (see "Approach" section below). Another way to look at electricity emissions is to consider the *GHG emissions produced by electricity generation facilities in the State.* This report covers both methods of accounting for emissions, but for consistency, all total results are reported as *consumption-based.*

[7] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC, 1996). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth), http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm.

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Sonora Greenhouse Gas Emissions: Sources and Trends

Table 1 provides a summary of GHG emissions estimated for Sonora by sector for the years 1990, 2000, 2005, 2010, and 2020. Table 1 presents results according to four types of GHG accounting: 1) consumption based emissions; 2) production based emissions; 3) nete emissions; 4) gross emissions. The specific type of accounting is specified in each of the figures and tables of the report. Moreover, it is important to note that comparisons with the Inventario Nacional de Emisiones de Gases de Efecto Invernadero (INEGEI) were made on the basis of *gross, production-base emissions* in order to be consistent with the type of GHG accounting employed by the authors of the INEGEI.

Details on the methods and data sources used to construct the emission estimates are provided in the appendices to this report**.** In the sections below, a brief discussion is provided on the GHG emission sources (positive, or *gross*, emissions) and sinks (negative emissions) separately in order to identify trends and uncertainties clearly for each.

This next section of the report provides a summary of the historical emissions (1990 through 2005) followed by a summary of the reference-case projection-year emissions (2006 through 2020) and key uncertainties. An overview of the general methodology, principles, and guidelines followed for preparing the inventories is then provided. Appendices A through H provide the detailed methods, data sources, and assumptions for each GHG sector.

Historical Emissions

Overview

Preliminary analyses suggest that in 2005, activities in Sonora accounted for approximately 19.8 million metric tons (MMt) of CO_2e emissions, an amount equal to about 3.0% of Mexico GHG emissions (based on 2005 national emissions)[8]. Sonora's gross GHG emissions are rising at a slightly higher rate than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). Sonora's gross GHG emissions increased 34% from 1990 to 2005, while national emissions rose by 31% from 1990 to 2005.

Figure 1 illustrates the State's emissions per capita and per unit of economic output. [9] On a per capita basis, Sonora emitted about 7.98 metric tons (t) of CO_2e annually in 1995, higher than the 1995 national average of 5.96 tCO_2e. Since 1995, Sonora's per capita emissions have increased to 8.28 tCO_2e in 2005. National per capita emissions for Mexico have also increased, though to a lower value of 6.35 tCO_2e. Although Sonora's population has grown at the national rate, emissions have increased in the state at a higher rate, causing state emissions per capita to grow from 1995 to 2005. On the other hand, Sonora's economic growth exceeded emissions growth throughout the 1990-2005 period leading to declining estimates of GHG emissions per unit of

[8] Comparison with national results were drawn from the official publication titled: *Mexico Tercera Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático.* Mexico: INE-SEMARNAT, 2006. Available at www.ine.gob.mx. Available annual emssions values were in the order of 498,747.57 and 618,071.73 gigagrams in 1990 and 2002 respectivively. 2005 emissions were dereived from these values at 655,476.60 gigagrams.
[9] Retrieved June, 2008 from: http://www.inegi.gob.mx/est/contenidos/espanol/cubos/default.asp?c=1413

state product. From 1995 to 2005, emissions per unit of gross product in Sonora dropped by 21.7%.[10]

Figure 2 compares gross GHG emissions for Sonora to emissions for Mexico in 2005 according to activity sectors used by Instituto Nacional de Ecología (INE). Principal sources of Sonora's GHG emissions include energy use and agriculture. Energy use includes activities such as power generation, transportation, fossil fuel production and exploration as well as residential, commercial, and industrial consumption of primary fuels (e.g. gasoline, diesel, coal, natural gas, liquefied petroleum gas). The agricultural sector focuses on the effects human activity has on the nitrogen cycle. Potential greenhouse gases may either be sequestered in or be released into the atmosphere at above normal rates as it is the case in aerobic decomposition of livestock manure. The agricultural sector also accounts for methane releases in the atmosphere by livestock through enteric fermentation and anaerobic decomposition of manure. In 2005, the energy and agriculture sectors accounted for 67% and 18% of total GHG emissions in the state of Sonora. These same sectors accounted at the national level 63% and 7% of Mexico's gross GHG emissions in 2005.

[10] Based on domestic product at constant 2003 Mexican pesos values and using an exchange rate of 10 pesos to 1 dollar. Instituto Nacional de Estadísticas, Geografía e Informática, 2005. *Consulta de: Valores corrientes Por: Nacional y entidad Según: Año.* On line: http://www.inegi.org.mx/inegi/default.aspx

Table 1. Sonora Historical and Reference Case GHG Emissions, by Sector[a]

(Millones de Toneladas Métricas de CO2e)	1990	1995	2000	2005	2010	2015	2020
Energy Consumption Based	**9.6**	**12.4**	**13.3**	**13.4**	**15.7**	**19.3**	**23.7**
Electricity Consumption Based	**4.03**	**5.50**	**7.03**	**6.84**	**7.58**	**9.76**	**12.2**
Fuel Oil	4.03	5.5	6.72	4.84	3.95	6.42	8.86
Natural Gas	0	0	0.30	2.00	3.63	3.34	3.32
Net Electricity Imports	1.20E-03	1.70E-03	2.30E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Electricity Production Based	*4.03*	*5.5*	*7.03*	*6.84*	*7.58*	*9.76*	*12.2*
Res/Com/Ind (RCI)	**1.58**	**2.56**	**1.27**	**1.06**	**1.43**	**1.78**	**2.30**
Liquefied Petroleum Gas	0.58	0.58	0.55	0.44	0.47	0.49	0.52
Natural Gas	0.24	0.27	0.28	0.33	0.37	0.41	0.46
Diesel	0.7	1.65	0.37	0.24	0.54	0.82	1.26
Wood	0.06	0.06	0.06	0.05	0.05	0.05	0.06
Transportation	**3.78**	**4.12**	**4.79**	**5.25**	**6.46**	**7.57**	**8.94**
Transportation - Gasoline	1.65	1.75	1.96	2.44	3.17	3.73	4.39
Transportation - Diesel	0.93	1.18	1.54	1.54	1.83	2.16	2.55
Marine Vessels	0.11	0.11	0.17	0.20	0.32	0.50	0.79
Aviation	0.26	0.28	0.32	0.26	0.29	0.30	0.31
Rail	0.17	0.14	0.14	0.15	0.20	0.22	0.24
Other	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Fossil Fuel Industry	**0.16**	**0.18**	**0.19**	**0.22**	**0.23**	**0.24**	**0.25**
Natural Gas Systems	0.16	0.18	0.19	0.22	0.23	0.24	0.25
Transmission	0.04	0.05	0.05	0.05	0.05	0.06	0.06
Distribution	0.12	0.14	0.14	0.15	0.16	0.16	0.17
Flared	0	0	0	0.02	0.02	0.02	0.02
Industrial Processes	**0.69**	**0.93**	**1.25**	**1.66**	**2.23**	**2.99**	**4.04**
Cement Production (CO2)	0.59	0.79	1.06	1.44	1.89	2.55	3.43
Lime Production (CO2)	0.03	0.04	0.05	0.07	0.09	0.12	0.16
Limestone & Dolomite Use (CO2)	0.03	0.04	0.05	0.07	0.09	0.12	0.16
ODS Substitutes (HFC, CFC)	0.03	0.04	0.05	0.02	0.09	0.10	0.15
Other (CO2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste Management	**0.95**	**1.09**	**1.18**	**1.34**	**1.43**	**1.52**	**1.61**
Open Burning	0.13	0.17	0.21	0.29	0.3	0.31	0.33
Landfills	0.34	0.38	0.42	0.46	0.51	0.56	0.61
Wastewater	0.48	0.55	0.56	0.6	0.62	0.65	0.68
Agriculture	**3.76**	**3.1**	**2.77**	**3.47**	**3.70**	**3.98**	**4.31**
Enteric Fermentation	1.98	1.57	1.36	1.83	1.97	2.13	2.3
Manure Management	0.18	0.16	0.16	0.18	0.18	0.19	0.2
Managed Soils	1.57	1.34	1.22	1.4	1.52	1.64	1.78
Rice Cultivation	0	0	0	0	0	0	0
Residue Burning	0.03	0.03	0.03	0.07	0.03	0.03	0.03
Forestry and Land Use	**-8.21**	**-9.12**	**-6.29**	**-8.42**	**-7.96**	**-7.96**	**-8.69**
Forest Land	-8.21	-9.12	-6.29	-8.42	-7.96	-7.96	-8.69
Forest Fires	1.80E-04	1.70E-04	3.40E-04	2.30E-04	2.50E-04	2.50E-04	2.10E-04
Gross Emissions Consumption Based	**15.0**	**17.5**	**18.5**	**19.8**	**23.1**	**27.8**	**33.6**
increase relative to 1990		*17%*	*23%*	*33%*	*54%*	*86%*	*124%*
Emission Sinks	**-8.21**	**-9.12**	**-6.29**	**-8.42**	**-7.96**	**-7.96**	**-8.69**
Net Emissions (incl. forestry*)	**6.74**	**8.36**	**12.2**	**11.4**	**15.1**	**19.9**	**24.9**
increase relative to 1990		*24%*	*81%*	*70%*	*124%*	*195%*	*270%*

(Millones de Toneladas Métricas de CO2e)	1990	1995	2000	2005	2010	2015	2020
Gross Emissions Production Based	**15.0**	**17.5**	**18.5**	**19.8**	**23.1**	**27.8**	**33.6**
increase relative to 1990		*17%*	*23%*	*33%*	*54%*	*86%*	*125%*
Net Emissions (incl. forestry*)	**6.7**	**8.3**	**12.1**	**11.4**	**15.0**	**19.8**	**24.8**
increase relative to 1990		*24%*	*81%*	*70%*	*124%*	*195%*	*270%*

Figure 1. Historical Sonora and Mexico Gross GHG Emissions per Capita and per Unit Gross Product in Dollars

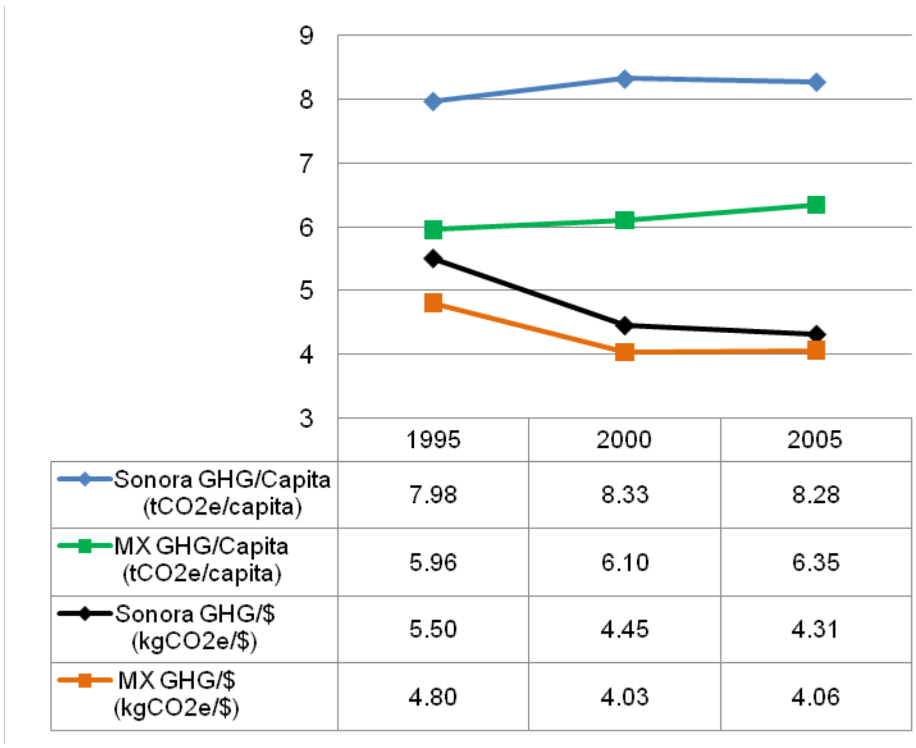
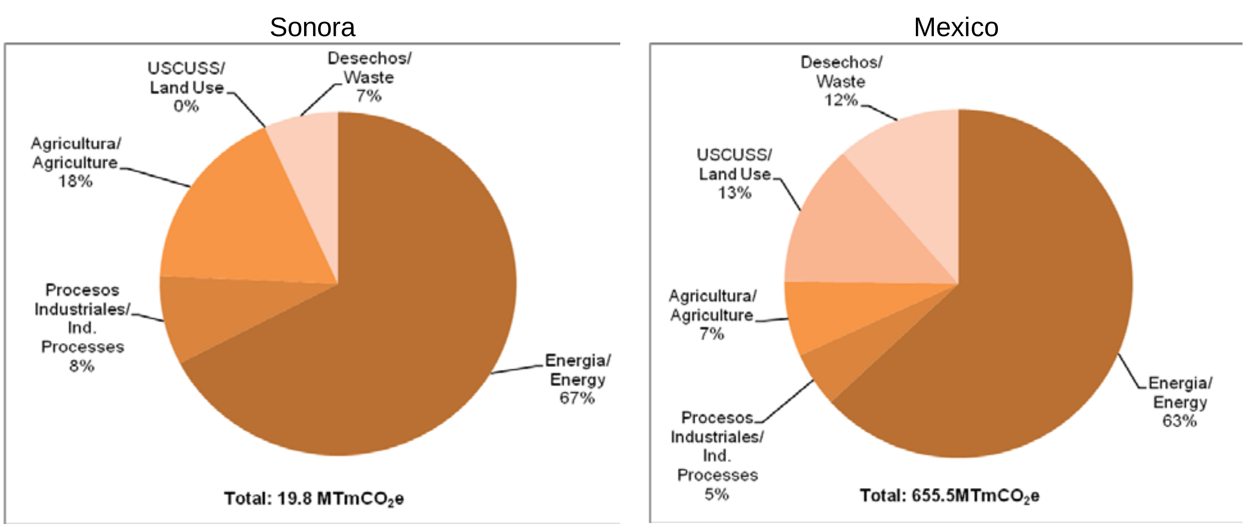


Figure 2. Gross GHG Emissions by Sector, 2005, Sonora and Mexico

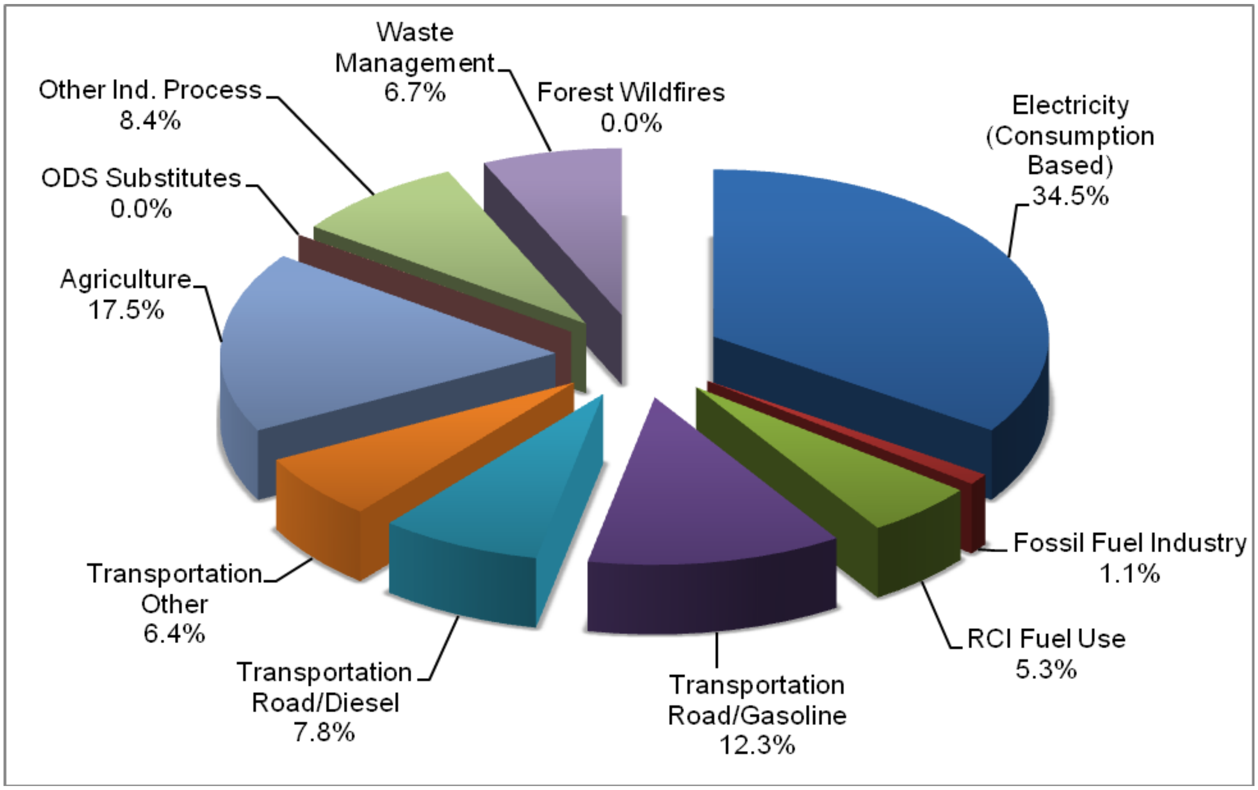


This inventory and forecast for Sonora is presented with some additional detail as compared to the Mexico national inventory prepared by INE. Table 2 provides correspondence between the Sonora and INE GHG sectors and Figure 3 shows the distribution of emissions according to Sonora GHG activity sectors for the year 2005

Table 2. Correspondence between INE and Sonora GHG Sectors

INE	Sonora
Energia / Energy	Electricity (Consumption Based)
Energia / Energy	Fossil Fuel Industry
Energia / Energy	RCI Fuel Use
Energia / Energy	Transportation Road/Gasoline
Energia / Energy	Transportation Road/Diesel
Energia / Energy	Aviation
Agricultura / Agriculture	Agriculture
Procesos Industriales / Ind. Processes	ODS Substitutes
Procesos Industriales / Ind. Processes	Other Ind. Process
Desechos / Waste	Waste Management
USCUSS / Land Use	Forestry and Land Use (net emissions)

Figure 3. Sonora Gross GHG Emissions by Sector, 2005



A Closer Look at the Three Major Sources: Electricity Supply, Transportation, and Agriculture Sectors

Electricity Supply Sector

Five power plants provide electricity in the state of Sonora. The plants with the largest output are Puerto Libertad in the municipality of Pitiquito and Guaymas II in the municipality of Guaymas generating a total of gross electricity of 3,081 and 2,044 GWh respectively in 2004. Both plants operate conventional thermal units that combust fuel oil.[11] Natural gas is the energy source at the plants of Hermosillo in the city of Hermosillo and Naco Nogales in the municipality of Agua Prieta. The Hermosillo and Naco Nogales plants generated 1,253 and 1,717 GWh of gross electricity in 2004, and operate combined cycle units. A small amount of electricity is generated at El Novillo hydroelectric plant located in the municipality of Soyopa. Gross electricity generation at El Novillo in 2004 totaled 174 GWh. Imported electricity from natural gas power plants in the US accounted for another 6 GWh in 2004.[12]

Except for the hydroelectric plant of El Novillo, the power plants in Sonora combust some form of fossil fuel to generate electricity. In 2004, energy from the combustion of fuel oil accounted for 73% of total primary energy used with the remainder coming from combustion of natural gas. Fossil fuel consumption for electricity production was responsible for 6.5 $MMtCO_2e$ of greenhouse gas emissions in 2004 and is estimated to increase to 12.2 $MMtCO_2e$ by 2020.

The fraction of electricity use associated with imported electricity in Sonora was estimated to be negligible (0.1%). Because electricity imports are very small compared to in-state production, production-based emission and consumption-based emissions are the same to three significant digits. It is important to note that the consumption-based approach can better reflect the emissions (and emission reductions) associated with activities occurring in Sonora, particularly with respect to electricity use (and efficiency improvements), and is particularly useful for policy-making. The available literature indicated that Sonora has not been a net exporter of electricity to other states or the US.

Transportation Sector

Transportation activities accounted for about 26% of Sonora's gross GHG emissions in 2005 (about 5.2 $MMtCO_2e$). The sector was divided into six subsectors as follows: a) road vehicles fueled by gasoline, b) road vehicles fueled by diesel, c) marine vessels fueled by diesel, d) airplanes fueled by kerosene, e) railroads, and f) unspecified vehicles fueled by other hydrocarbon fuels.

In 2005, transportation emissions totaled 5.2 $MMtCO_2e$, of which 46% resulted from gasoline combustion by onroad light-duty vehicles, 29% resulted from diesel combustion by on-road heavy-duty vehicles, 5% from jet fuel combustion by airplanes, 4% from diesel combustion by marine vessels, and 13% from diesel combustion in railroads. The remaining 13% share of

[11] Virtually all fuel oil comes from combustóleo (residual fuel oil). Activity data collected by CEDES from the Comisión Federal de Electricidad suggests that trace amounts of diesel are burned in lieu of combustóleo, when the latter is not available to supply all energy needs at these plants.
[12] José Alberto Díaz Montaño, ed. *Prospectiva del Sector Eléctrico 2005-2014*. Mexico: SENER, 2006 (50, 116).

emissions was attributed to non–specified sources combusting lubricants and small amounts of liquefied petroleum gas. By 2020, transportation emissions are estimated to reach 8.9 $MMtCO_2e$, of which gasoline combustion from on-road vehicles accounts for 49%, diesel combustion by on-road heavy vehicles for 29%, diesel combustion by marine vessels for 9%, and jet fuel combustion by airplanes for 7%. The share of non-specified sources is estimated at 6%.

Agricultural Sector

Non-fuel combustion emissions from agricultural activities are reported in the agricultural sector which accounted for 18% of the gross GHG emissions in 2005. This is significantly higher than the national average for agricultural emissions for the same year (7%). However, this is not at all surprising considering the importance of the agricultural sector to the economy in Sonora.

These emissions primarily come from enteric fermentation and agricultural soils. Enteric fermentation is the result of normal digestive processes of ruminant livestock resulting in methane emissions. Agricultural soils emit nitrous oxide emissions as a result of the addition of commercial nitrogen fertilizers, manure, nitrogen fixing crops, and decomposing crop residues. Emissions from the agricultural sector are projected to increase by about 24% between 2005 and 2020, with the majority of this increase coming through agricultural soils and enteric fermentation with mean annual growth rates of 1.7% and 1.5% respectively.

Smaller sources of GHG emissions in the agricultural sector include methane and nitrous oxide emissions from livestock manure management and crop residue burning. A notable subsector for which data were not available to estimate net CO_2 emissions is changes in cropland management. Changes in cropland management include bringing new acres into active cultivation, use of no- or low-tillage systems, additions of manure, conservation programs that keep crop land under permanent cover, and other management methods. Each of these management methods can result in net losses/gains in agricultural soil carbon, which means that CO_2 has been directly lost or indirectly sequestered from the atmosphere. Additional details for the agricultural sector inventory and forecast are provided in Appendix F.

Reference Case Projections

Relying on a variety of sources for projections, as noted below and in the appendices, CCS/CEDES developed a simple reference case projection of GHG emissions through 2020. As illustrated in Figure 4 below and shown numerically in Table 1 above, under the reference case projections, Sonora gross GHG emissions continue to grow steadily, climbing to about 33.5 $MMtCO_2e$ by 2020, 124% above 1990 levels. This equates to an annual rate of growth of 2.7% per year for the period starting 1990 through 2020.

From 1990 to 2005, the largest increase in emissions occurred in the electricity supply and industrial processes sectors with emission increases amounting to 2.8 and 1.5 $MMtCO_2e$, respectively. From 2005 to 2020, the largest increase in emissions occurs in the electricity supply sector with increased emissions in the order of 5.4 $MMtCO_2e$, followed by increases in the transportation sector of 3.7 $MMtCO_2e$ (sum of 3 subsectors), and the industrial processes sector of 2.2 $MMtCO_2e$. Table 3 summarizes the growth rates that drive the growth in the Sonora reference case projections, as well as the sources of these data.

Inventory estimates and reference case projections are shown in Figure 4 for all sectors. Sector contributions to gross GHG emissions growth are shown in Figure 5. Figure 5 provides estimates of contribution to growth in gross GHG emissions between inventory (1990-2005) and reference case projection (2005-2020) estimates.

Figure 4. Sonora Gross GHG Emissions by Sector, 1990-2020

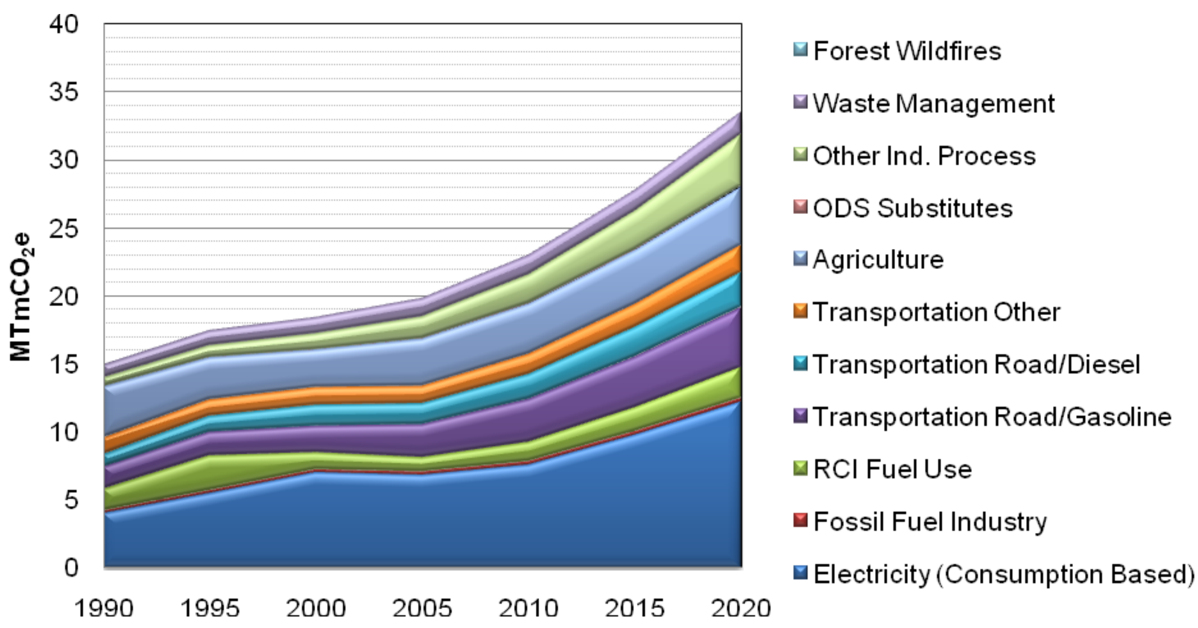
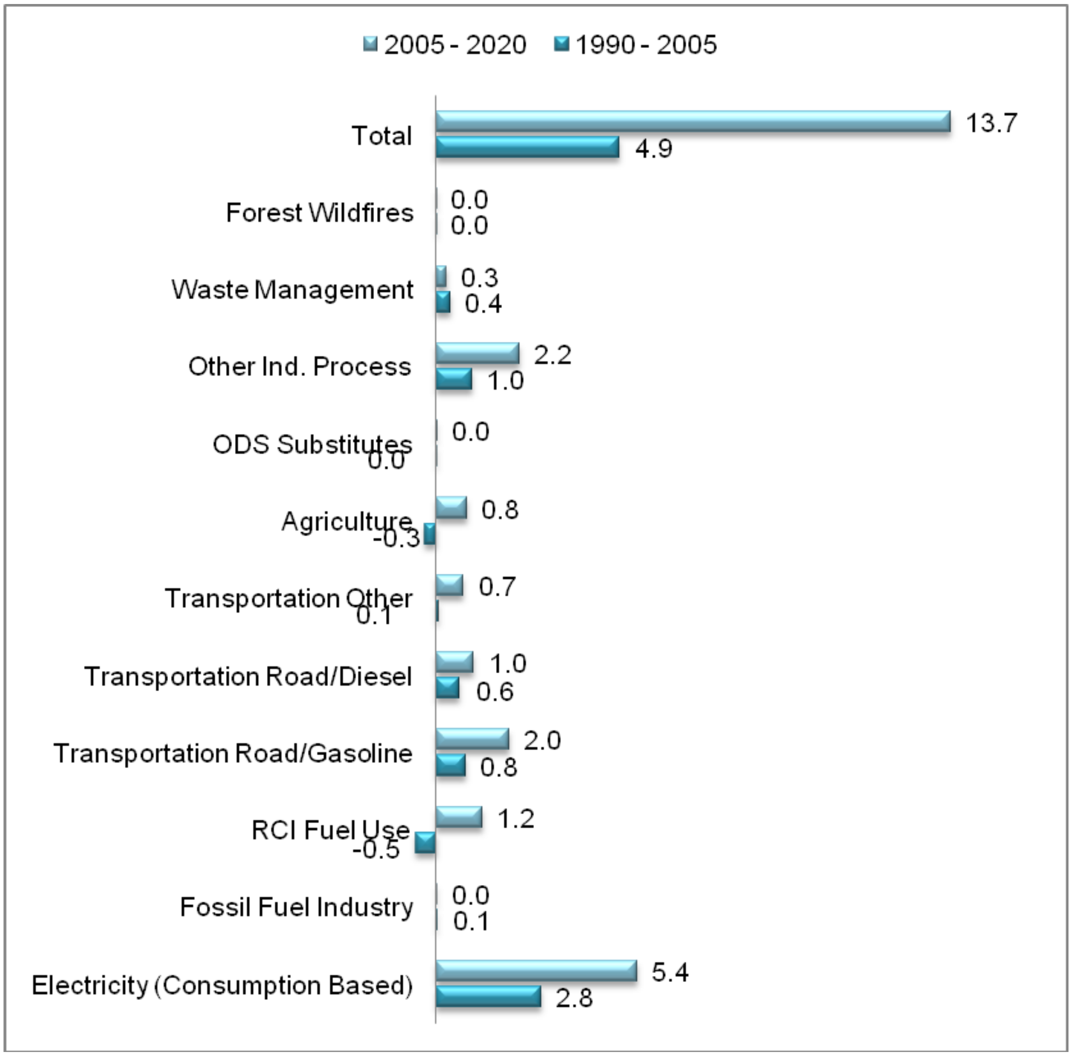


Figure 5. Sector Contributions to Gross Emissions Growth in Sonora, 1990-2020



Res/Comm – direct fuel use in residential and commercial sectors. ODS – ozone depleting substance. HFCs – hydrofluorocarbons. Emissions associated with other industrial processes include all of the industries identified in Appendix D except emissions associated with ODS substitutes. ODS substitutes are shown separately in this graph because of high expected growth in emissions seen in US state inventories for these substances.

Table 3. Key Annual Growth Rates for Sonora, Historical and Projected

Activity Data	Rate Period	Mean Annual Rate (%)	Sources
Population	1990 1995 2000 2005 2010	2.60 2.20 1.90 1.00 0.88	José Luis Luege Tamargo. *Mexico Tercera Comunicación Nacional ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático*. Mexico: INE-SEMARNAT, 2006
Electricity Demand	1994-2004 1996-2016	4.07 2.70	José Alberto Díaz Montaño, ed. *Prospectiva del Sector Eléctrico 2005-2014*. Mexico: SENER, 2006 (50, 116) Verónica Irastorza Trejo ed. *Prospectiva del Mercado de Gas Natural 2007-2016*. México: SENER, 2007
Liquefied Petroleum Gas Demand	1995-2015	1.69	José Alberto Díaz Montaño, ed. *Prospectiva del Mercado de Gas Licuado de Petroleo 2006-2015*. Mexico: SENER, 2006
Gasoline	1990-2007	3.33	Sonora Secretaría de Energía
Jet Kerosene	1990-2006	0.52	Sonora Secretaría de Energía
Fish Harvest	1998-2002	9.57	Gobierno del Estado de Sonora, Anuario Estadístico, Anexo Estadístico VI Informe (1997-2003)
Heavy Vehicle Registration	1990-2004	5.96	INEGI. Estadísticas de vehículos de motor registrados en circulación
Construction Spending	2000-2007	6.13	INEGI, Banco de Información Economica
Livestock Population	1990-2004	0 - 0.04[13]	SIACON
Crop Production	1990-2005	0 – 8.48[14]	SIACON

Key Uncertainties and Next Steps

Some data gaps exist in this inventory, and particularly in the reference case projections. Key tasks for future refinement of this inventory and forecast include review and revision of key drivers, such as demand for electricity from fuel oil, imported electricity, and electricity from hydroelectric plants. Additional information relating to the segregation of in-state diesel consumption by mode of transportation (marine vessel, railway, on-road) for inventory years can help reduce uncertainty in projected emissions. Historical activity data relating to cement production, lime production, and limestone use can also reduce uncertainty associated with forecast estimates.

[13] Mean annual growth value range for animal species considered in this report.
[14] Mean annual growth value range for crop types considered in this report.

Additional work is needed to: further refine the carbon sequestration estimates for the forested landscape; add sequestration estimates for urban forests; add net CO_2 flux for agricultural soils; and add net CO_2 flux associated with other land use change (e.g. losses/gains in forest acreage).

Applied growth rates are driven by uncertain economic, demographic and land use trends (including growth patterns and transportation system impacts), all of which deserve closer review and discussion. These are listed in Table 3. More details on key uncertainties and suggested next steps for the refinement of the estimates presented in this report are provided in each of the sector appendices.

Approach

The principal goal of compiling the inventories and reference case projections presented in this document is to provide the State of Sonora with a general understanding of Sonora's historical, current, and projected (expected) GHG emissions. The following sections explain the general methodology and the general principles and guidelines followed during development of these GHG estimates for Sonora.

General Methodology

CCS/CEDES prepared this analysis in close consultation with Sonora agencies. The overall goal of this effort was to provide simple and straightforward estimates, with an emphasis on robustness, consistency, and transparency. As a result, CCS/CEDES relied on reference forecasts from best available State and regional sources where possible. Where reliable existing forecast data were lacking, CCS/CEDES used straight-forward spreadsheet analysis and constant growth-rate extrapolations of historical trends rather than complex modeling.

In most cases, CCS/CEDES followed the same approach to emissions accounting for historical inventories as used by the US EPA in its national GHG emissions inventory[15] and its guidelines for States.[16] These inventory guidelines were developed based on the guidelines from the Intergovernmental Panel on Climate Change (IPCC), the international organization responsible for developing coordinated methods for national GHG inventories.[17] The inventory methods provide flexibility to account for local conditions. The key sources of activity and projection data used are shown in Table 4. This table also provides the descriptions of the data provided by each source and the uses of each data set in this analysis.

General Principles and Guidelines

A key part of this effort involves the establishment and use of a set of generally accepted accounting principles for evaluation of historical and projected GHG emissions, as follows:

[15] US EPA, "Inventory Of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005," April 2007 http://www.epa.gov/climatechange/emissions/usinventoryreport.html.
[16] http://yosemite.epa.gov/oar/globalwarming.nsf/content/EmissionsStateInventoryGuidance.html.
[17] http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

- **Transparency:** CCS/CEDES report data sources, methods, and key assumptions to allow open review and opportunities for additional revisions later based on input from others. In addition, key uncertainties are reported, where they exist.
- **Consistency:** To the extent possible, the inventory and projections were designed to be externally consistent with current or likely future systems for State and national GHG emission reporting. CCS/CEDES have used the EPA tools for State inventories and projections as a starting point. These initial estimates were then augmented and/or revised as needed to conform with State-based inventory and reference-case projection needs. For consistency in making reference case projections, CCS/CEDES define reference case actions for the purposes of projections as those *currently in place or reasonably expected over the time period of analysis.*
- **Priority of Existing State and Local Data Sources:** In gathering data and in cases where data sources conflicted, CCS/CEDES placed highest priority on local and State data and analyses, followed by regional sources, with national data or simplified assumptions such as constant linear extrapolation of trends used as defaults where necessary.
- **Priority of Significant Emissions Sources:** In general, sources with relatively small emissions levels received less attention than those with larger GHG contributions.
- **Comprehensive Coverage of Gases, Sectors, State Activities, and Time Periods:** This analysis aimed to comprehensively cover GHG emissions/sinks associated with activities in Sonora. It covers all six GHGs covered by IPCC guidelines and reported in national inventories: CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs. The inventory estimates are for the year 1990, with subsequent years included up to most recently available data (typically 2002 to 2005), with projections to 2020.
- **Use of Consumption-Based Emissions Estimates:** To the extent possible, CCS/CEDES estimated emissions that are caused by activities that occur in Sonora. For example, emissions associated with the electricity consumed in Sonora were reported. The rationale for this method of reporting is that it can more accurately reflect the impact of State-based policy strategies such as energy efficiency on overall GHG emissions. It can also resolve double-counting and exclusion problems with multi-emissions issues. This approach can differ from how inventories are compiled, for example, on an in-state production basis, in particular for electricity.

As mentioned above, CCS/CEDES estimated the emissions related to electricity *consumed* in Sonora. This entails accounting for the electricity sources used by Sonora utilities to meet consumer demands. As this analysis is refined in the future, one could also attempt to estimate other sectoral emissions on a consumption basis, such as accounting for emissions from transportation fuel used in Sonora, but also accounting for extraction, refining, and distribution emissions (some of these occurring out of state). As in this example, this can require venturing into the relatively complex terrain of life-cycle analysis. In general, CCS recommends considering a consumption-based approach, where it will significantly improve the estimation of the emissions impact of potential mitigation strategies. For example, in the solid waste management sector, re-use, recycling, and source reduction can lead to emission reductions resulting from lower energy requirements for material production (such as paper, cardboard, and aluminum), even though production of those materials, and emissions associated with materials production, may not occur within the state.

Details on the methods and data sources used to construct the inventories and forecasts for each source sector are provided in the following appendices:

- Appendix A. Electricity Use and Supply
- Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion
- Appendix C. Transportation Energy Use
- Appendix D. Industrial Processes
- Appendix E. Fossil Fuel Industry
- Appendix F. Agriculture
- Appendix G. Waste Management
- Appendix H. Forestry

Table 4. Key Data Sources for Sonora and Comparison of Methodologies with the National GHG Inventory

Sector	Key Data Sources	Method	Comparison with INEGEI
Electricity Consumption and Supply	SENER and CFE: state-level sector-based electricity consumption data; INEGI: state-level electricity generation data	2006 IPCC, Tier 1 method, where fuel consumption is multiplied by default emission factors.	1996 IPCC, Tier 1 method; national electricity production data from SENER.
Residential, Commercial, and Industrial (RCI) Fuel Combustion	SENER: state-level fuel consumption for RCI sectors	2006 IPCC, Tier 1 method, where fuel consumption is multiplied by default emission factors	1996 IPCC, Tier 1 method; national-level fuel consumption from SENER.
Transportation Energy Use	SENER- Sonora: State-level fuel consumption by fuel type SCT: State-level statistics used to allocate fuel sales to end use (e.g. rail infrastructure, national cargo movement by water) Anuario Estadístico de PEMEX, 2005. Fuel consumption by key sectors of the economy	2006 IPCC, Tier 1 method, where fuel consumption is multiplied by default emission factors.	1996 IPCC, Tier 1 method; SENER provided fuel consumption data for all sources except aircraft. 1996 IPCC, Tier 2 method for aviation based on landing & takeoff statistics.
Industrial Processes and Product Use	SEMARNAT: production data for cement, lime, limestone production in 2005	EPA, SIT Tool	1996 IPCC, Tier 1 method; national cement production data from CANACEM.

Sector	Key Data Sources	Method	Comparison with INEGEI
	INEGI: state-level vehicle registration data and IPCC emission factors for HFC emissions as originally developed by Centro Mario Molina, Inventario Estatal de Emisiones de GEI del Estado de Baja California, 2005	IPCC: HFC emissions - the number mobile air conditioning (AC) units are multiplied by an IPCC default emission factor.	1996 IPCC, Tier 1 method, where fugitive HCF are calculated through mass balance using national production, import and export data.
Fossil Fuel Industry	CEDES: Natural gas infrastructure data SENER: volume of natural gas consumed.	EPA, SIT method, where fossil fuel industry infrastructure is multiplied by US industry average emission factors.	1996 IPCC, Tier 1 method, where national production data from PEMEX is multiplied by default emission factors.
Agriculture	SAGARPA - SIACON: crop and livestock production data at the state-level, International Fertilizer Industry Association: fertilizer application data	2006 IPCC, Tier 1 method and emission factors.	1996 and 2003 IPCC guidelines and SAGARPA-SIACON national data. A number of emission factors were the updated based on field studies conducted in Mexico.
Waste Management	SEDESOL: state-level solid waste generation data maintained by SNIARN CONAGUA: domestic wastewater treatment data at the state-level	2006 IPCC, Tier 1 method and emission factors.	1996 IPCC, Tier 1 method with SEDESOL national data for solid waste generation.
Forestry and Land Use	CONAFOR: Land use, vegetation information. Forest management statistics. CEDES: processed digital maps INEGI 1993, 2003.		2003 IPCC methods. INE assessed carbon flux based on national digital maps (mapas de vegetación del INEGI, 1993, 2003). INE's assessment covers carbon flux in selected land use categories due to land use practices, and changes in land use.

Appendix A. Electricity Supply and Use

Overview

This appendix describes the data sources, key assumptions, and the methodology used to develop an inventory of greenhouse gas (GHG) emissions over the 1990-2005 period associated with the generation of electricity to meet electricity demand in Sonora. It also describes the data sources, key assumptions, and methodology used to develop a forecast of GHG emissions over the 2005 -2020 period associated with meeting electricity demand in the state. Specifically, the following topics are covered in this Appendix:

- *Data sources:* This section provides an overview of the data sources that were used to develop the inventory and forecast, including publicly accessible websites where this information can be obtained and verified.
- *Greenhouse Gas Inventory methodology:* This section provides an overview of the methodological approach used to develop the Sonora GHG inventory for the electric supply sector.
- *Greenhouse Gas Forecast Methodology – Reference Case:* This section provides an overview of methodological approach used to develop the Sonora GHG reference case projections (forecast) for the electric supply sector.
- *Greenhouse Gas Inventory Results:* This section provides an overview of key results of the Sonora GHG inventory for the electric supply sector.
- *Greenhouse Gas Forecast Results:* This section provides an overview of key results of the Sonora GHG forecast for the electric supply sector.

Data Sources

We considered several sources of information in the development of the inventory and forecast of carbon dioxide equivalent (CO_2e) emissions from Sonora power plants. These are briefly summarized below:

- *Energy content of petroleum products:* This information was obtained from Secretaría de Energía (SENER) in the publication titled "Balance Nacional de Energía 2006" available at http://www.sener.gob.mx/webSener/index.jsp.
- *Historic and projected sales of natural gas:* This information is available from SENER in a publication titled "Prospectiva del Mercado de Gas Natural 2007-2016". It can be accessed directly from http://www.sener.gob.mx/webSener/index.jsp. Available temporal series, 1994-2004. Official outlook extends to 2014.
- *State electricity generation data.* This information is available from SENER. The publication titled "Prospectiva del Sector Electrico 2005-2014" compiles renewable energy data, electricity import and export data, efficient capacity of existing plants, and total gross generation of electricity across technology and fuel types. It can be accessed directly from http://www.sener.gob.mx/webSener/index.jsp.

- *Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emission factors.* For all fuels, these emission factors were based on default values listed on Tables 2.2, 2.3, 2.4, 2.5, Chapter 2, Volume 2, of 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. This information can be accessed directly from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html.
- *Global warming potentials.* These are based on values proposed by the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report. This information can be accessed directly from http://www.ipcc.ch/ipccreports/assessments-reports.htm.
- *Sonora Population.* Population numbers were prepared by CCS based on census data available from Instituto Nacional de Geografía, Estadísticas, e Informática[18] and Tercera Comunicación Nacional ante la Convencion de las Naciones Unidas.[19]
- *Volume of fossil fuel consumption*: Comisión de Ecología y Desarrollo Sustentable (CEDES) del Estado de Sonora obtained from Comisión Federal de Electricidad (CFE) the state's fuel consumption for the purposes of power generation for the period 1993 to 2012. The information was provided in the form of total volume of fuel consumed per fuel type: natural gas, combustóleo (residual fuel oil), and diesel. Although considered, this source was not used to calculate emissions from fossil fuel combustion, because SENER's information found in *Prospectiva del Sector Electrico 2005-2014* provided more detailed segregated information for the entire electricity supply sector. A comparison of CFE and SENER data sets is provided in Figure A-1. It is important to note that the energy allocation of diesel by CFE was combined with that of residual fuel oil for the purposes of comparison with SENER's data set. Furthermore, energy from diesel only accounted in average for 0.66% of fuel oil energy (the sum of diesel and residual fuel oil energy).

Greenhouse Gas Inventory Methodology

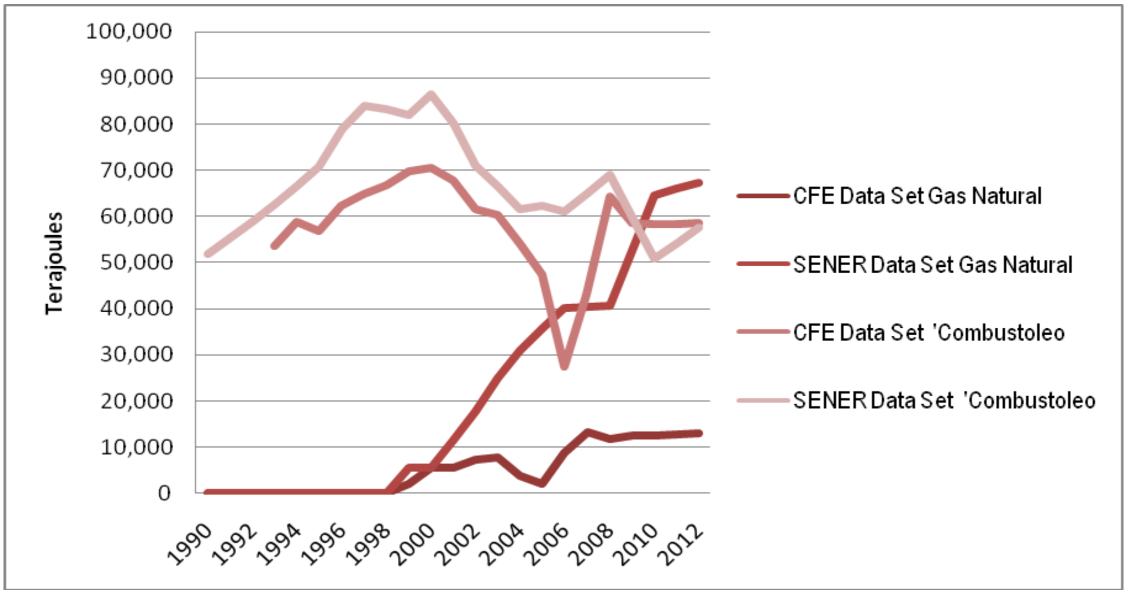
The 2006 IPCC Guidelines offer three approaches for estimating emissions from fossil fuel combustion. Based on available information in the case of Sonora, a Tier 1 approach was selected. Based on 2004 data, Sonora generates 62% of its electricity using fuel oil, 36% from natural gas and 2% from hydroelectricity. Also, Sonora imports a very small amount of electricity (about 0.1%) and exports no electricity. Additional details are provided in the Results section below.

The 2006 IPCC Guidelines estimate GHG emissions in terms of the species which are emitted. During the combustion process, most of the carbon is immediately emitted as CO_2. However, some carbon is released as carbon monoxide (CO), methane (CH_4) or non-methane volatile organic compounds (NMVOCs). Most of the carbon emitted as these non-CO_2 species eventually oxidizes to CO_2 in the atmosphere. In the case of fuel combustion, the emissions of these non-CO_2 gases contain very small amounts of carbon compared to the CO_2 estimate and, at Tier 1, it is often more accurate to base the CO_2 estimate on the total carbon in the fuel. This is because

[18] Retrieved May, 2008 from: http://www.inegi.gob.mx/inegi/default.aspx
[19] Retrieved May, 2008 from: http://maindb.unfccc.int/public/country.pl?country=MX

the total carbon in the fuel depends on the fuel alone, while the emissions of the non-CO_2 gases depend on many factors such as combustion technology, equipment maintenance, and other factors which, in general, are not well known.

Figure A-1. Comparison Between CFE and SENER Data Sets



The Tier 1 method is fuel-based and emissions from all sources of combustion are estimated on the basis of the quantities of fuel combusted and average emission factors. Tier 1 emission factors are available for each of the relevant greenhouse gases. The quality of these emission factors differs between gases. For CO_2, emission factors mainly depend upon the carbon content of the fuel. Combustion conditions (combustion efficiency, carbon retained in slag and ash, etc.) are relatively unimportant. Therefore, CO_2 emissions can be estimated fairly accurately based on the total amount of fuels combusted and the averaged carbon content of the fuels. However, emission factors for methane and nitrous oxide depend on the combustion technology and operating conditions and vary significantly, both between individual combustion installations and over time. Due to this variability, use of averaged emission factors for these gases introduces relatively large uncertainties.[20]

The approach used for inventory CO_2e emissions gave priority to available historic records. The largest set of historic records pertained to gross electricity generation in giga-watt-hours (GWh) for the state of Sonora from 1994 to 2004. The second largest set of historic records detailed electricity imports for the same time period. Imported electricity is generated from the combustion of natural gas in the US.[21] The final set of historic data detailed the distribution of electricity producers by fuel (fuel oil or natural gas) and technology (hydraulic, combined cycle, or thermal) for the year 2004. Table A-1 shows inventory electricity generation values where

[20] This paragraph is quoted with minor editing from Chapter 1, Volume 2 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories, page 1.6. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf
[21] Based on research conducted by Mr. Francisco Maytorena of CEDES, May 2008.

values in bold font represent actual numbers and values in regular font are numbers calculated as described below:

- State total electricity generation for years 1990 to 1993 was back calculated using the 1994-1995 mean annual growth rate of Sonora's energy per capita ratio.
- Electricity production from El Novillo hydraulic plant was assumed to generate power at the same level as 2004.
- The volume of natural gas dedicated to the energy industry was used to calculate electricity production in GWh from Union Fenosa plant in Hermosillo and CCC Naco Nogales plant in Agua Prieta. Volume of natural gas was multiplied by the energy content of natural gas using net energy content values published by SENER in Balance Nacional de Energía 2004.[22]
- Electricity production from the combustion of fuel oil in Puerto Libertad and Guaymas II was calculated as the difference of energy produced from natural gas, hydraulic, and import sources from total energy production in Sonora.
- Energy values in GWh were converted to primary energy consumption values in terajoules for using average heat rate values for each type of electricity generation technology. Table A-2 displays average heat rate values used for this report.[23]
- Default IPCC emission factors were used to estimate GHG emissions and are listed on Table A-3 below.

Table A-1. Inventory Gross Electricity Generation Values in GWh

Year	Fuel Oil	Natural Gas	Import	Hydroelectric	Total
1990	4,318	0	2	174	4,494
1991	4,595	0	2	174	4,771
1992	4,889	0	2	174	5,065
1993	5,201	0	2	174	5,377
1994	5,533	0	2	174	**5,709**
1995	5,884	0	**3**	174	**6,061**
1996	6,585	0	**3**	174	**6,762**
1997	7,000	0	**3**	174	**7,177**
1998	6,930	0	**3**	174	**7,107**
1999	6,823	**517**	**4**	174	**7,518**
2000	7,197	**519**	**4**	174	**7,894**
2001	6,675	**1,103**	**4**	174	**7,956**
2002	5,917	**1,687**	**5**	174	**7,783**
2003	5,528	**2,382**	**5**	174	**8,089**
2004	**5,125**	**2,970**	**6**	**174**	**8,514**

[22] Retrieved May, 2008 from: http://www.sener.gob.mx/
[23] Heat rate values from Table 3.10. Lower and Upper Limits Applied to Heat Rate Data in NEEDS 2006. Retrieved June, 2008 from http://epa.gov/airmarkt/progsregs/epa-ipm/docs/Section-3.pdf.

Table A-2. Average Heat Rate Values

Technology	Average Heat rate	
	Btu/kWh	TJ/GWh
Oil/Gas steam	11,400	12.03
Combined cycle natural gas	9,869	10.41

Table A-3. Selected Emission Factors

Fuel Type	EF CO2 (kg/TJ)	EF N2O (kg/TJ)	EF CH4 (kg/TJ)
Import	56,100	0.1	1
Natural Gas	56,100	0.1	1
Residual Fuel Oil	77,400	0.6	3

Greenhouse Gas Forecast Methodology – Reference Case

Whenever possible, official forecast numbers and figures were used for constructing a GHG forecast. Attempts to obtain the following information were made: detailed state-specific data regarding projected sales, gross in-state generation, supply-side efficiency improvements, planned capacity additions and retirements by plant type/vintage, changes over time regarding losses associated with on-site use, transmission and distribution. However, while some of this information was available, some key data were not at the time the forecast was prepared. Available information included projected sales and gross in-state electricity generation estimates. The methodological steps used for forecasting CO_2e emissions are described below. Forecast electricity demand is shown in Table A-4 where values in bold font represent official forecast values by SENER[24].

Electricity demand. An overview of the methodology applied to forecast electricity demand is briefly summarized below:

- Energy consumption for 1994-2004 was estimated as the amount of electricity generated in state plus the amount imported. An energy per capita ratio was developed for each year from these values using Sonora's population.
- The 1994-2004 energy-per-capita values were used to calculate the mean annual growth rate, which was used to grow the energy consumption in each year of the forecast period (2005 to 2020).
- Forecast electricity consumption was estimated in each year by multiplying by Sonora's population forecast.

Natural Gas. An overview of the methodology applied to forecast natural gas used in Sonora power stations is briefly summarized below:

- SENER provided projected sales of natural gas to the energy sector through 2016.
- The mean annual growth rate for period 1996 to 2016 (2.7%) was applied to all subsequent years. Overall, the use of natural gas rose sharply during inventory years.

Hydroelectric power. An overview of the methodology applied to forecast hydroelectric power generation in Sonora is briefly summarized below:

[24] SENER. *Prospectiva del Mercado de Gas Natural 2007-2016*. 168

- Hydroelectric power generation information was only available for year 2004. During inventory years, it was assumed that the rate of electricity generation was equal to that of 2004.
- Forecast values were assumed to grow at the same mean annual growth rate as total electricity demand for years 1994 through 2004 (4.1%) not to exceed the power generation capacity of the plant.

Import/Export. An overview of the methodology applied to forecast import/export electricity in Sonora is briefly summarized below:

- Import electricity generation was available for years 1994-2004; however, the literature indicates that Sonora is not a net exporter of electricity.[25]
- For the period 2005 to 2020, import forecast values were assumed to equal the electricity demand that exceeded in-state capacity. However, projected electricity demand was met by domestic supply.

Residual fuel oil. An overview of the methodology applied to forecast residual fuel oil used in Sonora power stations is briefly summarized below:

- The amount of residual fuel oil (combustóleo) combusted for electricity generation purposes was only available for the year 2004. Forecast values were determined by means of energy balance; specifically, energy from residual fuel oil was assumed to be equal to total energy demand minus energy supplied by natural gas, hydroelectric power, and imported energy.

Table A-4. Forecast Gross Electricity Generation Values in GWh

Year	Fuel Oil	Natural Gas	Import	Hydroelectric	Total
2005	5,177	**3,421**	0	181	8,779
2006	5,089	**3,848**	0	188	9,126
2007	5,422	**3,868**	0	196	9,486
2008	5,755	**3,901**	0	204	9,860
2009	4,985	**5,052**	0	212	10,249
2010	4,230	**6,203**	0	221	10,654
2011	4,500	**6,331**	0	230	11,061
2012	4,786	**6,459**	0	240	11,484
2013	5,291	**6,382**	0	249	11,923
2014	5,813	**6,306**	0	259	12,379
2015	6,873	**5,709**	0	270	12,852
2016	7,951	**5,112**	0	281	13,344
2017	8,312	**5,250**	0	293	13,854
2018	8,688	5,392	0	304	14,384
2019	9,080	5,537	0	317	14,933
2020	9,488	5,687	0	330	15,504

Results

Table A-5 and Figure A-2 summarize the characteristics of the electricity supply system in Sonora. Included in this information is the total electricity generation by fuel type, total energy

[25] SENER. *Prospectiva del Sector Electrico 2005-2014. 50.*

consumption, and the associated GHG emissions for 2004. The following subsections provide an overview of the results of the GHG emissions inventory and reference case projections estimated using the methodological approach described above. Gross electricity generation is summarized in Figure A-3. Primary energy consumption in Sonora comes predominantly from the combustion of fuel oil (combustóleo). SENER projects that natural gas power plants will supply increasingly more electricity to the grid and that those natural gas power plant will peak production in 2012. Hydroelectric power represents a small fraction of total gross electric energy generation. Primary energy consumption is shown in Figure A-4. Finally, GHG emissions per mode of generation are shown in Figure A-5.

Figure A-2. Summary of Electric Generation Characteristics, 2004

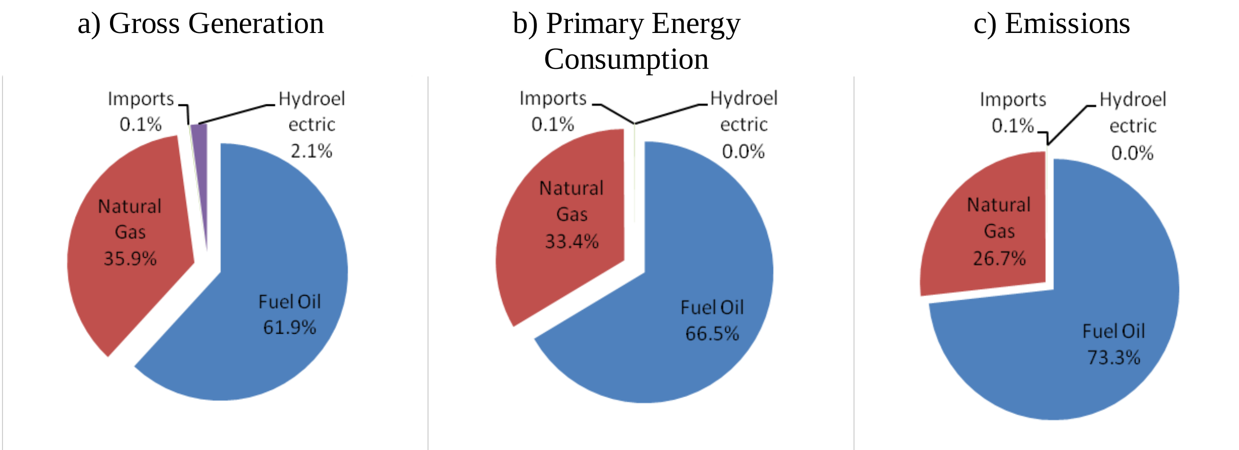


Table A-5. Summary of Electric Generation Characteristics, 2004

Fuel	Gross Electric Energy Generation	Primary Energy Consumption	Emissions
	GWh	Terajoules	$MMtCO_2e$
Fuel Oil	5,125	61,642	4.77
Natural Gas	2,970	30,925	1.73
Imports	6.0	62	0.00
Hydroelectric	174	0	0.00

Figure A-3. Gross Electricity Generation in Sonora

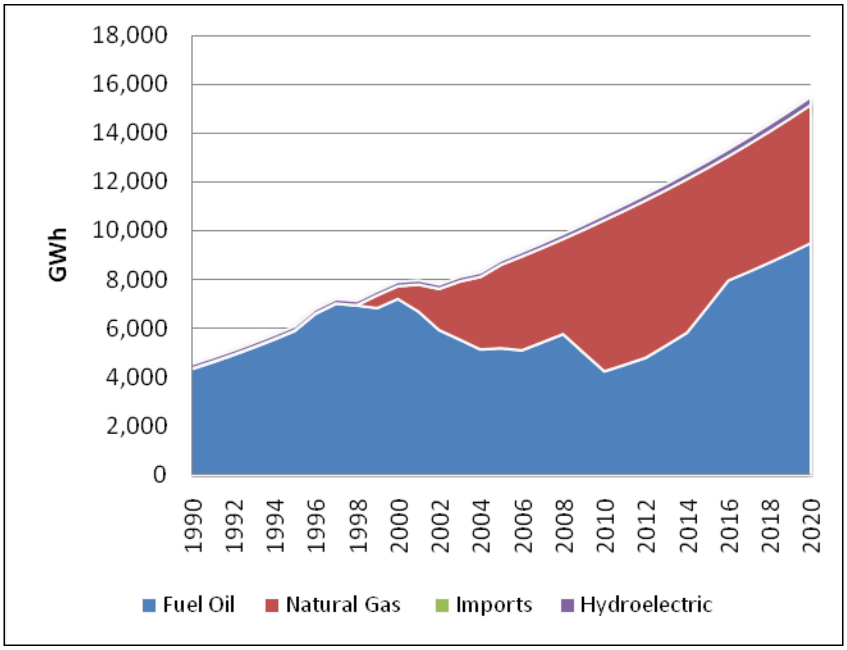


Table A-6. Gross Electricity Generation in Sonora in GWh

Year	Fuel Oil	Natural Gas	Imports	Hydroelectric
1990	4,318	0	2	174
1992	4,889	0	2	174
1994	5,533	0	2	174
1996	6,585	0	3	174
1998	6,930	0	3	174
2000	7,197	519	4	174
2002	5,917	1,687	5	174
2004	5,125	2,970	6	174
2006	5,089	3,848	0	188
2008	5,755	3,901	0	204
2010	4,230	6,203	0	221
2012	4,786	6,459	0	240
2014	5,813	6,306	0	259
2016	7,951	5,112	0	281
2018	8,688	5,392	0	304
2020	9,488	5,687	0	330

Figure A-4. Primary Energy Consumption

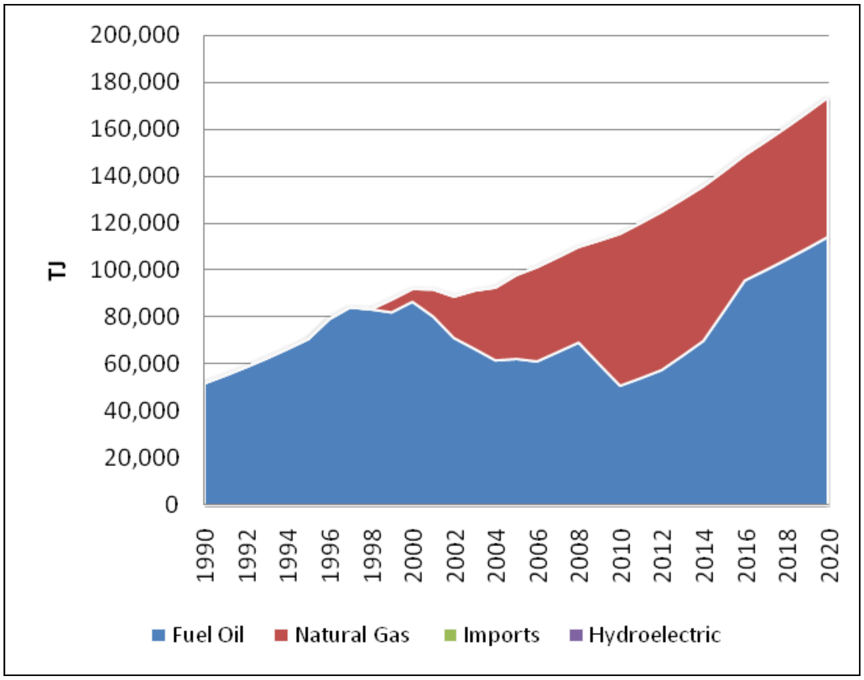


Table A-7. Primary Energy Consumption in Terajoules

Year	Fuel Oil	Natural Gas	Imports	Hydroelectric
1990	51,934	0	21	0
1992	58,805	0	21	0
1994	66,549	0	21	0
1996	79,202	0	31	0
1998	83,352	0	31	0
2000	86,568	5,399	41	0
2002	71,164	17,569	51	0
2004	61,642	30,925	62	0
2006	61,210	40,066	0	0
2008	69,219	40,618	0	0
2010	50,876	64,584	0	0
2012	57,559	67,252	0	0
2014	69,923	65,660	0	0
2016	95,630	53,225	0	0
2018	104,491	56,138	0	0
2020	114,119	59,210	0	0

Figure A-5. Total GHG Emissions Associated with Electric Demand

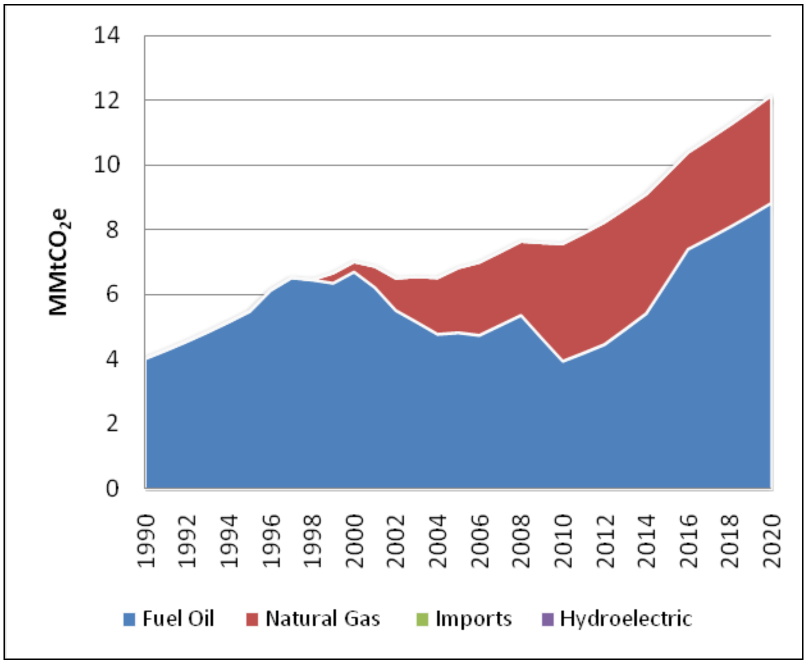


Table A-8. Total GHG Emissions Associated with Electric Demand in $MMtCO_2e$

Year	Fuel Oil	Natural Gas	Imports	Hydroelectric
1990	4.020	0.000	0.001	0.000
1992	4.551	0.000	0.001	0.000
1994	5.151	0.000	0.001	0.000
1996	6.130	0.000	0.002	0.000
1998	6.451	0.000	0.002	0.000
2000	6.700	0.303	0.002	0.000
2002	5.508	0.986	0.003	0.000
2004	4.771	1.735	0.003	0.000
2006	4.738	2.248	0.000	0.000
2008	5.358	2.279	0.000	0.000
2010	3.938	3.623	0.000	0.000
2012	4.455	3.773	0.000	0.000
2014	5.412	3.684	0.000	0.000
2016	7.402	2.986	0.000	0.000
2018	8.088	3.149	0.000	0.000
2020	8.833	3.322	0.000	0.000

Key Uncertainties

A Tier I approach was used to estimate GHG emissions from the energy supply sector. According to 2006 IPCC guidelines, a Tier I method is best suited when the energy sector does not represent a key source of emissions. Historically, electricity generation accounts for one third of total state greenhouse gas emissions, therefore, it is recommended to adopt and develop Tier II or Tier III methods. Tier III methods consist of either emission measurements at power generation plants or emissions modeling that matches state fuel statistics. Tier II method consists in emission measurements for each type of fuel used in the power generation sector.

Emission factors for methane and nitrous oxide depend on the combustion technology and operating conditions and vary significantly, both between individual combustion installations and over time. Due to this variability, use of averaged emission factors for these gases introduces relatively large uncertainties; however, these non-CO_2 gases contribute relatively little to the CO_2 equivalent total emissions from combustion units at power plants.

Better information is needed to increase the accuracy of the forecast emissions for this sector. For example, it is plausible that expiring fuel oil plants will be replaced by cleaner energy technologies during the forecast period (e.g. natural gas units).

Finally, fuel price changes influence consumption levels and, to the extent that price trends for competing fuels differ, these may encourage switching among fuels, which could greatly affect the forecast emissions estimates. Unanticipated events that affect fuel prices could affect the electricity forecast for Sonora.

Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion

Overview

Activities in the RCI[26] sectors produce CO_2, CH_4, and N_2O emissions when fuels are combusted to provide space heating, water heating, process heating, cooking, and other energy end-uses. In 2005, total GHG emissions were 4.3 $MMtCO_2e$ of which 51% was emitted by industrial sources and 48% by residential sources. Although some energy use was quantified for commercial and agriculture sources, their emissions are negligible in comparison to greenhouse gas emissions from industrial and residential sources.

Emissions and Reference Case Projections

The 2006 IPCC Guidelines offer three approaches for estimating emissions from fossil fuel combustion by stationary sources. Based on available information, a Tier 1 approach was selected.

The 2006 IPCC Guidelines estimate carbon emissions in terms of the species which are emitted. During the combustion process, most carbon is immediately emitted as CO_2. However, some carbon is released as carbon monoxide (CO), CH_4 or non-methane volatile organic compounds (NMVOCs). Most of the carbon emitted as these non-CO_2 species eventually oxidizes to CO_2 in the atmosphere. In the case of fuel combustion, the emissions of these non-CO_2 gases contain very small amounts of carbon compared to the CO_2 estimate and, at Tier 1, it is more accurate to base the CO_2 estimate on the total carbon in the fuel. This is because the total carbon in the fuel depends on the fuel alone, while the emissions of the non-CO_2 gases depend on many factors such as technologies, maintenance etc which, in general, are not well known.

The Tier 1 method is fuel-based, since emissions from all sources of combustion can be estimated on the basis of the quantities of fuel combusted and average emission factors. Tier 1 emission factors are available for all relevant direct greenhouse gases. The quality of these emission factors differs between gases. For CO_2, emission factors mainly depend upon the carbon content of the fuel. Combustion conditions (combustion efficiency, carbon retained in slag and ashes etc.) are relatively unimportant. Therefore, CO_2 emissions can be estimated fairly accurately based on the total amount of fuels combusted and the averaged carbon content of the fuels. However, emission factors for methane and nitrous oxide depend on the combustion technology and operating conditions and vary significantly, both between individual combustion installations and over time. Due to this variability, the use of averaged emission factors for these gases will introduce relatively large uncertainties. [27]

In order to capture the difference in CH_4 and N_2O emissions, default emission factors in 2006 IPCC guidelines are listed in separate tables according to four subsectors: 1) energy industries,

[26] The industrial sector includes emissions associated with agricultural energy use and natural gas consumed as lease and plant fuel. Emissions associated with pipeline fuel use are included in Appendix E.
[27] This paragraph is quoted with minor editing from Chapter 1, Volume 2 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories, page 1.6. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf

2) manufacturing industries and construction, 3) commercial and institution, and 4) residential and agriculture/forestry/fishing farms. [28] A brief description of the methods and activity data used to develop reference case projections follows below.

Diesel

Diesel consumption in the RCI sector was determined as the difference between total diesel energy consumption in the state of Sonora and diesel energy consumption in the transportation sector. This energy balance approach was selected because total diesel energy consumption information was available from the Secretaría de Energía de Sonora[29] and transportation energy information was available from Petróleos Mexicanos.[30] Further, it was assumed that diesel consumption within the RCI sector pertained to industrial applications. Projection numbers were derived from inventory years. Historically, diesel consumption sharply declined from 1996 through 2004. Steady consumption growth was only apparent from 1990 to 1998. Consequently, forecast values were calculated using the mean annual growth rate of (3.9) derived from the period 1990 to 1998.

Liquefied Petroleum Gas

State consumption of liquefied petroleum gas (LPG) and forecast consumption were obtained from SENER.[31] Segregated fuel consumption information by subsector was not available at the state level. For that reason, total LPG consumption was divided into subsectors according to national statistics. SENER official LPG consumption projections were available through 2015. For the remaining forecast years, state total consumption was assumed to grow at the 1995-2015 mean annual growth rate of 1.2% and subsector distribution was kept equal to that of year 2015. Table B-1 shows national LPG consumption distribution per subsector during inventory and projection years.

Table B-1. National LPG Consumption Distribution

Subsector	1990	1995	2000	2005	2010	2015	2020
Residential	78%	78%	65%	63%	61%	61%	61%
Commercial	13%	13%	14%	13%	14%	14%	14%
Industrial	6.9%	6.9%	9.4%	8.3%	8.1%	9.0%	9.0%
Agriculture	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Natural Gas

State consumption of natural gas and forecast consumption data were obtained from SENER.[32] Some segregated fuel consumption information by subsector was available at the state level. Also, SENER official natural gas consumption projections were available through 2016. For

[28] Default emission factor tables are found in Chapter 2, Volume 2 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.
[29] Sonora's Secretería de Energía provided hydrocarbons sale information to Comisión de Ecología y Desarrollo Sustentable (CEDES) del Estado de Sonora upon its request.
[30] Detailed source information is presented in Appendix C, "Inventory and Reference Case Projections" Section, "Methodology" paragraph.
[31] SENER: *Prospectiva del Mercado de Gas LP 2006-2015*. It can be accessed directly from http://www.sener.gob.mx/webSener/index.jsp.
[32] SENER: "Prospectiva del Mercado de Gas Natural 2007-2016". It can be accessed directly from http://www.sener.gob.mx/webSener/index.jsp.

remaining forecast years, state total consumption was assumed to grow at the 1996-2016 mean annual growth rate of 2.7% and subsector distribution was kept equal to that of year 2006. Table B-2 shows partial national natural gas consumption distribution per subsector during inventory and projection years.

Table B-2. Partial Natural Gas Consumption Distribution in Sonora

	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016
Industrial	87%	84%	43%	22%	13%	13%	12%	8.2%	8.3%	8.7%	11%
Residential[33]	13%	16%	5.4%	2.6%	1.4%	1.0%	1.3%	1.0%	1.0%	1.1%	1.4%

Solid Biofuels: Wood

The use of wood by residences was derived from two sources of information. First, the 2000 Censo de Población y Vivienda (Population and Housing Census) provided the breakdown of homes according to the type of fuel consumed for cooking. This source was used to determine the fraction of homes with wood fuel stoves (5.0%) and the fraction of homes with gas fuel stoves that burned either LPG or natural gas (94%). The second source of information was SENER which provided residential consumption of gas fuel (see paragraphs above titled *Liquid Petroleum Gas* and *Natural Gas*). Energy use from wood fuel was therefore calculated as the product of energy from residential gas fuel consumption and the ratio of the fraction of home kitchens fueled by wood to the fraction of home kitchens fueled by gas fuel.

Results

Energy use in the RCI sector totaled 16,499 tera joules (TJ) in 2005. In the same year, residential LPG consumption accounted for 43% of total RCI energy use, followed by natural gas consumption in industry (33%) and industrial consumption of diesel (19%). Energy consumption values are shown in Table B-3.

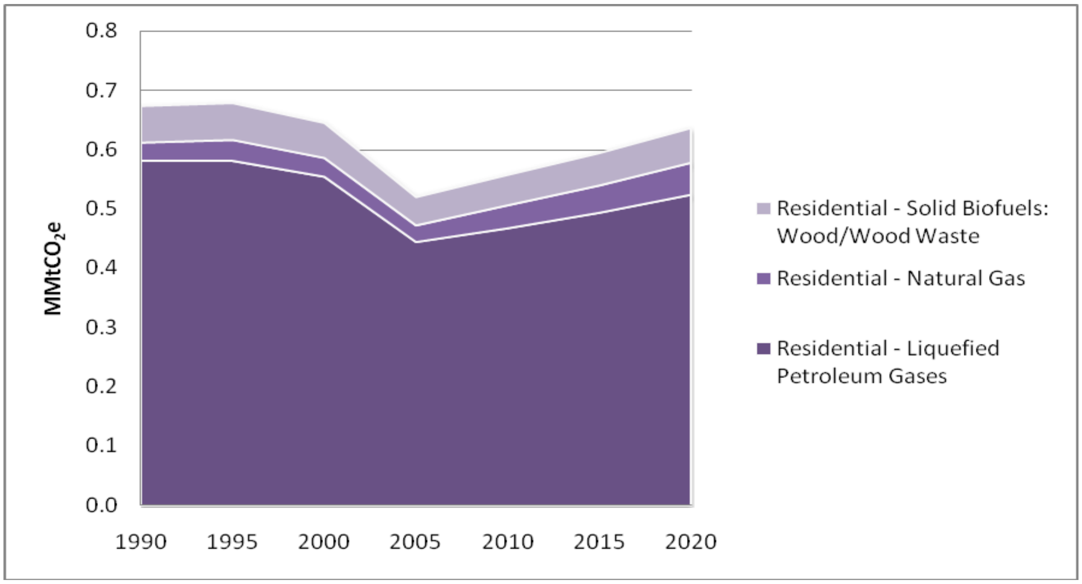
Table B-3. Energy Used in RCI Sector, TJ

Source	Fuel Type	1990	1995	2000	2005	2010	2015	2020
Ag.[34]	Liq. Petroleum Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Com.	Liq. Petroleum Gas	0.10	0.10	0.09	0.08	0.08	0.08	0.08
Ind.	Gas/Diesel Oil	9,440	22,167	4,966	3,187	7,275	11,094	16,919
	Liq. Petroleum Gas	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Natural Gas	3,704	4,232	4,485	5,397	5,895	6,411	7,228
Res.	Liq. Petroleum Gas	9,175	9,175	8,753	7,020	7,385	7,797	8,276
	Natural Gas	550	628	566	497	688	818	957
	Solid Biofuels: Wood	516	520	494	399	428	457	490

Emissions from residential sources were driven by the combustion of liquefied petroleum gas with 86% of total residential emissions in 2005. Emissions relating to the combustion of wood fuels and natural gas were in the order of 9% and 5% respectively. Historical and projected residential greenhouse gas emission trends are shown in Figure B-1.

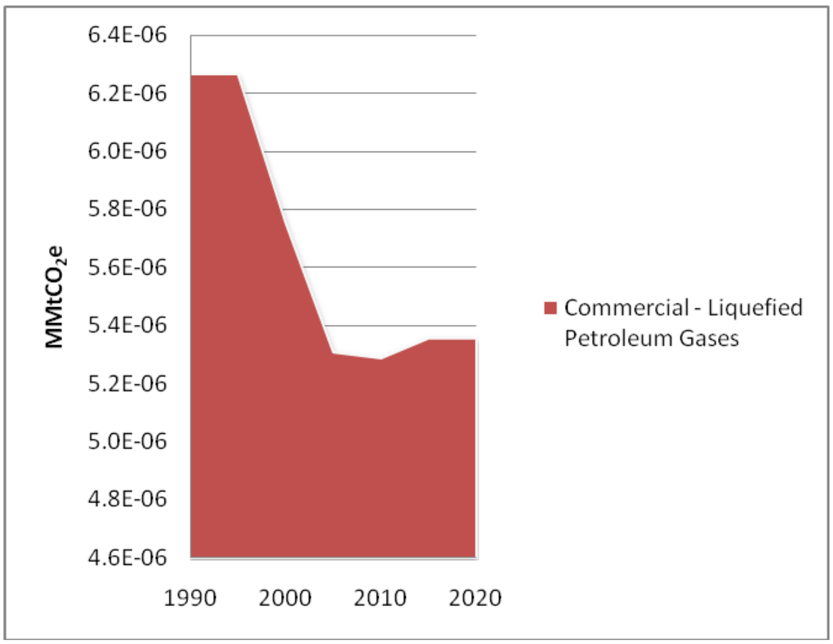
[33] An unknown fraction pertains to natural gas consumption by commercial users.
[34] Energy use in agriculture is negligible in units of terajoules per year.

Figure B-1. GHG Emissions Residential Sources



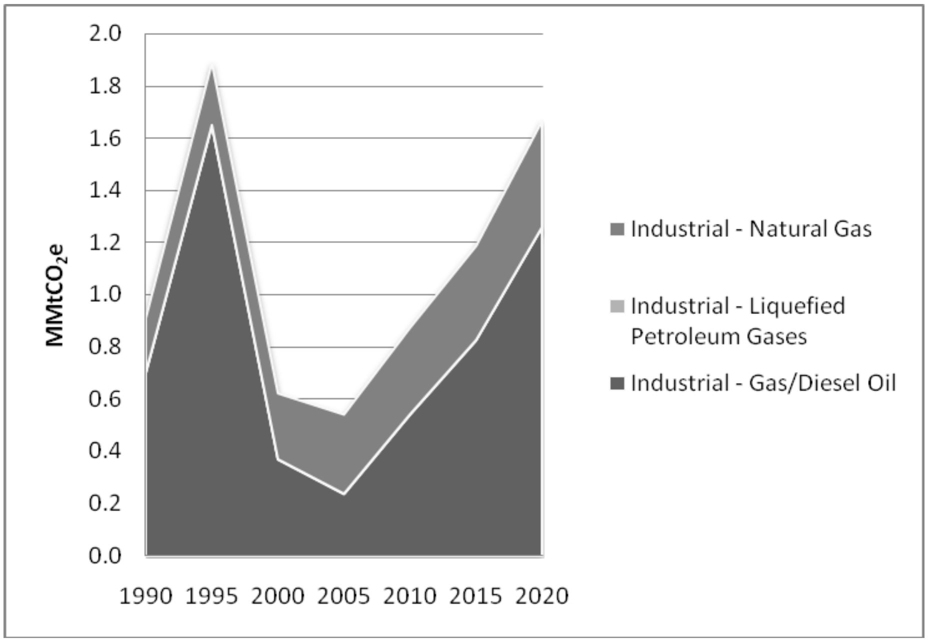
Emissions from commercial sources were estimated to be negligible. In 2005, emissions amounted to 5.3 tons of carbon dioxide equivalents and were driven by the combustion of liquefied petroleum gas (LPG). The latter is associated with stoves for the purposes of cooking. It seems plausible that the restaurant business utilizes LPG in significant quantities. If that is the case, then emissions values for the commercial sector are expected to be larger. Additional work is warranted to better profile this sector. Historical and projected commercial greenhouse gas emission trends are shown in Figure B-2.

Figure B-2. GHG Emissions Commercial Sources



Emissions from industrial sources were driven by the combustion of natural gas followed by emissions relating to the combustion of diesel oil. The contribution of liquid petroleum gas combustion to total emissions was negligible. Historical and projected residential greenhouse gas emission trends are shown in Figure B-3.

Figure B-3. GHG Emissions from Industrial Sector Fuel Combustion



Many activities in the agricultural sector require the use of fuel energy such as the operation of tractors and machinery. However, segregated information relating to the consumption of energy in the agricultural sector was only available for one form of fuel, namely, liquefied petroleum gas (LPG). The latter is not representative of primary energy consumption in the agricultural sector; actually, the predominant form of energy is diesel which fuels tractors and heavy machinery ancillary to agricultural practices. Diesel fuel consumption by vehicles (tractors, trailers, etc.) is captured under Transportation: Road/Diesel (see Appendix C); diesel fuel consumption by agricultural machinery is captured under RCI: Industrial Sector (Appendix B). In 2005, LPG combustion resulted in 0.2 tons of carbon dioxide equivalents. Additional work is warranted to better profile fuel-combustion related emissions in the agricultural sector.

In 2020, total RCI greenhouse gas emissions are projected at 2.3 million metric tons of carbon dioxide equivalent of which 72% results from industrial fuel combustion and nearly 28% from residential fuel combustion. Although emissions from commercial and agriculture sources are very small in comparison to GHG emissions from industrial and residential sources, there are reasons to believe these are much larger because they do not reflect source specific energy use, particularly, diesel consumption. Overall, RCI emissions are driven by the combustion of diesel in industry. The combustion of liquid petroleum gas in residential settings also represents a large contributor to greenhouse gas emissions in this sector. Figure B-4 and Tables B-4 and B-5 provide a summary profile of greenhouse gas emissions for the entire RCI sector.

Figure B-4. GHG Emissions RCI Sector

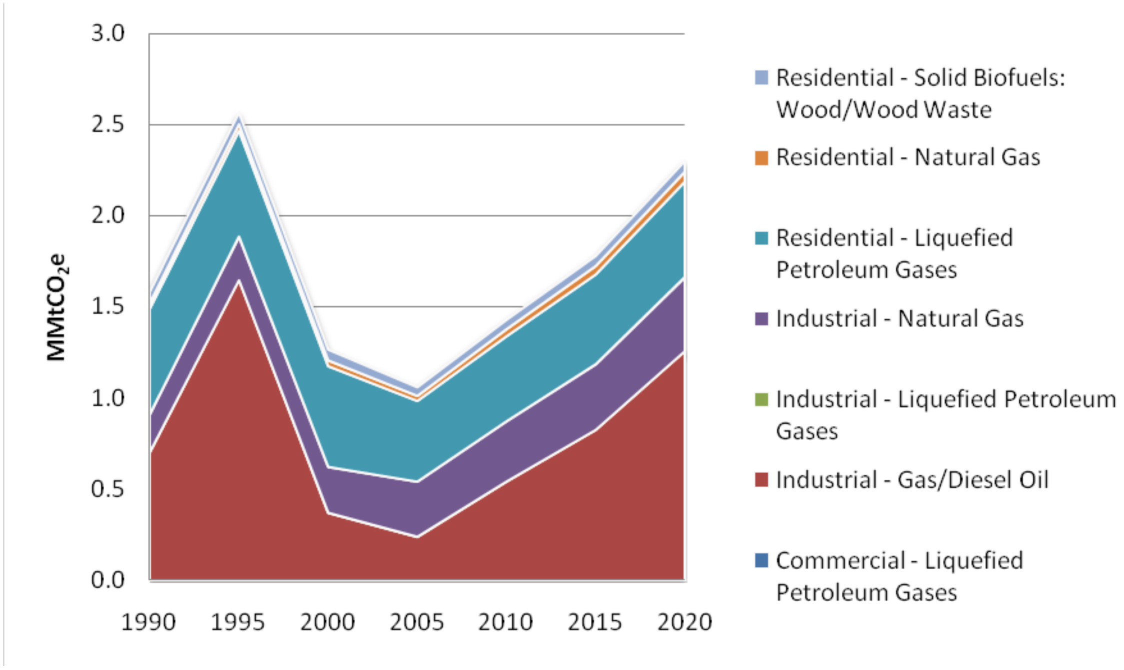


Table B-4. GHG Emissions RCI Sector

Source	Fuel Type	1990	1995	2000	2005	2010	2015	2020
Commercial	Liquefied Petroleum Gases	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial	Gas/Diesel Oil	0.70	1.65	0.37	0.24	0.54	0.82	1.26
	Liquefied Petroleum Gases	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Natural Gas	0.21	0.24	0.25	0.30	0.33	0.36	0.41
Residential	Liquefied Petroleum Gases	0.58	0.58	0.55	0.44	0.47	0.49	0.52
	Natural Gas	0.03	0.04	0.03	0.03	0.04	0.05	0.05
	Solid Biofuels: Wood/Wood Waste	0.06	0.06	0.06	0.05	0.05	0.05	0.06
Total		**1.73**	**1.58**	**2.56**	**1.27**	**1.06**	**1.43**	**1.78**

Table B-5. GHG Emissions Distribution in RCI Sector

Source	Fuel Type	1990	1995	2000	2005	2010	2015	2020
Commercial	Liquefied Petroleum Gases	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial	Gas/Diesel Oil	44%	64%	29%	22%	38%	46%	55%
	Liquefied Petroleum Gases	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Natural Gas	13%	9.3%	20%	29%	23%	20%	18%
Residential	Liquefied Petroleum Gases	37%	23%	44%	42%	33%	28%	23%
	Natural Gas	2.0%	1.4%	2.5%	2.6%	2.7%	2.6%	2.3%
	Solid Biofuels: Wood/Wood Waste	3.9%	2.4%	4.7%	4.5%	3.6%	3.1%	2.5%

Key Uncertainties

Segregated RCI activity data per state, per fuel and per subsector were not always available. Several assumptions were made during the activity data segregation process in an attempt of assessing RCI emissions. The most significant assumption pertains to diesel fuel consumption by industry. One available data set from Sonora's SENER only listed total diesel consumption in the state. A second data set from PEMEX only listed a breakdown of diesel consumption into two source categories, namely, on-road and marine vessel transportation. In the absence of diesel fuel breakdown by RCI categories, the difference between SENER's and PEMEX diesel fuel values was attributed to industrial diesel fuel consumption[35]. Although the designation of diesel fuel balance as industrial was justifiable, it was altogether arbitrary, and warrants future action allowing access to better defined fuel consumption values.

Also the process of segregating energy use from the combustion of liquid petroleum gas (LPG) introduced some uncertainty. Although LPG energy consumption inventory and official forecast information was available, energy consumption breakdown into RCI subsectors was only available at the national level. In light of existing constraints, national LPG energy distribution values were applied to Sonora's LPG energy consumption data.

Additional uncertainty resulted from the fact that natural gas consumption information was combined into one value for the residential and commercial subsectors. Because natural gas sales to residences are growing in Sonora[36], it was assumed that all natural gas consumption would go to residential users.

Energy use from wood fuel was calculated as the product of energy from residential gas fuel consumption and the ratio of the fraction of home kitchens fueled by wood to the fraction of home kitchens fueled by gas fuel. The use of surrogate activity data and the use a fixed fuel type distribution ratio added substantial uncertainty. However, the contribution to total greenhouse gas emissions sector from wood fuel combustion is very small (less than 2%).

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[35] Sonora's Secretería de Energía provided hydrocarbons sale information to Comisión de Ecología y Desarrollo Sustentable del Estado de Sonora (CEDES). PEMEX values retrieved by CEDES from their 2005 annual report.
[36] Based on professional estimate by Francisco Maytorena of CEDES.

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Appendix C. Transportation Energy Use

Overview

This appendix summarizes emissions from energy consumption associated with each of the following sources: onroad transportation, marine vessels, rail engines, and aviation. The fossil fuels combusted in these sources produce carbon dioxide in addition to small amounts of methane and nitrous oxide. Carbon dioxide accounts for over 98% of greenhouse gas emissions followed by nitrous oxide (1.2%) and methane (0.7%) emissions.[37]

Inventory and Reference Case Projections

Methodology

Based on the information available, emissions were estimated on a fuel consumption basis. According to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (2006 IPCC), emissions are expressed as a function of energy consumption and the rate of emissions in terms of mass of greenhouse gases per energy unit. Because the method estimates emissions in terms of energy consumption (e.g. joules), fossil fuel sales data were converted from units of volume to units of energy according to the energy content of each fuel. Information relating to energy content was obtained from the Secretaría de Energía (SENER).[38] This method is expressed as follows:

$$Emission = \Sigma\,[Fuel_a \times EF_a]$$

Where:

Emission = Greenhouse gas emissions in kilograms (kg)

$Fuel_a$ = fuel sold in terajoules (TJ)

EF_a = emission factor (kg/TJ). This is equal to the carbon content of the fuel multiplied by the atomic weight ratio of carbon dioxide to carbon (44/12)[39]

a = type of fuel (e.g. petrol, diesel, natural gas, LPG etc)

Fuel consumption information was obtained from Petróleos Mexicanos (PEMEX) and Sonora's Secretaría de Energía for each year.[40] Because of limited information on road transportation-diesel and marine vessel energy consumption, surrogate sets of data were used in conjunction with energy consumption in 2005 per subsector. Table C-1 lists all transportation sources and their corresponding activity data. Additional details of the emissions estimation methods are provided by sector below.

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[37] In terms of million metric tons of carbon dioxide equivalent.
[38] Subsecretaría de Planeación Energética y Desarrollo Tecnológico, Dirección General de Información y Estudios Energéticos. *Balance Nacional de Energía 2006.* SENER 2007
[39] Emission factors for mobile combustion sources are listed in Chapter 3, Volume 2 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
[40] Sistema de Información Energética, con información de Petróleos Mexicanos.

Table C-1. Activity Factors by Transportation Mode

Source	Activity Data	Source
Road Transportation - Gasoline	State of Sonora: fuel consumption, 1990-2007	Secretaría de Energía de Sonora: Sistema de Información Energética, with information from Petróleos Mexicanos.
Road Transportation - Diesel	State of Sonora: energy consumption, 2005 State of Sonora: heavy vehicle registration 1980-2006	Secretaría de Energía de Sonora: Sistema de Información Energética, with information from Petróleos Mexicanos. INEGI. Estadísticas de vehículos de motor registrados en circulación.[41]
Marine Vessels	State of Sonora: energy consumption, 2005 State of Sonora: tons of fish harvest in open waters	PEMEX Anuario Estadístico[42] Estado de Sonora, Anexo Estadístico VI Informe (1997-2003)[43]
Aviation	State of Sonora: fuel consumption, 1990-2007	Secretaría de Energía de Sonora: Sistema de Información Energética, con información de Petróleos Mexicanos.
Other	State of Sonora: energy consumption, 2005	PEMEX Anuario Estadistico[44]
Railroad	National consumption by railroad,1990-2002 National consumption by railroads, 2003-2007 Length of railways by state.	Instituto Nacional de Ecología: Inventario Nacional de Emisiones de Gases de Efecto Invernadero 1990-2002[45] Secretaría de Energía: Prospectiva de Petrolíferos 2008 – 2017[46] Secretaría de Comunicaciones y Transportes: Longitud de Vías Férreas Existentes Por Entidad Federativa Según Tipo de Vía[47]

[41] http://www.inegi.gob.mx/inegi/default.aspx
[42] Information collected and provided to CCS by staff at Comisión de Ecología y Desarrollo Sustentable (CEDES) del Estado de Sonora.
[43] http://www.sonora.gob.mx/portal/Runscript.asp?p=ASP\pg134.asp
[44] Information collected and provided to CCS by staff at Comisión de Ecología y Desarrollo Sustentable (CEDES) del Estado de Sonora.
[45] INE 2002. Inventario Nacional de Emisiones de Gases de Efecto Invernadero 1990-2002. Disponible en: http://www.ine.gob.mx/descargas/cclimatico/mexico_nghgi_2002.pdf
[46] Secretaría de Energía. *Prospectiva de Petrolíferos 2008-2017*. SENER 2008. Disponible en: http://www.sener.gob.mx/webSener/res/PE_y_DT/pub/Prospectiva%20Pet%202008-2017.pdf
[47] Secretaría de Comunicaciones y Transportes: " Longitud De La Red Carretera Y Ferroviaria Por Mesoregión Y Entidad Federativa" Disponible en: http://Dgp.Sct.Gob.Mx/Fileadmin/User_Upload/Estadistica/Indicadores/Infra-Comytrans/Io5.Pdf
y "Distribución Porcentual De La Infraestructura De Transportes Y Comunicaciones Por Entidad Federativa Según Modo De Transporte Y Servicio De Comunicaciones". Disponible en: http://dgp.sct.gob.mx/fileadmin/user_upload/Estadistica/Indicadores/Infra-ComyTrans/IO4.pdf

Forecast greenhouse gas emissions were estimated on the basis of growth factors. Historical records served as the basis for mean annual growth rates. The time range selected to calculate a mean annual growth rate for each source was unique. Forecast mean annual growth rates with adjustment comments are listed in Table C-2.

Table C-2. Mean Annual Growth Rates

Source	2005-2010	2010-2015	2015-2020	Comments
Road Transportation	4.6%	3.4%	3.4%	Based on mean annual growth rate for gasoline consumption starting 1990 through 2007 and on the mean annual growth rate for diesel consumption during the period 1990-2007.
Marine Vessels	9.6%	9.6%	9.6%	Based on mean annual growth rate for fish captured in open waters starting 1998 through 2002.
Aviation	2.7%	0.5%	0.5%	Based on mean annual growth rate for kerosene consumption during the period 1990-2007.
Other	0.0%	0.0%	0.0%	Unspecified source. Therefore, mean annual growth rate was assumed to be flat.
Railroad	3.1%	2.3%	1.3%	Based on SENER's outlook for fuel consumption by marine vessels and railroads; *Prospectiva de Petrolíferos 2008-2017* de la SENER[48]

Road Transportation

Onroad transportation is a significant source of greenhouse gas emissions. In 2005, road transportation emissions accounted for 76% of total greenhouse gases emitted by the transportation sector. Gasoline and diesel greenhouse gas emissions were responsible for 47% and 29% respectively of carbon dioxide equivalent emissions associated with this sector. Diesel energy consumption in road transportation was only available for year 2005. Consequently, the use of surrogate data was adopted to extrapolate energy consumption before and beyond 2005. The choice of surrogate data was limited by the availability of state specific statistical data. Heavy vehicle registration records were the only type of statistical information available that most closely related to diesel energy consumption, assuming that the bulk of diesel energy is consumed by trucks and heavy vehicles. Activity data associated with road transportation energy consumption is listed in Table C-1.

Marine Vessels

Energy consumption by marine vessels was only available for year 2005. Consequently, the use of surrogate data was adopted to extrapolate energy consumption before and beyond 2005. The choice of surrogate data was limited by the availability of state specific statistical data. Fish harvest was the only statistical information available that most closely related to movement of marine vessels. [49] In 2005, Marine Vessels activity accounted for 4% of total transportation greenhouse gas emissions.

48 Secretaría de Energía. *Prospectiva de Petrolíferos 2008-2017*. SENER 2008. Disponible en: http://www.sener.gob.mx/webSener/res/PE_y_DT/pub/Prospectiva%20Pet%202008-2017.pdf
49 Anuario Estadístico 2003available at http://www.sonora.gob.mx/portal/Runscript.asp?p=ASP\pg168.asp.

Aviation

Five airports operate in the state of Sonora: General Ignacio Pesqueira, General José María Yañez, Ciudad Obregón, Nogales, and Puerto Peñasco. These airports cater to the needs of private, commercial, and governmental travelers and goods shipment. In 2002, these airports serviced 1,173,439 passengers and experienced a total of 70,716 flights. Aviation is a significant source of greenhouse gas emissions accounting for 5% of total transportation emissions in 2005. Activity data associated with aviation energy consumption is listed in Table C-1

Railways

Rail diesel consumption was not available for Sonora. Therefore, consumption was estimated for this fuel by allocating national usage to the state level. National rail fuel consumption for 1990-2002 was taken from the Inventario Nacional de Emiciones de Gases de Efecto Invernadero. Consumption values were grown from 2002 to 2007 using daily rail diesel consumption values from SENER's *Prospectiva de Petrolíferos 2008-2017*. National consumption was allocated to Sonora using the proportion of national rail lines in the state. Actual activity, such as ton-miles of rail freight would provide more accurate allocation; however, these data are not available.

Other

This source sector includes combustion of liquefied petroleum gas (LPG) and lubricant use. Although the end use of these petroleum products is uncertain, emissions from the combustion of LPG and lubricants were arbitrarily added to the transportation sector in order to be accounted for in the final summary report.

Results

During inventory years (1990 through 2005), total transportation emissions increased by 39% reaching levels of about 5.2 $MMtCO_2e$ in 2005. In 1990, the largest sources of greenhouse gas emissions were activities relating to onroad gasoline and onroad diesel combustion. Road vehicle circulation alone accounted for 68% of total transportation GHG emissions in 1990. The fastest growing source through the time period was marine vessels with a mean annual growth rate of 4.4%, followed by road transportation - gasoline (2.7%).

In 2020, total transportation emissions will be in the order of 8.9 $MMtCO_2e$ representing a 167% increase from 1990. Most GHG emissions result from activities relating to onroad gasoline and onroad diesel fuel combustion. Releases from onroad vehicles alone account for 78% of total transportation GHG emissions in 2020. The fastest growing source through the time period is marine vessels with a mean annual growth rate of 6.9%, followed by onroad transportation – diesel (3.4%) and road transportation – gasoline (3.3%).

Table C-3 and Figure C-1 summarize greenhouse gas emission estimates by source. The distribution of greenhouse gas emissions by source is presented in Table C-4. Finally, emissions growth rates for selected time intervals are listed in Table C-5.

Table C-3. GHG Emissions from Transportation ($MMtCO_2e$)

Source	1990	1995	2000	2005	2010	2015	2020

Road Transportation - Gasoline	1.65	1.75	1.96	2.44	3.17	3.73	4.39
Road Transportation - Diesel	0.93	1.18	1.54	1.54	1.83	2.16	2.55
Marine Vessels	0.11	0.11	0.17	0.20	0.32	0.50	0.79
Aviation	0.26	0.28	0.32	0.26	0.29	0.30	0.31
Railroad	0.17	0.14	0.14	0.15	0.20	0.22	0.24
Other	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Total	**3.77**	**4.12**	**4.79**	**5.25**	**6.46**	**7.57**	**8.94**

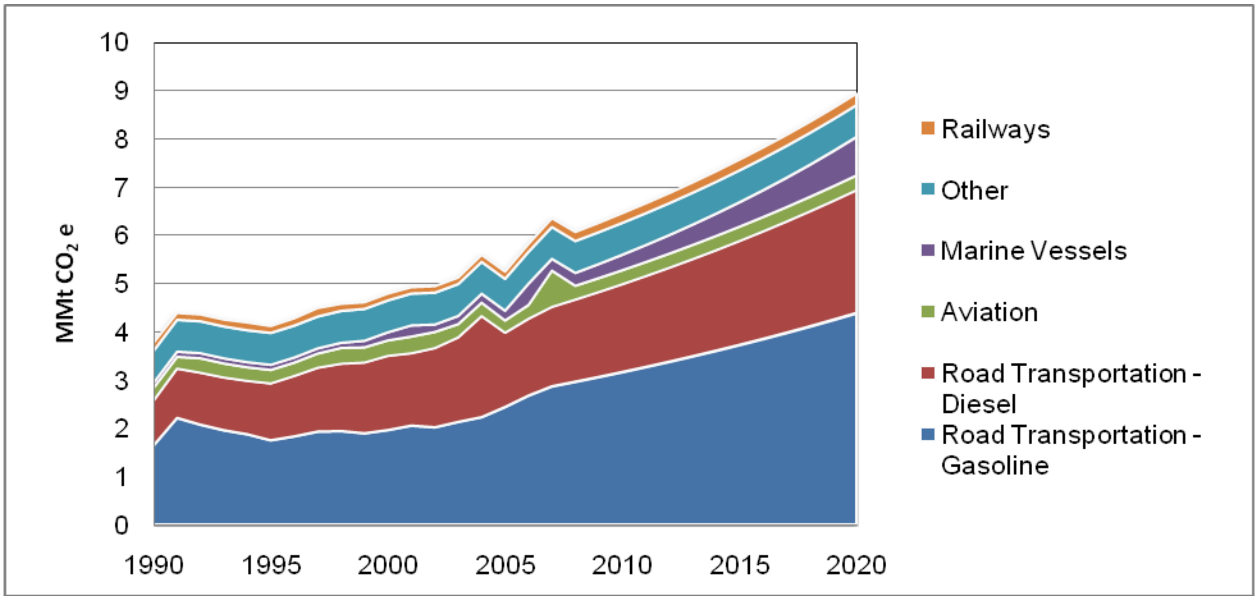
Table C-4. GHG Emissions Distribution in the Transportation Sector

Source	1990	1995	2000	2005	2010	2015	2020
Road Transportation - Gasoline	43.6%	42.5%	41.0%	46.5%	49.0%	49.3%	49.1%
Road Transportation - Diesel	24.7%	28.7%	32.2%	29.4%	28.3%	28.5%	28.6%
Marine Vessels	2.8%	2.6%	3.5%	3.8%	4.9%	6.7%	8.9%
Aviation	7.0%	6.8%	6.7%	4.9%	4.5%	3.9%	3.4%
Railroad	4.4%	3.4%	2.9%	2.8%	3.1%	2.9%	2.7%
Other	17.4%	16.0%	13.7%	12.5%	10.2%	8.7%	7.4%

Table C-5. Percentage Change in GHG Emissions for Selected Time Intervals

Source	1990-2005	2005-2020	1990-2020
Road Transportation - Gasoline	48%	80%	167%
Road Transportation - Diesel	65%	65%	174%
Marine Vessels	90%	294%	647%
Railroad	-3%	20%	16%
Aviation	-11%	61%	43%
Other	0%	0%	0%
Total	39%	70%	137%

Figure C-1. Transportation Gross GHG Emissions by Fuel, 1990-2020



Key Uncertainties

Per 2006 IPCC guidelines, fuel energy consumption is the preferred form of activity data.[50] Energy consumption for most inventory years was unavailable for onroad diesel and marine vessel subsectors. In order to estimate inventory and reference case projections, surrogate data sets were used, namely heavy vehicle registration and fish harvest numbers. Uncertainty associated with historical and projected emission estimates can be reduced by pinpointing historical energy information for these subsectors. For rail, national emissions were allocated to Sonora based on the proportion of it total rail line to the national total. More accurate estimates would be derived using estimates of actual rail activity (e.g., tonne-kilometers and/or passenger-kilometers). Based on current estimates, the contribution from the rail sector is very small.

Lubricant and LPG sales were reported by Petróleos Mexicanos along with other petroleum products as “Other” energy used in the transportation sector. However, there is no information to determine whether lubricants and LPG were used in transportation or another energy sector such as Residential, Commercial, and Industrial (RCI). Since lubricants and LPG amounted to 8.4% of total transportation GHG emissions in 2005, it is recommended to verify the actual use of these petroleum products.

Nitrous oxide and methane emission estimates are based on fuel consumption and on the type of control equipment installed in a vehicle. In order to factor the effect of control technology (e.g. oxidation catalyst) on greenhouse gas emissions, it is necessary to obtain a profile of Sonora’s vehicle fleet indentifying the fraction of vehicles with control equipment.

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[50] Section 3.2.1.3, Chapter 3, Volume 2 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

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Appendix D. Industrial Processes and Product Use

Overview

Emissions in the industrial processes sector span a wide range of activities, and reflect non-combustion sources of GHG emissions. The industrial processes that exist in Sonora, and for which emissions are estimated in this inventory, include the following:

- Carbon dioxide from:
  - Cement production
  - Lime production
  - Limestone use
  - Other sources, including
    - Wineries
    - Breweries
    - Edible oils manufacturing
    - Feed manufacturing
    - Parts assembly
- Hydrofluorocarbons from:
  - Mobile air conditioning
  - Refrigeration and stationary air conditioning

Other industrial processes that are sources of GHG emissions but are not found in Sonora include the following:

- N_2O from adipic acid production
- PFCs from aluminum production
- HFCs from hydrochlorofluorocarbon-22 (HCFC-22) production
- HFCs used in fire suppression and explosion protection
- SF_6 from magnesium production and processing
- HFCs, PFCs, and SF_6 from semiconductor manufacture
- CH_4 from aluminum production
- CH_4 from petrochemical production

Historical Emissions and Reference Case Projections

GHG emissions from cement, lime and limestone production activities were estimated using the US EPA State Greenhouse Gas Inventory Tool (SIT) software, and the methods provided in the

Emission Inventory Improvement Program (EIIP) guidance document for this sector.[51] SIT calculates emissions as a function of clinker content in the annual cement production. Based on national cement statistics covering the period 1994-2008, the weighted average concentrations of clinker per cement blend was determined. Prior to 1994, the average concentration of clinker was applied. Table D-7 summarizes the analysis of clinker content by cement blend. Finally, the amount of clinker produced is multiplied by the default SIT emission factor (0.507 metric tons CO_2 per metric ton of clinker) to calculate emissions. To convert lime production and limestone use into emissions, SIT emission factors were used (0.75 metric ton CO_2 per metric ton of lime produced and 0.44 metric ton CO_2 per metric ton limestone consumed). CEDES provided activity data for the year 2005.[52] Cement production, lime production, and limestone use for the remaining inventory years was estimated with the use of surrogate data, namely annual construction spending in the state of Sonora from 2000 to 2007.[53] The 2000-2007 mean annual growth rate of 6.1% in construction spending was applied to inventory years prior to 2000 and forecast years after 2007.

GHG emission information for other carbon dioxide sources was obtained directly from light industry emission reports administered by CEDES. Sources in the light industry sector included wineries, breweries, edible oils manufacturing, feed manufacturing, and parts assembly. Emission information for these sources was only provided for the year 2005; therefore, surrogate data were used to estimate emissions prior and after 2005. Sonora's population numbers were assumed to be directly proportional to emissions from brewery and food manufacturing sources.[54] Total livestock population numbers were assumed to be directly proportional to emissions from feed manufacturing sources.[55] Finally, grape production numbers were assumed to be directly proportional to emissions from wineries.[56]

Emissions of HFC's from mobile air-conditioning systems were calculated using an approach developed for the State of Baja California's 2005 GHG inventory.[57] This approach consists of basing emissions on the number of circulating vehicles and the assumption that all vehicles are equipped with air conditioning units. This approach deviates from methodology outlined in Section 7.5.2, Chapter 7, Volume 3 of the 2006 Intergovernmental Panel on Climate Change

[51] GHG emissions were calculated using SIT, with reference to EIIP, Volume VIII: Chapter. 6. "Methods for Estimating Non-Energy Greenhouse Gas Emissions from Industrial Processes", August 2004. Referred to as "EIIP" below.
[52] CEDES obtained cement production numbers from Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT) which administrates environmental permits for heavy industry including cement production.
[53] Retrieved May 2008 from: Instituto Nacional de Estadísticas, Geografía, e Informática (INEGI), Banco de Información Económica at http://dgcnesyp.inegi.gob.mx/cgi-win/bdieintsi.exe/NIVE100006#ARBOL?c=1414
[54] CCS estimated Sonora's population from official census data available at Instituto Nacional de Geografía, Estadísticas e Informática (INEGI) for years 1995 through 2000 and 2005. Additional population information was obtained from SEMARNAT's 2006 publication titled México. Tercera Comunicación Nacional ante la Convención Marco de las Naciones Unidas (p. 14).
[55] Appendix F provides a detailed description of activity data pertaining to livestock population.
[56] Appendix F provides a detailed description of activity data pertaining to crop production. Although details were not available on the winery and brewery sources involved here; CCS believes that some of these could be related to biogenic carbon dioxide emitted during fermentation. If this is the case, these should be removed during future refinements to the inventory and forecast.
[57] *Inventario de Emisiones de Gases de Efecto Invernadero del Estado de Baja California 2005: Versión Final Secretaría de Protección al Ambiente del gobierno del estado Baja California,* Centro Mario Molina, Diciembre, 2007, pp. 26-27.

(IPCC) Guidelines for National Greenhouse Gas Inventories[58]; however, it was adopted in the absence of better activity data (e.g. HFCs sales information). The number of mobile air conditioning units was converted to emissions using an emission factor of 166 kg CO_2 per vehicle published by IPCC in a special technical report.[59]

Similarly, ODS substitute emissions from refrigeration and stationary air conditioning were calculated using the approach adopted in Baja California's GHG inventory. This approach consists of basing emissions on the number and size of homes connected to the electricity grid. It is assumed that all homes with electricity have one refrigerator and one stationary air conditioning unit. Homes with two or more rooms were assumed to own two air conditioning units. This approach deviates from methodology outlined in Section 7.5.2, Chapter 7, Volume 3 of the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories[60]; however, it was adopted in the absence of better activity data (e.g. HCFCs sales information). Moreover, this approach assumes that 10% of all units have leaks and 15% of the refrigerant released is composed of HCFC-22. The latter is a hydrochlorofluorocarbon subject to the stipulation of the Montreal Protocol and exempt from GHG inventory considerations. Emissions associated with HCFC-22 were included in this appendix for the purposes of comparison with Baja California's GHG inventory. Nonetheless, HCFC-22 emissions will not be incorporated in the state summary of GHG emissions.

Table D-1 summarizes the approach utilized for estimating inventory emissions. Table D-2 shows the assumptions made to estimate forecast emission values.

Table D-1. Approach to Estimating Inventory Emissions

Source Category	Available Activity Data	Available Surrogate Data Type	Available Data Source
Mobile Air Conditioning	None	Rate of refrigerant release Vehicle registration	Centro Mario Molina. *Inventario de Emisiones de Gases de Efecto Invernadero del Estado de Baja California 2005* INEGI. *Estadísticas de vehículos de motor registrados en circulación.* *IPCC. Safeguarding the Ozone Layer and the Global Climate System: Issues related to hydrofluorocarbons and perfluorocarbons*
Refrigeration and Stationary Air Conditioning	None	Population Homes with access to electricity	Centro Mario Molina. *Inventario de Emisiones de Gases de Efecto Invernadero del Estado de Baja California*

[58] Retrieved May, 2008 from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
[59] IPCC/TEAP, Bert Metz, Lambert Kuijpers, Susan Solomon, Stephen O. Andersen, Ogunlade Davidson, José Pons, David de Jager, Tahl Kestin, Martin Manning, and Leo Meyer (Eds). *Safeguarding the Ozone Layer and the Global Climate System: Issues related to hydrofluorocarbons and perfluorocarbons*. Cambridge University Press: Cambridge, England. 2005 (p. 306) http://www.ipcc.ch/pdf/special-reports/sroc/sroc_full.pdf
[60] Retrieved May, 2008 from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Source Category	Available Activity Data	Available Surrogate Data Type	Available Data Source
		Distribution of homes by number of rooms	*2005* *INEGI. II Conteo de Población y Vivienda 2005*
Cement Manufacture	Cement Production 2005	Construction spending in the state of Sonora	CEDES: Data obtained from environmental permits administered by SEMARNAT
Lime Manufacture	Lime Production 2005	Construction spending in the state of Sonora	CEDES: Data obtained from environmental permits administered by SEMARNAT
Limestone Use	Limestone Use 2005	Construction spending in the state of Sonora	CEDES: Data obtained from environmental permits administered by SEMARNAT
Wineries	2005 CO2 Emissions	Grape Production	Sistema de Información Agropecuaria de Consulta (SIACON)
Breweries & Edible Oils Manufacturing	2005 CO2 Emissions	State Population	CEDES: Data obtained from environmental permits administered by CEDES
Feed Manufacturing	2005 CO2 Emissions	State Population	CEDES: Data obtained from environmental permits administered by CEDES
Parts Assembly	2005 CO2 Emissions	None (negligible emissions)	CEDES: Data obtained from environmental permits administered by CEDES

Table D-2. Approach to Estimating Projections for 2005 through 2025

Source Category	Projection Assumptions	Mean Annual Growth Rate		
		2005 - 2010	2010 - 2015	2015 - 2020
Mobile Air Conditioning	Emissions directly proportional to the number of vehicles as expressed in vehicle registration records from 1990 to 2005	5.5%	5.5%	5.5%
Cement Manufacture	Emissions directly proportional to cement demand as expressed in construction spending 2000 to 2007	5.7%	6.1%	6.1%
Lime Manufacture	Emissions directly proportional to cement demand as expressed in construction spending 2000 to 2007	5.7%	6.1%	6.1%
Limestone Use	Emissions directly proportional to cement demand as expressed in construction spending 2000 to 2007	5.7%	6.1%	6.1%
Refrigeration and Stationary Air Conditioning	Emissions directly proportional to refrigeration and air conditioning units as expressed in the fraction of the population owning them.	1.0%	0.9%	0.9%
Wineries	Emissions directly proportional to wine production as expressed in grape production numbers from 1990 to 2005	0.5%	0.5%	0.5%
Breweries & Edible Oils Manufacturing	Emissions directly proportional to demand as expressed in historical and projected population numbers from 1990 to 2020	0.9%	0.9%	0.9%
Feed Manufacturing	Emissions directly proportional to demand as expressed in historical and projected livestock population numbers from 1990 to 2020	1.4%	1.4%	1.4%
Parts Assembly	Emissions were negligible, therefore, mean annual growth was assumed to be zero	0.0%	0.0%	0.0%

Results

In 2005, GHG emissions from non-combustion industrial processes were in the order of 1.70 million metric tons of carbon dioxide equivalent ($MMtCO_2e$). The largest source of emissions was the result of cement production, followed by limestone consumption.

Forecast non-combustion industrial process emissions are in the order of 4.08 $MMtCO_2e$ in 2020. The largest source is cement production expected to account for 84% of total emissions in 2020. The share of emissions from limestone consumption in 2020 is estimated to be about 7.3%.

GHG emissions have been summarized in Figure D-1 and Table D-3. The distribution of emissions in the industrial processes sector is shown for selected years in Table D-4.

Figure D-1. GHG Emissions from Industrial Processes 1990-2020

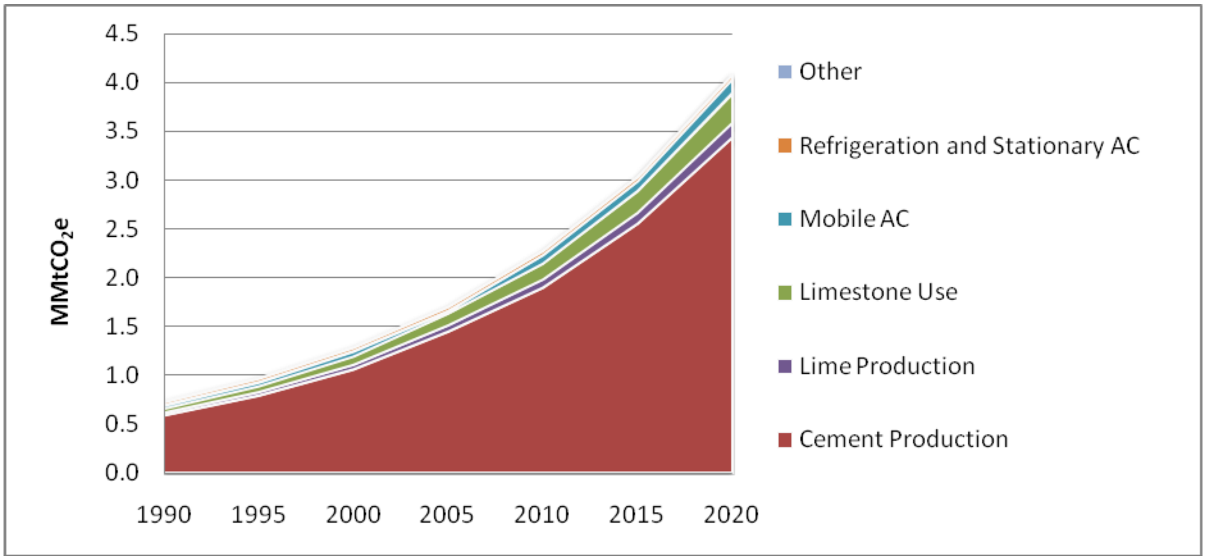

Table D-3. Historic and Projected GHG Emissions for Industrial Processes (MMtCO$_2$e)

Source	1990	1995	2000	2005	2010	2015	2020
Cement Production	0.587	0.789	1.057	1.444	1.895	2.551	3.434
Lime Production	0.026	0.035	0.048	0.066	0.087	0.117	0.157
Limestone Use	0.050	0.067	0.091	0.125	0.165	0.222	0.298
Mobile AC	0.029	0.037	0.050	0.024	0.085	0.099	0.146
Refrigeration and Stationary AC+	0.033	0.038	0.038	0.041	0.043	0.045	0.047
Other*	0.001	0.001	0.001	0.001	0.001	0.001	0.002
Total	**0.73**	**0.97**	**1.28**	**1.70**	**2.28**	**3.04**	**4.08**

+Refrigeration and stationary AC emissions are included in this table is supplemental information; however, they are not counted toward state total emissions because HCFCs are not subject to GHG accounting under Kyoto Protocol.
*Aggregate emissions for wineries, breweries, parts assembly, feed and food manufacturing. Total emissions are negligible.

Table D-4. GHG Emission Distribution for Industrial Processes

Distribution	1990	1995	2000	2005	2010	2015	2020
Cement Production	81%	82%	82%	85%	83%	84%	84%
Lime Production	3.6%	3.7%	3.7%	3.9%	3.8%	3.8%	3.8%
Limestone Use	6.9%	7.0%	7.1%	7.3%	7.2%	7.3%	7.3%
Mobile AC	4.0%	3.8%	3.9%	1.4%	3.8%	3.3%	3.6%
Refrigeration and Stationary AC	4.6%	3.9%	3.0%	2.4%	1.9%	1.5%	1.2%
Other	0.2%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%

Table D-5. Clinker Content in National Production of Cement

Year	National production by cement blend in metric tons					Clinker content (weighted average)
	Portland Gris (96% clinker)	Blanco (28.8% clinker)	Mortero (64% clinker)	Other (64.4% clinker)	Clinker (100% clinker)	
1994	30,243,326	516,684	720,232	113,625	220,619	94.1%
1995	24,033,981	441,975	645,663	173,169	793,455	94.0%
1996	26,440,746	466,440	1,140,024	127,125	1,447,276	93.8%
1997	27,679,233	530,803	1,316,355	158,327	1,073,967	93.4%
1998	28,608,786	568,795	1,549,994	187,670	592,846	93.1%
1999	29,738,734	642,632	1,420,243	156,321		93.1%
2000	31,518,759	613,075	1,096,005	201,128		93.5%
2001	30,177,359	636,394	1,319,868			93.3%
2002	30,897,412	623,680	1,850,420			93.0%
2003	31,143,454	632,386	1,817,561			93.0%
2004	32,374,824	680,380	1,937,238			92.9%
2005	34,571,534	773,499	2,106,583			92.8%
2006	37,180,967	843,869	2,337,166			92.7%
2007	37,757,921	864,999	2,590,337			92.6%
2008	36,608,126	823,449	2,679,457			92.5%
Elaborated by CCS from typical clinker composition (2006 IPCC) and industry production data (INEGI, Encuesta Industrial Mensual (EIM)).						

Key Uncertainties

Significant uncertainty stems from the method adopted to estimate GHG emissions from mobile air-conditioning systems. These were calculated according to the approach described in State of Baja California's 2005 GHG inventory.[61] Although this approach deviates from the methodology outlined in 2006 IPCC Guidelines for National Greenhouse Gas Inventories, it allowed the quantification of ODS substitute emissions. According to 2006 IPCC guidelines, more accurate estimates can be obtained by collecting information from equipment manufacturers/importers on the total charge of the equipment they manufacture or import. Alternatively, an estimate can be conducted with information from chemical manufacturers/importers on their sales to equipment manufacturers and distributors. Moreover, segregated sales information can be used to trace sources of emissions more precisely according to Table 7.1, Chapter 7, Volume 3, of 2006 IPPC guidelines. An image of Table 7.1 is shown in Figure D-2.

Similarly, there is much uncertainty associated with ODS substitute emissions from refrigeration and stationary air conditioning. These were calculated using the approach adopted in Baja California's GHG inventory. This approach consists of basing emissions on the number and size

[61] Estado de Sonora. *Inventario de Emisiones de Gases de Efecto Invernadero del Estado de Baja California 2005: Versión Final Secretaría de Protección al Ambiente del gobierno del estado Baja California.* Centro Mario Molina. Diciembre, 2007 (26-27)

of homes connected to the electricity grid. It is assumed that all homes with electricity have one refrigerator and one stationary air conditioning unit. Homes with two or more rooms were assumed to own two air conditioning units. Not only this approach is based on broad assumptions about a non-Kyoto Protocol greenhouse gas, but also deviates from methodology outlined in Section 7.5.2, Chapter 7, Volume 3 of the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories[62]. According to 2006 IPCC guidelines, more accurate estimates can be obtained by collecting information from equipment manufacturers/importers on the total charge of the equipment they manufacture or import. Alternatively, an estimate can be conducted with information from chemical manufacturers/importers on their sales to equipment manufacturers and distributors. Moreover, segregated sales of information can be used to trace sources of emissions more precisely according to Table 7.1, Chapter 7, Volume 3, of 2006 IPPC guidelines. An image of Table 7.1 is shown in Figure D-2.

Additional uncertainty results from the use of surrogate data to supplement activity data for each of the sources in the industrial processes sector. It is good practice to develop greenhouse gas emissions inventories with historical activity data. In the case of Sonora, future work could uncover additional historical data; however, it was unavailable during the information collection phase of this project.

[62] Retrieved May, 2008 from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Figure D-2. IPCC Listing of Potential Sources of HFCs

TABLE 7.1
MAIN APPLICATION AREAS FOR HFCS AND PFCS AS ODS SUBSTITUTES [1]

Chemical	Refrigeration and Air Conditioning	Fire Suppression and Explosion Protection	Aerosols		Solvent Cleaning	Foam Blowing	Other Applications[2]
			Propellants	Solvents			
HFC-23	X	X					
HFC-32	X						
HFC-125	X	X					
HFC-134a	X	X	X			X	X
HFC-143a	X						
HFC-152a	X		X			X	
HFC-227ea	X	X	X			X	X
HFC-236fa	X	X					
HFC-245fa				X		X	
HFC-365mfc				X	X	X	
HFC-43-10mee				X	X		
PFC-14[3] (CF_4)		X					
PFC-116 (C_2F_6)							X
PFC-218 (C_3F_8)							
PFC-31-10 (C_4F_{10})		X					
PFC-51-14[4] (C_6F_{14})					X		

[1] Several applications use HFCs and PFCs as components of blends. The other components of these blends are sometimes ODSs and/or non-greenhouse gases. Several HFCs, PFCs and blends are sold under various trade names; only generic designations are used in this chapter.

[2] Other applications include sterilisation equipment, tobacco expansion applications, plasma etching of electronic chips (PFC-116) and as solvents in the manufacture of adhesive coatings and inks (Kroeze, 1995; U.S. EPA, 1992a).

[3] PFC-14 (chemically CF_4) is used as a minor component of a proprietary blend. Its main use is for semiconductor etching.

[4] PFC-51-14 is an inert material, which has little or nil ability to dissolve soils. It can be used as a carrier for other solvents or to dissolve and deposit disk drive lubricants. PFCs are also used to test that sealed components are hermetically sealed.

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Appendix E. Fossil Fuel Industries

Overview

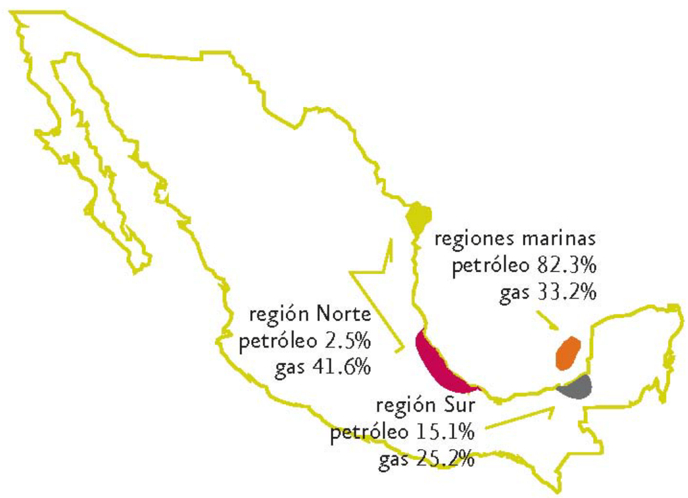
The inventory for this subsector of the Energy Supply sector includes methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) emissions associated with the production, processing, transmission, and distribution of fossil fuels in Sonora.[63] In 2005, emissions from the subsector accounted for an estimated 0.22 $MMtCO_2e$ of GHG emissions in Sonora and are estimated to increase to about 0.25 $MMtCO_2e$ by 2020.

Emissions and Reference Case Projections

Oil and Gas Production

Sonora possesses neither oil nor gas reserves. Petroleum rich areas are located around the Gulf of Mexico in three distinct regions: regiónes marinas (maritime region), region norte (northern region), and region sur (southern region). The maritime region was largest producer of oil with 82.3% of total national oil production in 2005. In the same year, the northern region was the largest producer of gas with 41.6 % of the national production. Figure E-1 shows a map with oil and gas rich regions in the Mexican territory.

Figure E-1. Mexico Oil and Gas Production by Region[64]



Fuente: Sistema de Información Energética, Sener.
La suma de los parciales puede no coincidir con los totales, debido al redondeo de las cifras.

Oil and Gas Industry Emissions

Sonora's emissions associated with the fossil fuel industries come from the transport of natural gas through the state's transmission pipelines and fugitive emission in the distribution system. Emissions can occur at several stages of production, processing, transmission, and distribution of gas. Based on the information provided in the Emission Inventory Improvement Program (EIIP)

[63] Note that emissions from natural gas consumed as lease fuel (used in well, field, and lease operations) and plant fuel (used in natural gas processing plants) are included in Appendix B in the industrial fuel combustion category..
[64] Secretaría de Energía. *Balance Nacional de Energía 2006.* (p.37)

guidance[65] for estimating emissions for this sector, transmission pipelines are large diameter, high-pressure lines that transport gas from production fields, processing plants, storage facilities, and other sources of supply over long distances to local distribution companies or to large volume customers. Sources of CH_4 emissions from transmission pipelines include leaks, compressor fugitives, vents, and pneumatic devices. Distribution pipelines are extensive networks of generally small diameter, low-pressure pipelines that distribute gas within cities or towns. Sources of CH_4 emissions from distribution pipelines are leaks, meters, regulators, and mishaps. Carbon dioxide, CH_4, and N_2O emissions occur as the result of the combustion of natural gas by internal combustion engines used to operate compressor stations.

With one operational gas processing plants and nearly 355 kilometers of gas pipelines, there are significant uncertainties associated with estimates of Sonora's GHG emissions from this sector. This is compounded by the fact that there are no regulatory requirements to track GHG emissions. Therefore, estimates based on emissions measurements in Sonora are not possible at this time.

The EPA's State Greenhouse Gas Inventory Tool (SIT) facilitates the development of a rough estimate of state-level GHG emissions. GHG emission estimates are calculated by multiplying emissions-related activity levels (e.g., miles of pipeline, number of compressor stations) by aggregate industry-average emission factors. Emissions of CO_2, CH_4, and N_2O associated with pipeline natural gas combustion (flaring) were estimated using 2006 Intergovernmental Panel on Climate Change (IPCC) emission factors[66] and Sonora 1990-2005 natural gas data from Secretaría de Energía (SENER).[67]

Coal Production Emissions
There is no coal production in Sonora.

Emission Forecasts
Table E-1 provides an overview of data sources and approaches used to develop projected fossil fuel sector emission estimates for Sonora. Whenever gaps were present in activity data, a surrogate set of data was used to estimate emissions. A description of surrogate data is also provided on Table E-1.

Table E-1. Approach to Estimating Historical/Projected Emissions by Fossil Fuel Systems

Activity	Approach to Estimating Historical Emissions		Surrogate Data	Forecasting Approach
	Required SIT Data	Data Source		Projection Assumption
Natural Gas Distribution	Total number of services	Instituto Nacional de Estadísticas,	Sonora population	Population was assumed to be directly proportional to the

[65] Emission Inventory Improvement Program, Volume VIII: Chapter 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems," August 2004.
[66] GHG emissions were calculated using method and emission factors outlined in Chapter 2, Volume 2, 2006 IPCC with reference to "Table 2.2 Default Emission Factors for Stationary Combustion in the Energy Industries". Guidelines are available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.
[67] Natural Gas inventory and forecast consumption was available in publication *Balance Nacional de Energía 2006* for years 1996 to 2016. It is available from www.semer.gob.mx.

Activity	Approach to Estimating Historical Emissions		Surrogate Data	Forecasting Approach
	Required SIT Data	Data Source		Projection Assumption
		Geografía e Informática (INEGI)[68]		number of residence with access to natural gas for cooking
Natural Gas Pipeline Fuel Use (CO_2, CH_4, N_2O)	Volume of natural gas consumed by pipelines	SENER[69]	None	Official forecast values through 2016. A flat growth rate was applied to years 2017-2020
Natural Gas Processing	Number of gas processing plants	Comisión de Ecología y Desarrollo Sustentable (CEDES)	None	No change over time
Natural Gas Transmission	Miles of gathering pipeline	CEDES	None	No change over time
	Miles of transmission pipeline	CEDES	None	No change over time
	Number of gas transmission compressor stations	CEDES	None	No change over time

Results

Table E-2 displays the estimated emissions from the fossil fuel industry in Sonora for select years over the period 1990 to 2025. Emissions from this sector grew by 35% from 1990 to 2005 and are projected to increase by an additional 14% between 2005 and 2025. Natural gas transmission is the major contributor to both historic emissions and emissions growth. Figure E-2 displays process-level emission trends from the fossil fuel industry, on a million-metric-tons-of-carbon-dioxide-equivalent (MMtCO_2e) basis.

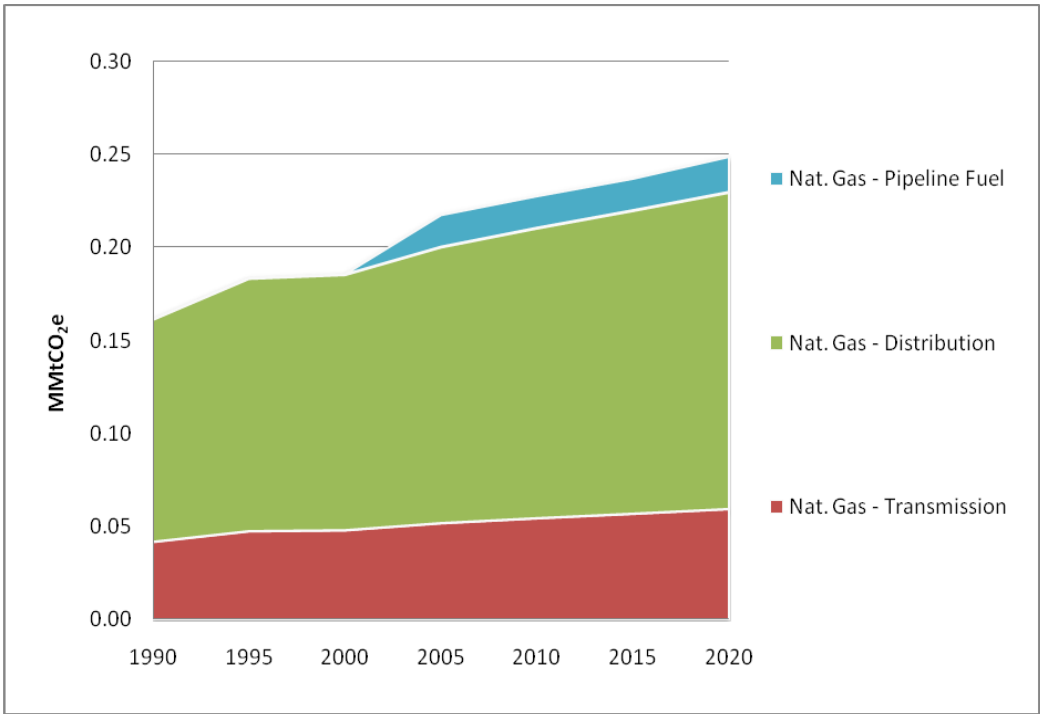
Table E-2. Historical and Projected Emissions for the Fossil Fuel Industry in MMtCO_2e

Source	1990	1995	2000	2005	2010	2015	2020
Fossil Fuel Industry	0.161	0.183	0.185	0.217	0.227	0.237	0.248
Natural Gas Industry	0.161	0.183	0.185	0.217	0.227	0.237	0.248
Transmission	0.042	0.047	0.048	0.052	0.054	0.057	0.059
Distribution	0.120	0.136	0.137	0.148	0.156	0.163	0.170
Pipeline Fuel	0.000	0.000	0.000	0.017	0.017	0.017	0.019

Note: Calculations based on approach described in text.

[68] INEGI: Censo General de la Población y Vivienda 2000; viviendas; combustible para cocina.
[69] SENER: Prospectiva del Mercado de Gas Natural 2007-2016.

Figure E-2. Fossil Fuel Industry Emission Trends (MMtCO$_2$e)



Source: Calculations based on approach described in text.

Key Uncertainties

Key sources of uncertainty underlying the estimates above are as follows:

- Current levels of fugitive emissions. These are based on industry-wide averages, and until estimates are available for local facilities, significant uncertainties remain.
- Projections of future production of fossil fuels. The assumptions used for the projections do not reflect all potential future changes that could affect GHG emissions, including future capital expenditures, potential changes in regulations and emissions-reducing improvements in oil and gas production, processing, and pipeline technologies.

Appendix F. Agriculture

Overview

The emissions covered in this appendix refer to non-energy methane (CH_4) and nitrous oxide (N_2O) emissions from livestock and crop production. Emissions and sinks of carbon in agricultural soils due to changes in cultivation practices are also covered. Energy emissions (combustion of fossil fuels in agricultural equipment) are included in the residential, commercial, and industrial (RCI) sector estimates (see Appendix B). The primary GHG sources and sinks - livestock production, agricultural soils, and crop residue burning are further subdivided as follows:

- *Enteric fermentation:* CH_4 emissions from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock. Microbes in the animal digestive system break down food and emit CH_4 as a by-product. More CH_4 is produced in ruminant livestock because of digestive activity in the large fore-stomach.
- *Manure management:* CH_4 and N_2O emissions from the storage and treatment of livestock manure (e.g., in compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition. The environmental conditions of decomposition drive the relative magnitude of emissions. In general, the more anaerobic the conditions are, the more CH_4 is produced because decomposition is aided by CH_4-producing bacteria that thrive in oxygen-limited conditions. In contrast, N_2O emissions are increased under aerobic conditions. 2006 IPCC segregates this source as follows:
    - CH_4 emissions due to manure management
    - Direct N_2O emissions due to manure management
    - Indirect N_2O emissions due to leaching
    - Indirect N_2O emissions due to volatilization
- *Agricultural soils:* The management of agricultural soils can result in N_2O emissions and net fluxes of carbon dioxide (CO_2) causing emissions or sinks. In general, soil amendments that add nitrogen to soils can also result in N_2O emissions. Nitrogen additions drive underlying soil nitrification and de-nitrification cycles, which produce N_2O as a by-product. 2006 IPCC segregates this source as follows:
    - Direct N_2O emissions due to managed soils
    - Indirect N_2O emissions due to atmospheric deposition
    - Indirect N_2O emissions due to leaching & runoff
- *Residue burning:* CH_4 and N_2O emissions are produced when crop residues are burned.

Emissions and Reference Case Projections

Inventory Data

Enteric fermentation. Methane emissions for 1990 through 2005 were estimated using a Tier 1 method described the 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (2006 IPCC)[70]. This method multiplies annual methane emission

[70] GHG emissions were calculated using a Tier 1 method described in Volume 4, Chapter 10 of the 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories, published by the

factors specific to each type of ruminant animal to activity data (livestock population by animal type). The activity data were provided by Comisión de Ecología y Desarrollo del Estado de Sonora (CEDES)[71] and is summarized on Table F-1. This methodology, as well as the others described below, is based on international guidelines developed by sector experts for preparing GHG emissions inventories.[72]

Table F-1. Inventory Livestock Population

Livestock	1990[73]	1995	2000	2005
Breeding Swine	1,156,048	1,155,500	1,208,092	1,210,195
Broilers	3,479,959	210,000	382,118	530,457
Dairy Cows	0	1,070	1,250	18,719
Goats	109,987	25,600	24,776	47,471
Horses	79,716	79,716	79,716	79,716
Layers (dry)	12,885,323	10,505,800	10,618,045	11,418,309
Other Cattle	1,623,622	1,283,476	1,104,944	1,479,935
Sheep	30,805	14,765	27,067	41,715
Turkeys			328,588	438,936

Manure management. 2006 IPCC guidelines were used to estimate methane and nitrous oxide emissions using activity data on livestock populations from the State of Sonora from 1980 to 2005. The activity data were supplied by CEDES from Sistema de Información Agropecuaria de Consulta (SIACON; see Table F-1).

To calculate CH4 emissions due to manure management, population numbers are multiplied by an estimate for typical animal mass and a volatile solids (VS) production rate to estimate the total VS produced. The VS estimate for each animal type is then multiplied by a maximum potential CH_4 emissions factor and a weighted methane conversion factor to derive total CH_4 emissions. The methane conversion factor (MCF) adjusts the maximum potential methane emissions based on the types of manure management systems employed in Sonora.

The emission factors were derived from a combination of regional expert studies[74] and state practices in manure management. Default emission and conversion factors were used for all emission sources in this sector with input information relating to livestock population by type, geographical area, and climate region. The geographical area category selected for Sonora was Latin America and climate region categories selected were warm (>26 degrees C) and temperate

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National Greenhouse Gas Inventory Program of the IPCC, available at (http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

[71] CEDES provided livestock information based on two sources: 1) Sistema de Información Agropecuaria de Consulta (SIACON), a national database that stores agriculture and animal farming statistics; 2) Anuario Estadístico del Estado de Sonora available at Instituto Nacionald de Estadísticas, Geografía e Informática (INEGEI).

[72] Revised 2006 1ntergovermental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories and Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, published in 2000 by the National Greenhouse Gas Inventory Program of the IPCC, available at: (http://www.ipcc-nggip.iges.or.jp/public/gp/english/).

[73] The sudden drop in some populations between 1990 and 1995 (broilers, goats and sheep) may indicate a data quality issue.

[74] Study results are summarized in Table 10-A-4 in Volume 4, Chapter 10, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

(15-25 degrees C) assigned to 95.8% and 4.2% of livestock population by type according to the terrain covered by each climate zone (see Figure F-1). The assumptions of livestock manure managed by system type and the associated methane conversion factors are shown in Tables F-2 and F-3 below. Manure management system distribution and methane conversion factors were assumed to remain constant through inventory and forecast years.

Figure F-1. Climate Zone Distribution in Sonora

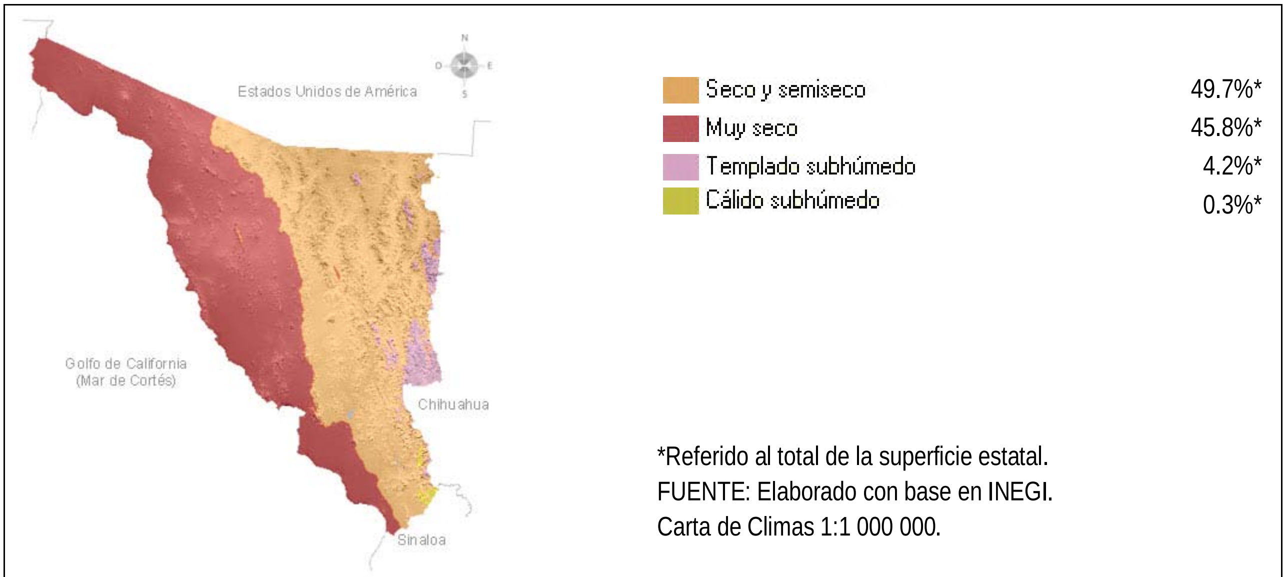


Table F-2. Default Manure Management Systems Distribution for Latin America

Livestock	Burned for fuel	Daily Spread	Digester	Dry Lot	Liquid Slurry	Other	Pasture, Range, Paddock	Solid Storage
Breeding Swine		2.0%	0.0%	41.0%	8.0%	40.0%		10.0%
Broilers						100.0%		
Dairy Cows	0.0%	62.0%	0.0%	0.0%	1.0%	0.0%	36.0%	1.0%
Goats						100.0%		
Horses						100.0%		
Layers (dry)						100.0%		
Layers (wet)						100.0%		
Market Swine		2.0%		41.0%	8.0%	40.0%		10.0%
Mule/Asses						100.0%		
Other Cattle	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	99.0%	0.0%
Sheep						100.0%		
Turkeys						100.0%		

Table F-3. MCF for Manure Management Systems by Climate Zone

Livestock	Climate	Burned for fuel	Daily Spread	Digest-er	Dry Lot	Liquid Slurry	Other	Pasture, Range, Paddock	Solid Storage
Breeding Swine	Temperate		0.5%	10.0%	1.5%	42.0%	1.0%		4.0%
	Warm		1.0%	10.0%	2.0%	78.0%	1.0%		5.0%
Broilers	Temperate						1.5%		
	Warm						1.5%		
Dairy Cows	Temperate	10.0%	0.5%	10.0%	1.5%	42.0%	10.0%	1.5%	4.0%
	Warm	10.0%	1.0%	10.0%	2.0%	78.0%	1.0%	2.0%	5.0%
Goats	Temperate						1.5%		
	Warm						2.0%		
Horses	Temperate						1.5%		
	Warm						2.0%		
Layers (dry)	Temperate						1.5%		
	Warm						1.5%		
Layers (wet)	Temperate						78.0%		
	Warm						80.0%		
Market Swine	Temperate		0.5%		1.5%	42.0%	1.0%		4.0%
	Warm		1.0%		2.0%	78.0%	1.0%		5.0%
Mule/ Asses	Temperate						1.5%		
	Warm						2.0%		
Other Cattle	Temperate	10.0%	0.5%	10.0%	1.5%	42.0%	1.0%	1.5%	4.0%
	Warm	10.0%	1.0%	10.0%	2.0%	78.0%	1.0%	2.0%	5.0%
Sheep	Temperate						1.5%		
	Warm						2.0%		
Turkeys	Temperate						1.5%		
	Warm						1.5%		

Direct N_2O emissions due to manure management are derived by using the same animal population numbers above multiplied by the typical animal mass and a total Kjeldahl nitrogen (K-nitrogen) production factor. The total K-nitrogen is multiplied by a non-volatilization factor to determine the fraction that is managed in manure management systems. The unvolatilized portion is then divided into fractions that get processed in either liquid (e.g. lagoons) or solid waste management systems (e.g. storage piles, composting). Each of these fractions is then multiplied by an N_2O emission factor, and the results summed, to estimate total N_2O emissions. Table F-4 shows the N_2O emission factor per manure management system.

Table F-4. Nitrous Oxide Emission Factors Applied to Manure Management Systems

Management System Name	Emission Factor (kg N_2O-N/N excreted)
Daily Spread	0
Digester	0
Dry Lot	0.02
Lagoon	0
Liquid Slurry	0.005
Other	0.001
Pit	0.002
Pit >1 month	0.002
Solid Storage	0.005

Indirect N_2O emissions due to leaching are derived by taking the mass of nitrogen excreted per animal per manure management system multiplied by the fraction of nitrogen released through leaching and runoff. The product is then multiplied by a N_2O emission factor. Indirect N_2O emissions due to volatilization are derived by taking the mass of nitrogen excreted per animal per manure management system multiplied by the fraction of nitrogen released through volatilization. The product is then multiplied by a N_2O emission factor. Table F-5 shows default values applied to indirect N_2O emissions due to leaching and volatilization.

Table F-5. Default Values for Indirect N_2O Emissions from Manure Management

		Volatilization		Leaching	
Livestock	Management System	Fraction	Emission Factor (kg N_2O-N/kg N)	Fraction	Emission Factor (kg N_2O-N/kg N)
Breeding Swine	Daily Spread	7.00%	0.01	4.50%	0.0075
Breeding Swine	Dry Lot	45.00%	0.01	4.50%	0.0075
Breeding Swine	Liquid Slurry	48.00%	0.01	4.50%	0.0075
Breeding Swine	Other	26.00%	0.01	4.50%	0.0075
Breeding Swine	Solid Storage	45.00%	0.01	4.50%	0.0075
Broilers	Other	45.00%	0.01	4.50%	0.0075
Dairy Cows	Daily Spread	7.00%	0.01	4.50%	0.0075
Dairy Cows	Liquid Slurry	40.00%	0.01	4.50%	0.0075
Dairy Cows	Pasture, Range, Paddock		0.01	4.50%	0.0075
Dairy Cows	Solid Storage	30.00%	0.01	4.50%	0.0075
Goats	Other	23.50%	0.01	4.50%	0.0075
Horses	Other	23.50%	0.01	4.50%	0.0075
Layers (dry)	Other	45.00%	0.01	4.50%	0.0075
Layers (wet)	Other	45.00%	0.01	4.50%	0.0075
Market Swine	Daily Spread	7.00%	0.01	4.50%	0.0075
Market Swine	Dry Lot	45.00%	0.01	4.50%	0.0075
Market Swine	Liquid Slurry	48.00%	0.01	4.50%	0.0075
Market Swine	Other	26.00%	0.01	4.50%	0.0075
Market Swine	Solid Storage	45.00%	0.01	4.50%	0.0075
Mule/Asses	Other	23.50%	0.01	4.50%	0.0075
Other Cattle	Other	35.00%	0.01	4.50%	0.0075
Other Cattle	Pasture, Range, Paddock		0.01	4.50%	0.0075
Sheep	Other	23.50%	0.01	4.50%	0.0075
Turkeys	Other	45.00%	0.01	4.50%	0.0075

Agricultural soils. The decomposition of crop residues including nitrogen fixing crops adds nitrogen to the nitrification and de-nitrification cycle in the soil, which produce N_2O as a by-product. The amount of nitrogen in crop soils was calculated as the product of crop dry matter harvested annually, the ratio of plant dry matter to crop dry matter, the nitrogen fraction of the plant dry matter, and the default nitrogen emission factor. Table F-6 identifies the group of nitrogen fixing crops as beans and pulses.

Table F-6. Inventory Crop Production in Metric Tons[75]

Crop	Cultivo	1990	1995	2000	2005
Alfalfa	Alfalfa	1,456,886	1,798,350	1,223,905	1,635,736
Barley	Cebada Grano	11,879	15,695	2,987	1,040
Beans & pulses	Chicharo	4,837	6,790	2,005	2,485
	Frijol	15,850	6,158	7,419	8,862
	Garbanzo Grano	17,664	10,577	35,708	34,225
Grass-clover mixtures	Pastos	7,666	28,825	64,804	36,406
Maize	Elote		4,524	14,802	8,244
	Maiz	122,178	491,476	82,681	131,560
Non-legume hay	Ajonjoli	16,704	2,115	4,658	452
	Alpiste	1,030	158		
	Forrajes	6,571	6,894	5,095	
Non-N-fixing forages	Avena Forrajera	3,848	4,916	49,796	71,289
	Cebada Forrajera En Verde	25,889	54,316	128,886	73,903
Oats	Avena grano			0	
Peanut (w/pod)	Cacahuate	819	1,314	1,531	708
Perennial grasses	Canola			2,006	956
	Cartamo	54,000	59,666	39,817	70,122
Potato	Papa	71,932	102,653	175,619	392,038
Root crops, other	Betabel		51	167	924
	Rabano	1,655	1,557	932	1,621
	Zanahoria	530	2,075	2,863	10,878
Rye	Rye Grass En Verde	158,396	75,305	77,191	174,181
Sorghum	Sorgo	837,774	1,612,449	3,948,869	3,261,288
Soybean	Soya	5,769	37,400		
Sugarcane	Caña de azucar	2,037	0	3,056	0
Wheat	Trigo	1,513,868	1,256,357	1,748,142	1,127,187

Application of synthetic fertilizer also adds nitrogen to the nitrification and de-nitrification cycle in the soil and contributes the release of N_2O in the atmosphere. Emissions from the application of fertilizer to agricultural lands were calculated from national statistics on fertilizer consumption[76] and cultivated area[77] adjusted to Sonora according to the state's share of cultivated land. Table F-7 shows available activity data and estimate nitrogen inputs to soil from synthetic fertilizers.

[75] Crop production data provided by CEDES from Sistema de Información Agropecuaria de Consulta (SIACON).
[76] Food and Agriculture Administration 2007. *FAOSTAT*. Online: http://faostat.fao.org/
[77] Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. 2007. *Sistema de Información Agroalimentaria y de Consulta 1980-2006*. Online: http://www.oeidrus-tamaulipas.gob.mx/cd_anuario_06/SIACON_2007.html

Table F-7. Fertilizer Application Data

Concept	1990	1995	2000	2005
National cultivated area (million ha)	19.73	20.94	21.78	21.64
Sonora cultivated area (million ha)	0.60	0.67	0.55	0.50
Quantity (1000 tons N)	40.96	33.43	33.70	25.65

Additions to the nitrification and de-nitrification cycle in the soil from organic fertilizers was calculated as the amount of total nitrogen available from reclaimed manure less the amount of this nitrogen dedicated for the purposes of feed, fuel or construction. In the case of Sonora, it was assumed no manure went to feed, fuel, or construction.

In regard to minerals application histosols, it was determined that the cultivation of highly organic soils did not apply to the climate and vegetation in Sonora. Similarly, no consideration was given to flooding and draining of organic soils because such practice does not occur in the state.

Nitrogen input to soils from the deposition of urine and dung by grazing animals on pasture, range, and paddock was calculated as the fraction of nitrogen in manure that is left unmanaged on fields as a result of grazing. Table F-3 identifies the default fraction of manure left unmanaged.

Residue burning. Agricultural burning can result in emissions of both N_2O and CH_4. Equation 2.27 in Volume 4, Chapter 2, of the 2006 IPCC guidance was used to calculate emissions along with cultivated surface area treated with fire.[78] The 2006 IPCC methodology calculates emissions as the product of the area burnt, the mass available for combustion per unit of surface area, the extent of combustion and emission factors. Default conversion and emission factors were applied to inventory information relating to residue burning on Sonoran agricultural land (see Table F-8 for activity data details).

F-8. Crop Land Treated by Residue Burning in Hectares

Crop	1999	2000	2001	2002	2003	2004	2005	2006
Avena Forrajera total	2	0	44	12	110	2	0	6
Cebada	25	0	88	0	36	0	0	0
Elote	0	0	0	0	0	595	0	0
Maiz	2,731	1,745	1,084	3,007	550	17,885	5,385	620
Rye Grass En Verde	0	0	11	13	0	0	0	113
Trigo	657	656	594	1,182	517	70		245
Total Area	**3,415**	**2,401**	**1,821**	**4,214**	**1,213**	**18,552**	**5,385**	**984**

Forecast Data

Forecast estimates were based on livestock population and crop production trends from 1990-2005. The resulting growth rates used to estimate 2005 through 2020 emissions are listed in

[78] Source: Oficina Estatal de Información para el Desarrollo Rural Sustentable del Estado de sonora (OEIDRUS) for years 1999-2006.

Tables F-9 and F-10. Note that a negative growth indicates a decrease in livestock population or crop production. A complete discontinuation of animal or vegetable farming is expressed by a complete negative unit (-100%). Based on these growth rates, forecast livestock and crop production activity were estimated into the year 2020. Forecast livestock population and crop production values are shown on Tables F-11 and F-12.

Table F-9. Growth Rates Applied to Livestock Population

Livestock	2006-2020 Growth Rate
Broilers	4.0%
Dairy Cows	2.6%
Goats	3.2%
Horses	0.0%
Layers (wet)	0.1%
Market Swine	0.3%
Other Cattle	1.5%
Sheep	1.7%
Turkeys	0.4%

Table F-10. Growth Rates Applied to Crop Production

Crop Name		Mean Annual Growth	
Spanish	English	Rate (%)	Period
Ajonjoli	Non-legume hay	2.7	1996-2004
Alfalfa	Alfalfa	0.7	1993-2005
Alpiste	Non-legume hay	0	NA
Avena Forrajera	Non-N-fixing forages	1.6	2003-2005
Avena grano	Oats	0	NA
Betabel	Root crops, other	4.3	1991-2002
Cacahuate	Peanut (w/pod)	2.9	1993-2005
Caña de azucar	Sugarcane	6.9	2002-2004
Canola	Perenniel grasses	0	NA
Cartamo	Perenniel grasses	1.8	1990-2005
Cebada Forrajera	Non-N-fixing forages	2.7	1998-2005
Cebada Grano	Barley	1.6	1996-2006*
Chicharo	Beans & pulses	8.5	1991-2005
Elote	Maize	0.3	1998-2005
Forrajes	Non-legume hay	3.8	1991-2000
Frijol	Beans & pulses	3.6	2000-2005
Garbanzo Grano	Beans & pulses	1.1	1996-2005
Maiz	Maize	7.5	2000-2004
Papa	Potato	4.1	1999-2004
Pastos	Grass-clover mixtures	1.8	1995-2005
Rabano	Root crops, other	3.9	1998-2005
Rye Grass En Verde	Rye	0.6	1990-2005
Sorgo	Sorghum	5.3	1995-2004
Soya	Soybean	7.7	1991-1993
Trigo	Wheat	4.1	1996-2003
Zanahoria	Root crops, other	2.2	1998-1999
* 2006 calculated as the average value during inventory years 1990-2005			

Table F-11. Forecast Livestock Populations 2005-2020

Row Labels	2005	2010	2015	2020
Breeding Swine	1,210,195	1,228,802	1,247,696	1,266,879
Broilers	530,457	646,524	787,987	960,402
Dairy Cows	18,719	21,260	24,148	27,427
Goats	47,471	55,635	65,202	76,415
Horses	79,716	79,716	79,716	79,716
Layers (dry)	11,418,309	11,450,282	11,482,344	11,514,496
Other Cattle	1,479,935	1,597,571	1,724,558	1,861,639
Sheep	41,715	45,351	49,305	53,604
Turkeys	438,936	447,282	455,787	464,453

Table F-12. Forecast Crop Production 2005-2020

Crop	Cultivo	2005	2010	2015	2020
Alfalfa	Alfalfa	1,635,736	1,693,172	1,752,625	1,814,166
Barley	Cebada Grano	1,040	13,557	14,704	15,947
Beans & pulses	Chicharo	2,485	3,733	5,609	8,426
	Frijol	8,862	10,586	12,646	15,105
	Garbanzo Grano	34,225	36,113	38,105	40,207
Grass-clover mixtures	Pastos	36,406	39,744	43,387	47,364
Maize	Elote	8,244	12,641	12,803	12,967
	Maiz	131,560	445,275	639,541	918,563
Non-legume hay	Ajonjoli	5,677	6,488	7,415	8,475
	Alpiste	656	656	656	656
	Forrajes		7,034	8,473	10,205
Non-N-fixing forages	Avena Forrajera	71,289	77,194	83,588	90,511
	Cebada Forrajera En Verde	73,903	84,558	96,749	110,698
Oats	Avena grano		0	0	0
Peanut (w/pod)	Cacahuate	708	815	938	1,079
Perenniel grasses	Canola	956	892	892	892
	Cartamo	70,122	76,502	83,463	91,057
Potato	Papa	392,038	202,473	247,965	303,679
Root crops, other	Betabel	924	161	199	245
	Rabano	1,621	1,958	2,366	2,858
	Zanahoria	10,878	12,143	13,554	15,130
Rye	Rye Grass En Verde	174,181	179,785	185,569	191,539
Sorghum	Sorgo	3,261,288	4,224,611	5,472,482	7,088,951
Soyabean	Soya	92,449	133,993	194,206	281,478
Sugarcane	Caña de azucar	688	961	1,342	1,874
Wheat	Trigo	1,127,187	1,376,366	1,680,629	2,052,153

Results

During inventory years (1990 through 2005), total agricultural emissions decreased by 8% reaching levels on the order of 3.47 million metric tons of carbon dioxide equivalents ($MMtCO_2e$). In 1990, the top two emitting sources were enteric fermentation, and agricultural soils. Enteric fermentation alone accounted for 52.6% of total greenhouse gas emissions in 1990. The fastest growing source through the time period was residue burning with a mean annual growth rate of 5.8%; all other sources had a negative mean annual growth.

During forecast years (2005 through 2020), total agriculture emissions are projected to increase by 24% attaining levels in the order of 4.18 million metric tons of carbon dioxide equivalents. In 2020, the top two emitting source sectors are enteric fermentation and agricultural soils. Enteric fermentation accounts for 53.3% of total greenhouse gas emissions in 2020. The fastest growing source through the time period is agricultural soils with a mean annual growth rate of 1.7%. Figure F-2 and Table F-13 summarize greenhouse gas emission numbers by source sector. The distribution of greenhouse gas emissions by source is presented in Table F-14. Finally, mean annual growth rates for selected time intervals are listed in Table F-15.

Figure F-2. GHG Emissions from Agriculture 1990-2020

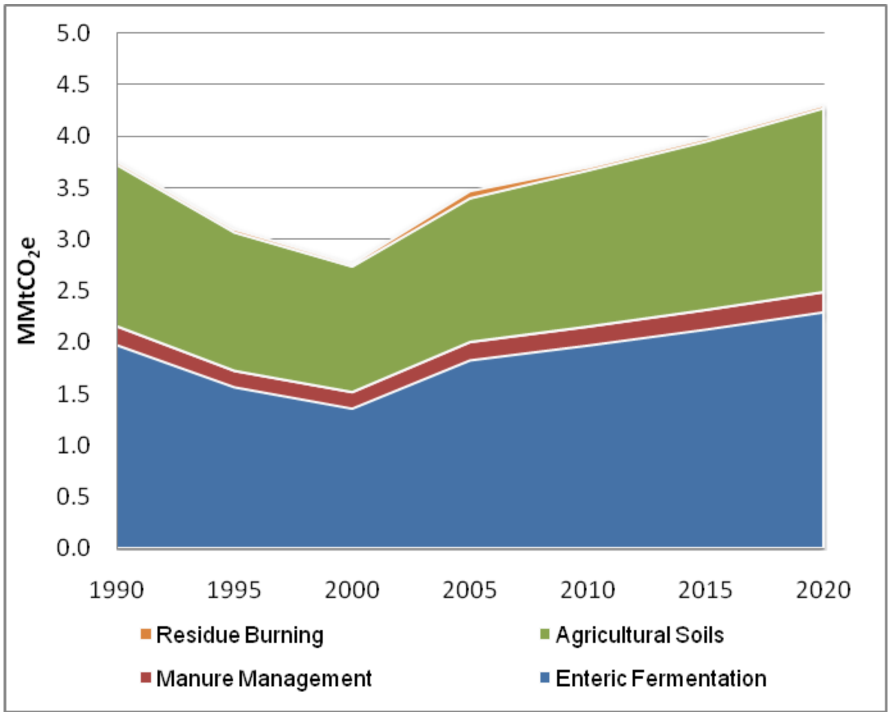


Table F-13. GHG Emissions from Agriculture ($MMtCO_2e$)

Source	1990	1995	2000	2005	2010	2015	2020
Enteric Fermentation	1.98	1.57	1.36	1.83	1.97	2.13	2.30
Manure Management	0.18	0.16	0.16	0.18	0.18	0.19	0.20
Agricultural Soils	1.57	1.34	1.22	1.40	1.52	1.64	1.78
Residue Burning	0.03	0.03	0.03	0.07	0.03	0.03	0.03
Total	3.76	3.10	2.77	3.47	3.70	3.98	4.31

Table F-14. GHG Emission Distribution in the Agriculture Sector

Source	1990	1995	2000	2005	2010	2015	2020
Enteric Fermentation	52.6%	50.6%	49.2%	52.7%	53.3%	53.4%	53.3%
Manure Management	4.8%	5.1%	5.8%	5.1%	5.0%	4.8%	4.5%
Agricultural Soils	41.7%	43.3%	44.1%	40.2%	40.9%	41.1%	41.4%
Residue Burning	0.8%	1.0%	1.0%	2.0%	0.8%	0.8%	0.7%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table F-15. GHG Mean Annual Growth Rate for Selected Time Intervals

Agriculture	1990-2005	2005-2020	1990-2020
Enteric Fermentation	-0.52%	1.52%	0.50%
Manure Management	-0.18%	0.65%	0.23%
Agricultural Soils	-0.78%	1.65%	0.43%
Residue Burning	5.78%	-5.46%	0.00%

Key Uncertainties

In order to reduce uncertainty associated with greenhouse gas emissions from enteric fermentation processes, it is recommended that an enhanced characterization of the livestock population be developed. In the case of Sonora, "other cattle" (non-dairy cows) accounts for 92% of the ruminant population. This broad category could be broken down into subcategories (e.g. calves, bulls, etc) and by the number of cattle in pasture versus on feedlots. Then emission factors specific to each of the subcategories could be applied. At a minimum, the following information is required to develop livestock subcategory specific emission factors: 1) feed intake estimate, 2) average animal weight, 3) animal activity index, 4) feeding conditions, and 5) mean winter conditions. Additional effort put into this source category will significantly impact a large share of total enteric fermentation emissions.

Emissions from the application of fertilizer to agricultural lands were calculated from a national value that was adjusted by means of surrogate data. Since the application of fertilizers varies significantly from crop to crop, it is recommended that nitrogen additions be segregated by crop and by fertilizer type, if possible (including different commercial fertilizers and organic fertilizers, like manure). This information combined with fertilized surface area by crop will result in decreased uncertainty.

A final contributor to the uncertainty in the emission estimates is the forecast assumptions. Mean annual growth rates were derived from historical trends during period 1990 through 2005; however, historical data was inconsistent. The early nineties experienced very high livestock population and crop production numbers which declined sharply by 2005. Even during high yield years, values oscillated sharply from one year to the next. The fluctuation of values may indicate poor quality data.

Appendix G. Waste Management

Overview

Greenhouse gas (GHG) emissions from waste management include:

- Solid waste management – methane (CH_4) emissions from municipal solid waste landfills (LFs), accounting for potential CH_4 that is flared or captured for energy production (this includes both open and closed landfills)[79];
- Solid waste combustion – CH_4, carbon dioxide (CO_2), and nitrous oxide (N_2O) emissions from the combustion of solid waste or residential open burning; and
- Wastewater management – CH_4 and N_2O from municipal wastewater and CH_4 from industrial wastewater (WW) treatment facilities.

Inventory and Reference Case Projections

Solid Waste Management

For solid waste management, landfill emplacement data were obtained from the Sistema Nacional de Información Ambiental y Recursos Naturales (SNIARN).[80] This database provided the annual mass of municipal solid waste (residuos sólidos urbanos) by state for the period 1998-2008. Historic population values were used to model emplacement starting in 1960; similarly, population projections were used to determine future municipal waste generation rates. Emissions were modeled using the first order decay model from the 2006 IPCC guidelines.[81]

The classification of industrial waste (desechos de manejo especial) exists in the Mexican legislation[82]; however, in practice municipal solid waste (desechos sólidos urbanos) and industrial waste (desechos de manejo especial) are consolidated at disposal sites. Consequently, no additional emissions were estimated for industrial waste since these emissions are already counted as part of emissions from municipal solid waste sites.

According to the United Nations Framework for Climate Change Convention (UNFCCC), there are eleven Clean Development Mechanism projects that capture landfill gas for destruction or energy generation purposes.[83] Although landfill gas-to-energy (LFGTE) systems have been built in Mexico in the last few years, none have been installed in the State of Sonora. Therefore, all modeled methane emissions from landfills were calculated as being released to the atmosphere.

[79] CCS acknowledges that N_2O and CH_4 emissions are also produced from the combustion of landfill gas; however, these emissions tend to be negligible for the purposes of developing a state-level inventory for policy analysis.

[80] Secretaría de Medio Ambiente y Recursos Naturales. *Sistema Nacional de Información Ambiental y Recursos Naturales*. Dimensión Ambiental, Residuos. Online at: http://www.semarnat.gob.mx/informacionambiental/Pages/index-sniarn.aspx

[81] IPCC. *2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 5: Waste*. Online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

[82] Ley General para la Prevención y Gestión Integral de los Residuos. Artículo 5.

[83] UNFCCC, 2009. CDM Project Search. http://cdm.unfccc.int/Projects/projsearch.html. Reference retrieved from Climate Action Reserve. *Protocolo de Reporte de Proyectos en Rellenos Sanitarios en México Recolección y Destrucción del Metano de los Rellenos Sanitarios; Versión 1.0.* March 2009

Solid Waste Combustion

According to CEDES personnel, there are no regulated sources of solid waste combustion in Sonora.[84]

Open burning of MSW at residential sites (e.g. backyard burn barrels) also contributes to GHG emissions. US EPA's 2002 National Emissions Inventory provides estimates of the quantity of waste burned per person at rural residential sites.[85] Emissions from open burning were calculated using Sonora population data from 1990 through 2025 and SIT emission factors and waste characteristics. Estimates from 2006 onward were calculated using the SIT waste characteristics for 2005. Future emissions from residential open burning were estimated using the projected (2005-2025) population growth rates[86], which is 0.91%.

Wastewater Management

GHG emissions from municipal wastewater treatment were also estimated. For municipal wastewater treatment, emissions are calculated in EPA's SIT based on state population, assumed biochemical oxygen demand (BOD) and protein consumption per capita, and emission factors for N_2O and CH_4. The key SIT default values are shown in Table G-1 below.

Table G-1. SIT Key Default Values for Municipal Wastewater Treatment

Variable	Default Value
BOD	0.09 kilogram (kg) /day-person
CH_4 emission factor	0.6 kg/kg BOD
Water treatment N_2O emission factor	4.0 g N_2O/person-yr
Biosolids emission factor	0.01 kg N_2O-N/kg sewage-N
Source: US EPA SIT – Wastewater Module.	

The percentage of Sonora residents on city sewer is 93%, according to data on number of households per residential area according to the 2005 census on population and housing.[87] For Sonora, the amount of BOD anaerobically digested is 41%, according to Comisión Nacional del Agua (CONAGUA) data.[88] The amount treated by mechanical water treatment plants is approximately 29%. Sixty-one percent of municipal wastewater is treated in anaerobic lagoons, 10% is treated in anaerobic digesters for sludge, and 0.2% is treated in septic systems. Municipal wastewater emissions were projected based on the projected population growth rate for 2005-2025 for a growth rate of 0.91% per year.

For industrial wastewater emissions, SIT provides default assumptions and emission factors for three industrial sectors: Fruits & Vegetables, Red Meat & Poultry, and Pulp & Paper.

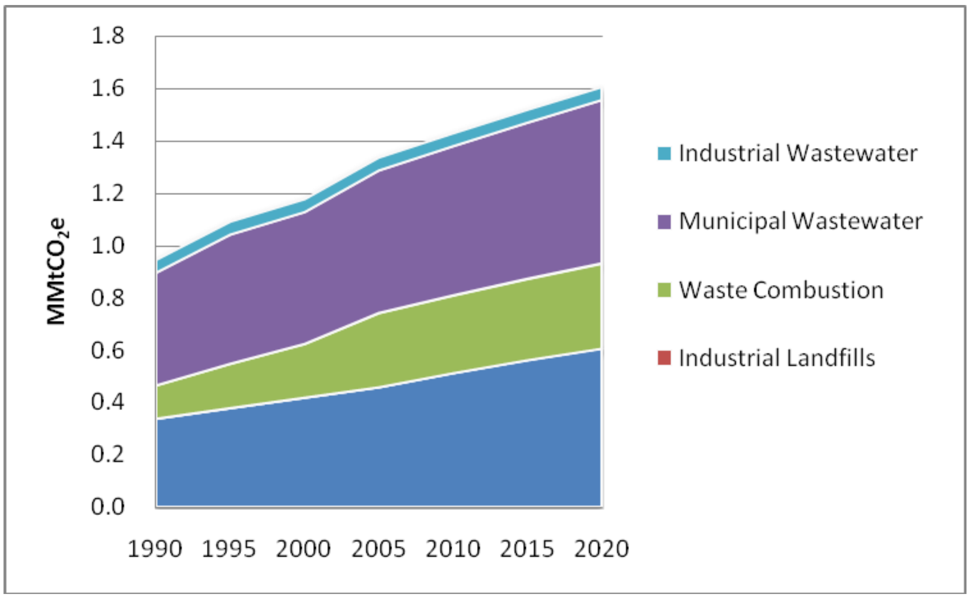
[84] Based on research conducted by Mr. Francisco Maytorena of CEDES, May 2008.
[85] EPA, ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/nonpoint/2002nei_final_nonpoint_documentation0206version.pdf.
[86] Tercera Comunicacion Nacional ante la Convencion de las NACIONES UNIDAS.
[87] Retrieved May, 2008 from: http://www.inegi.gob.mx/est/contenidos/espanol/sistemas/conteo2005/iter2005/selentcampo.aspx
[88] Information obtained from CONAGUA and provided to CCS by CEDES.

CONAGUA provided data on red meat processing.[89] No data were available for fruit and vegetable and poultry processing. There is no pulp and paper processing in the state. Current industrial wastewater flow data for red meat were used to estimate all historic years from 1990-2005. The SIT emission factors were used to estimate emissions for red meat production. Emissions were projected to 2025 based on the 1990-2005 annual growth rate of 0.0%.

Results

Figure G-1 and Table G2 show the emission estimates for the waste management sector. Overall, the sector accounts for 1.40 $MMtCO_2e$ in 2005, and emissions are estimated to be 1.68 $MMtCO_2e$/yr in 2025.

Figure G-1. Sonora, Mexico GHG Emissions from Waste Management, 1990-2020



Source: Based on approach described in text.

Table G-2. Sonora GHG Emissions from Waste Management ($MMtCO_2e$)

Source	1990	1995	2000	2005	2010	2015	2020
Municipal Solid Waste Landfills	0.34	0.38	0.42	0.46	0.51	0.56	0.61
Waste Combustion	0.13	0.17	0.21	0.29	0.30	0.31	0.33
Municipal Wastewater	0.43	0.50	0.51	0.55	0.57	0.60	0.63
Industrial Wastewater	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Total	**0.95**	**1.09**	**1.18**	**1.34**	**1.43**	**1.52**	**1.61**

Table G-3. GHG Emission Distribution in the Waste Management Sector

Source	1990	1995	2000	2005	2010	2015	2020

[89] See footnote number 6.

Municipal Solid Waste Landfills	36%	35%	35%	34%	36%	37%	38%
Waste Combustion	14%	16%	18%	21%	21%	21%	20%
Municipal Wastewater	46%	45%	43%	41%	40%	39%	39%
Industrial Wastewater	5%	5%	4%	4%	3%	3%	3%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

In 2005, the largest sources in the waste management sector were emissions from municipal wastewater and emissions from municipal landfills accounting for 41% and 34% of total sector emissions. By 2025, the contribution of emissions from landfills will reach the level of municipal waste water emmissions (38% and 39% respectively). Emissions from waste combustion contributed with 21% of waste sector emissions in 2005 and are expected to maintain the same proportion by 2025 (20%).

Key Uncertainties

According to the Guidelines of the IPCC, a first order decay model to estimate emission from solid waste disposal sites contains inherent uncertainties, which are described below:

- Decay of carbon compounds to methane involves a series of complex chemical reactions and may not always follow a first-order decay reaction. Higher order reactions may be involved, and reaction rates will vary with conditions at the specific SWDS. Reactions may be limited by restricted access to water and local variations in populations of bacteria.
- SWDS are heterogeneous. Conditions such as temperature, moisture, waste composition and compaction vary considerably even within a single site, and even more between different sites in a country. Selection of 'average' parameter values typical for a whole country is difficult.
- Use of the FOD method introduces additional uncertainty associated with decay rates (half-lives) and historical waste disposal amounts. Neither of these are well understood or thoroughly researched.

Another source of uncertainty is the quality of the activity data. Waste accumulation values that are available from SEMARNAT are based on population and waste generation rates per capita. Actual records of waste accumulation per site were not available for all waste disposal facilities. A comprehensive set of accumulation records would reduce some uncertainty associated with landfill methane emissions.

SIT default assumptions for waste composition that are optimized for municipal waste were used to estimate residential open burning emissions. Open burning quantities of waste at residential sites was estimated using EPA's National Emission Inventory (NEI) methodology and based on total Sonora population. Depending on actual burn rates and waste composition, this could be an over- or underestimate. Emissions from open burning of yard waste were not estimated but are expected to be small (for yard waste, only CH_4 and N_2O emissions would be of interest, since the CO_2 would be of biogenic origin).

For the wastewater sector, the key uncertainties are associated with the application of SIT default values for the parameters listed in Table G-1 above. To the extent that additional methane is being generated outside of the anaerobic digestion process, these emissions will be underestimated. Potential emissions from treatment plant sludge that is applied to the surface of landfills were not quantified in this inventory.

For industrial wastewater, emissions were only estimated for the red meat industry using state data. There are no data for fruit and vegetable processing or poultry processing facilities. Therefore, emissions from industrial wastewater are likely to be slightly underestimated.

Appendix H. Forestry and Land Use

Overview

Forestry and land use emissions refer to the net carbon dioxide (CO_2) flux[90] from forests in Sonora, which account for about 35% of the state's land area.[91] The definition of forest adopted by Comición Nacional Forestal (CONAFOR) was used to select the type of vegetation counted toward the quantification of carbon stock in forested land.[92] Dominant forest types in Sonora are "mezquital" (shrubland), "bosque de encino" (oak forest), and "selva baja caducifolia" (subtropical dry forest) accounting for 31.6%, 25.3%, and 21.7% of total forest land respectively. Additional forest land distribution data are provided in Table H-1.

Table H-1. Forest Land Distribution

Year	Forest Type	Surface (ha)	Fraction
2003	Mezquital	1,952,334	31.6%
2003	Bosque de Encino	1,563,093	25.3%
2003	Selva Baja Caducifolia	1,339,854	21.7%
2003	Selva Baja Caducifolia con Vegetaciòn Secundaria Arbustiva	478,682	7.8%
2003	Selva Baja Espinosa	417,934	6.8%
2003	Bosque Bajo Abierto	201,950	3.3%
2003	Bosque de Pino con Encino	170,146	2.8%
2003	Bosque de Tàscate	21,048	0.3%
2003	Bosque de Pino	18,483	0.3%
2003	Manglar	7,770	0.1%
2003	Bosque de Encino con Pino	3,387	0.1%
2003	Bosque de Encino con Vegetaciòn Arbustiva	1,500	0.0%
2003	Bosque Bajo Abierto con Vegetaciòn Secundaria Arbustiva	237	0.0%

Through photosynthesis, carbon dioxide is taken up by trees and plants and converted to carbon in forest biomass. Carbon dioxide emissions occur from respiration in live trees, decay of dead biomass, and combustion (both forest fires and biomass removed from forests for energy use). In addition, carbon is stored for long time periods when forest biomass is harvested for use in durable wood products. Carbon dioxide flux is the net balance of carbon dioxide removals from and emissions to the atmosphere from the processes described above.

The forestry and land use sector CO_2 flux is categorized into two primary subsectors:

- *Forested Landscape [IPCC Categories: Forestland remaining forestland and Land converted to Forestland]:* this consists of carbon flux occurring on lands that are not part of

[90] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.
[91] Detailed forest coverage information was compiled by CEDES. General land use, state surface area, and broad vegetation information were obtained from Instituto Nacional de Geografía, Estadísticas, e Informática (INEGEI) available at http://www.inegi.gob.mx/inegi/default.aspx?s=est. Total forest surface area amounted to 6,176,419 hectares in 2003; the state of Sonora has a total land area of 17,837,500 hectares.
[92] The definition of forest by Comisión Nacional Forestal was used to screen general vegetation categories for forest categories (Retrieved May, 2008 from: http://148.223.105.188:2222/snif_portal/index.php?option=com_content&task=view&id=12&Itemid=7#matorrales).

the urban landscape. Fluxes covered include net carbon sequestration, carbon stored in harvested wood products (HWP), and emissions from forest fires and prescribed burning.

- *Urban Forestry and Land Use [IPCC Categories: Settlements remaining settlements and Land converted to Settlements]:* this covers carbon sequestration in urban trees, flux associated with carbon storage from landscape waste into landfills, and nitrous oxide (N_2O) emissions from settlement soils (those occurring as a result of application of synthetic fertilizers).

Inventory and Reference Case Projections

Methodology

2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC) offers two methods for estimating carbon flux. Based on the information available for Sonora, the "gain-loss" method was adopted which expresses the annual change in carbon stocks in biomass in forested land as the annual increase in carbon stocks due to biomass growth minus the annual decrease of carbon stock due to biomass loss:

$$\Delta C_B = \Delta C_G - \Delta C_L$$

where:

ΔC_B = annual change in carbon stocks in biomass considering the total area, tons C/yr

ΔC_G = annual increase in carbon stocks due to biomass growth for each land sub-category, considering the total area, tons C/yr

ΔC_L = annual decrease in carbon stocks due to biomass loss for each land sub-category, considering the total area, tons C/yr

The annual increase in carbon stocks due to biomass growth (ΔC_G) is calculated for each vegetation type as the product of land area (A), mean annual biomass growth of dry matter (G_{TOTAL}) and the carbon fraction of dry matter (CF). Mean annual biomass growth is derived for each vegetation type as a function of average above and below ground biomass growth. Annual biomass growth is expressed as follows.

$$\Delta C_G = \Sigma A_i \bullet G_{TOTALi} \bullet CF_i$$

Several factors should be considered when estimating the annual decrease of carbon stocks due to biomass loss (ΔC_L), including harvesting wood products, fuel wood removals from forests, and carbon stock losses due to disturbances such as fires or insect infestations. Carbon stock decreases due to disturbances and wood harvesting were calculated; however, information relating to fuel wood removals was not available. Consequently, the annual decrease of carbon stocks was calculated as the sum of carbon losses due to disturbances ($L_{disturbance}$) and carbon losses due to wood removals ($L_{removals}$) according to the following equation.

$$\Delta C_L = L_{removals} + L_{disturbance}$$

For the "gain-loss" method, 2006 IPCC default emission factors specific to climate domain, ecological zone, and continent were used in conjunction with activity data for Sonora. Activity data included a vegetation profile of the land shown in Table H-1, forest land area disturbed by fires, and annual records of harvests for wood products.

Vegetation information was obtained from land surveys conducted in 1999 and 2003 by Instituto Nacional de Estadísticas, Geografía, e Informática (INEGEI)[93] and was compiled by CEDES. In order to supplement missing historical data, it was assumed that mean annual area for the time period 1990-2002 was equal to that of year 1999. Similarly, the mean annual area for period 2004 through 2020 was assumed to be equal to that of year 2003. Additionally, CONAFOR provided criteria to determine which vegetation type to count as forested land,[94] and CCS conducted the task of correlating CONAFOR's forest type categories to 2006 IPCC's. Forest land descriptions with CONAFOR and 2006 IPCC categories for available inventory years are shown in Table H-2. Table H-3 lists lower range annual increment in biomass factors (G_{TOTAL}) correlated to forest type.[95]

Table H-2. Forest Land Description and Coverage

Climate domain (i)	Ecological zone (j)	Forest Type	1999 (ha)	2003 (ha)
Sub-tropical	Dry forest	Bosque de Tàscate	19,739	21,048
		Mezquital	1,906,213	1,952,334
		Selva Baja Caducifolia	1,829,987	1,339,854
		Selva Baja Caducifolia con Vegetaciòn Sec. Arbustiva		478,682
		Selva Baja Espinosa	434,965	417,934
	Mountain system	Bosque Bajo Abierto	200,699	201,950
		Bosque Bajo Abierto con Vegetaciòn Sec. Arbustiva		237
Temperate	Mountain system	Bosque de Encino	1,445,964	1,563,093
		Bosque de Encino con Pino	1,753	3,387
		Bosque de Encino con Vegetaciòn Arbustiva		1,500
		Bosque de Pino	11,206	18,483
		Bosque de Pino con Encino	184,204	170,146
Tropical	Shrubland	Manglar	12,202	7,770

Table H-3. Annual Increment in Biomass

Forest Type	G total (tons dm /ha yr)
Bosque Bajo Abierto	2.30
Bosque Bajo Abierto con Vegetaciòn Secundaria Arbustiva	2.30
Bosque de Encino	0.62
Bosque de Encino con Pino	0.63
Bosque de Encino con Vegetaciòn Arbustiva	0.63
Bosque de Pino	0.65
Bosque de Pino con Encino	0.62

[93] http://www.inegi.gob.mx/inegi/default.aspx
[94] http://148.223.105.188:2222/snif_portal/index.php?option=com_content&task=view&id=12&Itemid=7#matorrales
[95] G_{TOTAL} is the product of above-ground net biomass growth and the ratio of below-ground to above-ground biomass. Table 4.9, Chapter 4, Volume 4 of 2006 IPCC guidelines lists values of above-ground net biomass growth in natural forests expressed as a range of plausible values. For the purposes of a conservative estimate of carbon sinks, lower end values were selected.

Forest Type	G total (tons dm /ha yr)
Bosque de Tàscate	1.42
Manglar	1.40
Mezquital	1.42
Selva Baja Caducifolia	1.22
Selva Baja Caducifolia con Vegetaciòn Secundaria Arbustiva	1.22
Selva Baja Espinosa	1.22

Forest fire information was obtained from CONAFOR for years 1994 through 2004[96]. For remaining years during the period 1990 to 2020, an average surface area was calculated using the immediate five historical values. Table H-4 shows the area disturbed by forest fire per forest type according to 2006 IPCC categories. Carbon stocks losses due to fire disturbances were calculated using default conversion numbers listed in Table H-5 and calculated as follows:

$$L_{disturbance} = \{A_{disturbance} \bullet B_W \bullet (1 + R) \bullet CF \bullet fd\}$$

Where:

$L_{disturbances}$ = annual other losses of carbon, ton C /yr

$A_{disturbance}$ = area affected by disturbances, ha /yr

B_W = average above-ground biomass of land areas affected by disturbances, ton d.m./ ha

R = ratio of below-ground biomass to above-ground biomass, in (ton d.m. below-ground biomass) /(ton d.m. above-ground biomass).

CF = carbon fraction of dry matter, ton C /(tonnes d.m.)

fd = fraction of biomass lost in disturbance, assume to be 90%

Table H-4. Area Disturbed by Fires in Hectares

Climate Domain & Zone Code	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Sub-tropical dry forest	1631	2576	2423	1557	569	1032	5731	2245	9376	538	400
Sub-tropical steppe	4203	2092	4297	3588	1194	9842	2400	1380	6689	5873	3914
Temperate mountain system <20 yr	519	519					1675	314	1301	672	0
Temperate mountain system >20 yr	3122	2448	3833	2539	2530	4261	3904	2799	3634	2981	2979

[96] Retrieved May, 2008 from:
http://www.semarnat.gob.mx/gestionambiental/forestalysuelos/Pages/anuariosforestales.aspx

Table H-5. Forest Area to Carbon Content Conversion Factors

Climate domain (i)	Ecological zone (j)	B W (tons dm/ha)	Avg of R [97] (ton root/ton shoot)	Avg of CF[98] (ton C/ton dm)
Sub-tropical	dry forest	210	0.30	0.46
Sub-tropical	steppe	70	0.32	0.47
Temperate	mountain system <20 yr	50	0.25	0.49
Temperate	mountain system >20 yr	130	0.25	0.49

Finally, wood harvest information was obtained from the Anuario Estadistico de la Producción Forestal published by Secretaría de Medio Ambiente y de Recursos Naturales (SEMARNAT) for the years 1995 through 2004.[99] Table H-6 lists the volume of wood harvest by forest type. An average mass of wood harvested from available data points was applied to the remaining years in the time period 1990-2020. The mass of wood harvested was calculated as the product of wood density and volume of merchantable wood products.

Table H-6. Volume of Merchantable Wood Products in Cubic Meters

Forest Type	Year									
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Encino / Oak	316	12,757	20,770	17,310	28,396	29,759	19,111	18,794	23,217	27,238
Pino / Pine	37,493	45,697	41,682	32,477	40,531	61,704	36,492	1,444	18,899	13,432
Latifoliadas / Elm	47,781	55,493	52,513	60,213	56,759	95,699	106,397	92,712	38,768	66,958

Forested Landscape

The underlying data, as shown in Table H-7, display an annual net increase in carbon stocks in Sonora's forested landscape. In comparison with the neighboring state of Baja California, Sonora's carbon stocks are four times larger (416%) and larger output of wood products (456%).[100]

Table H-7. Annual Change in Carbon Stocks in Biomass (Carbon Metric Tons)

Parameter	1990	1995	2000	2005
ΔC_G	-3,270,549	-3,270,654	-3,270,865	-3,321,949
ΔC_L	1,030,787	782,869	1,555,075	1,026,645
$\Delta C_{biomass}$	**-2,239,762**	**-2,487,784**	**-1,715,790**	**-2,295,303**

Positive numbers indicate net emission; negative numbers indicate carbon sequestration.

[97] Forest fire information was available at the segregation level of climate domain and ecological zone. For that reason, R values, which are forest type specific values, were averaged for all forest types in a given climate domain and ecological zone.
[98] Forest fire information was available at the segregation level of climate domain and ecological zone. For that reason, CF values, which are forest type specific values, were averaged for all forest types in a given climate domain and ecological zone.
[99] Retrieved May, 2008 from: http://www.semarnat.gob.mx/gestionambiental/forestalysuelos/Pages/anuariosforestales.aspx
[100] Carbon stocks in Baja California amounted to 1,795,000 metric tons of carbon in 2005 according to Centro Mario Molina. *Inventario Estatal de Gases de Efecto Invernadero*. Versión final Secretaría de protección al ambiente del gobierno del estado de Baja California: Diciembre, 2007. Merchantable wood production was 4,783 and 21,379 metric tons in 2003 for Baja California and Sonora respectively according to Anuario Estadistico de la Producción Forestal published by Secretaría de Medio Ambiente y de Recursos Naturales (SEMARNAT) available at http://www.semarnat.gob.mx/gestionambiental/forestalysuelos/Pages/anuariosforestales.aspx.

In Sonora's forested landscape, annual biomass growth exceeded biomass loss, thus sequestering carbon from the atmosphere. The extent of carbon sequestration expressed in million metric tons of carbon dioxide equivalent is shown in Table H-8.

Table H-8. Annual Change in Carbon Stocks in Forested Landscape Biomass ($MMtCO_2e$)

Parameter	1990	1995	2000	2005
ΔC_G	-11.99	-11.99	-11.99	-12.18
ΔC_L	3.78	2.87	5.70	3.76
$\Delta C_{biomass}$	**-8.21**	**-9.12**	**-6.29**	**-8.42**

Positive numbers indicate net emission; negative numbers indicate carbon sequestration. Totals may not sum exactly due to independent rounding. MMtC = million metric tons of carbon. Positive numbers indicate net emission. Stock change in MMtC was converted to $MMtCO_2e$ by multiplying by 44/12.

Biomass burned in forest fires emits carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), in addition to many other gases and pollutants. Since carbon dioxide emissions are captured under the total carbon flux calculations above, CCS used the United States Environmental Protection Agency's (US EPA's) State Guidance and Inventory Tool (SIT) to estimate methane and nitrous oxide emissions. The correlation between SIT and 2006 IPCC forest categories and associated emission factors is shown in Table H-9. Calculations indicate that forest fire non-CO_2 GHG emissions are negligible. Emissions in metric tons per year and combined $MMtCO_2e$ are listed in Table H-10.

Table H-9. 2006 IPCC & US EPA SIT Vegetation Type Correlation

2006 IPCC		US EPA SIT	
Climate domain (i)	**Ecological zone (j)**	**Vegetation Type 1**	**Vegetation Type 2**
Sub-tropical	dry forest	Forest	Savanna woodlands dry
Sub-tropical	humid forest	Forest	Savanna woodlands humid
Sub-tropical	mountain system	Forest	Other temperate forest
Sub-tropical	steppe	Savanna	Shrublands
Temperate	mountain system	Forest	Other temperate forest
Tropical	shrubland	Savanna	Tertiary tropical forest

Table H-10. Methane and Nitrous Oxide Emissions from Forest Fires

GHG	1990	1995	2000	2005
CH_4 (metric tons)	7.34	6.74	13.51	8.87
N_2O (metric tons)	0.1	0.1	0.19	0.14
Total tCO_2e	**185**	**172**	**343**	**228**
Total $MMtCO_2e$	**1.85E-04**	**1.72E-04**	**3.43E-04**	**2.28E-04**

Urban Forestry and Land Use

According to the US EPA SIT "changes in carbon stock in urban areas are equivalent to tree growth minus biomass losses resulting from pruning and mortality".[101] Although information was available to calculate urban forestry biomass growth, information pertaining to biomass losses (including flux associated with carbon storage from landscape waste into landfills) could

[101] SIT's Land-Change and Forestry module, Section 4.

not be obtained. Without data indicating urban forestry biomass losses, CCS was unable to calculate carbon flux for this subsector. According to information provided by CEDES, the urban area of the five largest municipalities in Sonora accounts for 18% of the state's land area (see Table H-11). Given the significant extent of urban land use in Sonora, urban forest canopy cover and the associated carbon fluxes should receive further assessment in future inventory efforts.

The data mentioned above on urban biomass deposited to landfills could also be used to estimate carbon storage in landfills. Future inventory work should capture the amount of urban forest biomass and landscape debris, deposited to landfills.

Additionally, information to estimate emissions of nitrous oxide from urban landscaped areas (those occurring as a result of application of synthetic fertilizers) was unavailable. This emissions subsector is likely to be a small contributor to overall GHG emissions due to the limited extent of lawns, golf courses, and other similar urban areas that would receive synthetic fertilizer application.

Table H-11. Urban Area Coverage for Sonora's Largest Municipalities

Municipality	Area (km^2)	Fraction
Sonora	178,375	100.0%
Hermosillo	14,285	8.0%
Guaymas	10,009	5.6%
Cajeme	3,565	2.0%
Navojoa	3,023	1.7%
Nogales	1,589	0.9%
Total	**32,470**	**18.2%**

Results

Carbon flux due to forestry and land use practices are summarized in Table H-12. The analysis of historical records indicates that 1) biomass growth in Sonora's forested landscape exceeds the carbon decrease due to disturbances (forest fires) and the harvest of wood products combined, and 2) biomass loss is largely attributed to harvesting activities for wood products. A notable and potentially significant data gap is the amount of wood harvested for use as a fuel.

Forecasted carbon flux was calculated with three basic assumptions. First, the surface area covered by the forested landscape was projected to remain constant at the levels surveyed in 2003. Second, harvesting of wood products was assumed to be equivalent to the average mass of wood removed during the period starting 1995 and ending 2004. Thirdly, the future yearly surface area affected by forest fires was assumed to equal the average surface area disturbed by fires during 1999 and 2004.

Table H-12. Forestry and Land Use Flux and Reference Case Projections ($MMtCO_2e$)

Subsector	1990	1995	2000	2005	2010	2015	2020
Forested Land	-8.21	-9.12	-6.29	-8.42	-7.96	-7.96	-8.69
Urban Forestry and Land Use	NA	NA	NA	NA	NA	NA	NA
Total	**-8.21**	**-9.12**	**-6.29**	**-8.42**	**-7.96**	**-7.96**	**-8.69**

Key Uncertainties

According to 2006 IPCC guidelines, the Forestry and Land Use Sector includes six land use categories: 1) forest land[102], 2) cropland, 3) grassland, 4) wetlands, 5) settlements[103], and 6) other land. Wetlands do not represent a key land use in Sonora. Emissions from crop lands are covered under the Agricultural Sector; categories one and five are covered in this appendix. Category three was not covered in this appendix; however, it may be included in the future revisions since grassland surface area information is readily-available. Based on available resources such as satellite imagery, it is possible to expand the detail of the inventory, especially for grasslands, settlements, and other land uses to include "matorrales", a widespread form of vegetation in Sonora that is excluded from forest land considerations by definition.[104] In order to proceed with the expansion of this sector, additional resources will need to be applied in correlating the 1999 and 2003 data sets. There is uncertainty with 1999 and 2003 land use area information which is partially presented in Table H-2. The data for 1999 are not fully populated for all land uses and there are significant differences for some of these land uses between 1999 and 2003. These issues should be explored further.

There is much uncertainty associated with the selection of above-ground net biomass growth values. Table 4.9, Chapter 4, Volume 4 of 2006 IPCC guidelines lists values of above-ground net biomass growth in natural forests expressed as a range of plausible values. For the purposes of a conservative estimate of carbon sinks, lower end values were selected. However, this was an assumption that needs verification. The selection of median values results in the carbon sequestration estimates listed in Table H-13.

Table H-13. Alternative Forestry and Land Use Flux and Reference Case Projections ($MMtCO_2e$)

Subsector	1990	1995	2000	2005	2010	2015	2020
Forested Land	-23.63	-24.54	-21.71	-24.37	-23.91	-23.91	-24.65
Urban Forestry and Land Use	NA	NA	NA	NA	NA	NA	NA
Total	**-23.63**	**-24.54**	**-21.71**	**-24.37**	**-23.91**	**-23.91**	**-24.65**

Several processes contributing to the annual decrease of carbon stocks due to biomass loss should be considered, including harvesting of wood products, fuel wood removals from forests, and carbon stock losses due to disturbances such as fires or insect infestations. For Sonora, information regarding the annual decrease of carbon stocks due to fuel wood removals was not available and could have a substantial impact on the estimated carbon flux. Additionally, carbon loss by insect infestation was not considered in these estimates.

There is also some uncertainty associated with the correlation of vegetation categories used by CONAFOR with the vegetation categories employed by the 2006 IPCC guidance documents. The harmonization consisted of reducing thirteen vegetation categories specific to Mexico to four vegetation categories expressed as a function of climate domain (e.g. subtropical, temperate)

[102] This land use category is named in the 2006 IPCC guidance document "Forest Land" and referred to in this appendix as "forested landscape".
[103] This land use category is named in the 2006 IPCC guidance document "Settlements" and referred to in this appendix as "urban forest and land Use".
[104] See footnote number 3.

and ecological zones (e.g. dry forest, steppe). Although necessary for emissions estimates at the Tier 1 level[105], the exercise of correlation generates a degree of uncertainty that can be greatly reduced with the results of state or country-specific studies.

[105] In 2006 IPCC guidelines, Tier 1 methods refer to emissions quantification approaches that rely on published emission factors as opposed to country or region specific values.

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