Canadian Environmental Sustainability Indicators 2007

Greenhouse Gas Emissions Indicator

Data Sources and Methods

June, 2008

Environment Canada
Statistics Canada
Health Canada

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1. Introduction

Canadians' health and their social and economic well-being are fundamentally linked to the quality of their environment. Recognizing this, in 2004, the Government of Canada committed to establishing national indicators of air quality, greenhouse gas emissions, and freshwater quality. The goal of these indicators is to provide Canadians with more regular and reliable information on the state of their environment and how it is linked with human activities. Environment Canada, Statistics Canada, and Health Canada are working together to develop and communicate these indicators. Reflecting the joint responsibility for environmental management in Canada, this effort has benefited from the cooperation and input of the provinces and territories.

This report is part of a suite of documents released under the Canadian Environmental Sustainability Indicators (CESI) initiative.[1] Each indicator reported in a given year under CESI has an associated "data sources and methods" report to provide technical detail and other background that will facilitate interpretation of the indicator or allow others to conduct further analysis using the CESI data and methods as a starting point.

This report deals with the underlying methods and data for the greenhouse gas emissions indicator as published in the 2007 CESI report.

2. Description of the indicator

The greenhouse gas (GHG) emissions indicator reports the trend in human-made greenhouse gas emissions at a national, provincial/territorial, and sectoral level for the six main greenhouse gases in Canada: carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, perfluorocarbons, and hydrofluorocarbons.

The indicator is based on GHG emissions data taken directly from the *National Inventory Report: Greenhouse Gas Sources and Sinks in Canada, 1990–2005* (Environment Canada 2007). As an Annex I Party (developed countries) to the United Nations Framework Convention on Climate Change (UNFCCC), Canada is required to prepare and submit a national inventory of anthropogenic sources and sinks of greenhouse gases on an annual basis.

Since direct measurement of emissions from all sources is not practical, the UNFCCC requires that countries develop, update, publish, and maintain national inventories using comparable emissions estimation methods.

Descriptions of the six greenhouse gases estimated and their main Canadian sources are outlined in Text Table 1. Emissions from natural sources (material decay, plant and animal respiration, volcanic and thermal venting, etc.) and absorption of emissions by natural sinks (forests, oceans) are not measured by this indicator.

[1] www.environmentandresources.ca and www.statcan.ca

Text Table 1: Greenhouse gas descriptions and main sources

Greenhouse gas	Description
Carbon dioxide (CO_2)	A naturally occurring gas produced by living organisms and fermentation, CO_2 is also produced by the burning (combustion) of hydrocarbon-based fuels, deforestation, biomass burning, and industrial processes such as aluminium smelting and lime production.
Methane (CH_4)	A naturally occurring, flammable gas emitted by geological coal formations and by the decomposition of organic matter. Landfills are a major source of CH_4 emissions in Canada. Other sources of CH_4 emissions include enteric fermentation[2], manure management, biomass burning, production and processing of oil and natural gas, and coal mining.
Nitrous oxide (N_2O)	Naturally occurring from microbial action in soil, N_2O is also emitted by the application of nitrogen fertilizers, soil cultivation, production of nitric acid and adipic acid, and the combustion of fossil fuels and wood.
Sulphur hexafluoride (SF_6)	A colorless gas soluble in alcohol and slightly soluble in water. It is mainly applied as cover gas in the production of magnesium. It can also be used as insulating material for high-voltage transformers and circuit breakers.
Perfluorocarbons (PFCs)	Synthetic chemicals composed of carbon and fluorine with high global warming potentials and atmospheric lifetimes of up to 50 000 years. PFCs are principally emitted as by-products during aluminium smelting.
Hydrofluorocarbons (HFCs)	Synthetic chemicals containing carbon, hydrogen, and fluorine. HFCs are used in various applications, such as air-conditioning systems, refrigeration systems, firefighting agents, aerosols and foam-blowing agents.

Sources: Derived from the Global Development Research Centre: Urban Environmental Management – Urban Waste Management GHG definitions (www.gdrc.org/uem/waste/waste-gases.html) and the United Nations Framework Convention on Climate Change glossary, (http://unfccc.int/resource/cd_roms/na1/ghg_inventories/english/8_glossary/Glossary.htm)

Estimates are provided at the national level, the provincial/territorial level, and the sectoral level for five emission source sectors as defined by the Intergovernmental Panel on Climate Change (IPCC): energy, industrial processes, solvent and other product use, agriculture, and waste. Text Table 2 provides a description of the main sources of the greenhouse gas emissions included in the indicator, broken down by IPCC sectors. Provincial and territorial emission totals do not include emissions from consumption of halocarbons, or from fugitive refinery emissions, since the activity data associated with these sources are only available at the national level. Emission estimates for use of mineral products, such as limestone, dolomite, soda ash, and magnesite, are also not available at provincial and territorial levels. Process-related emissions coming from ammonia production are included under “Other and Undifferentiated Production” at the provincial level (Environment Canada, 2007).

Although the greenhouse gas emissions indicator is quite comprehensive, some emission sources have not been included as a result of exclusions within the National Inventory Report (NIR). Owing to their relatively small contributions to the total emissions, these exclusions do not significantly affect the overall completeness of the inventory. A detailed discussion of the

[2] The digestion of carbohydrates by organisms in livestock.

emission sources not included can be found in Annex 5 of the NIR (Environment Canada, 2007).

Data from the land use, land-use change and forestry sector are excluded from the national totals in the NIR in accordance with the United Nations Framework on Climate Change reporting requirements and therefore are not included in the CESI report. The National Round Table on the Environment and the Economy's *Environment and Sustainable Development Indicators for Canada* report recommended that the GHG indicator exclude sources and sinks from land-use change and forestry (National Round Table on the Environment and the Economy, 2003).

Text Table 2: Sources of greenhouse gas emissions by IPCC sectors

Source Categories		Description
ENERGY		
	a) Stationary Fuel Combustion	
	Electricity and Heat Generation	Emissions from fuel consumed by:
	Electricity Generation	Utility and industry electricity generation
	Heat Generation	Steam generation (for sale)
	Fossil Fuel Industries	Emissions from fuel consumed by:
	Petroleum Refining and Upgrading	Petroleum refining industries (including upstream facilities)
	Fossil Fuel Production	Conventional and non-conventional oil and gas production industries (some refining is included)
	Mining	Emissions from commercial fuel sold to:
		Metal and non-metal mines, stone quarries, and gravel pits
		Oil and gas extraction industries
		Mineral exploration and contract drilling operations
	Manufacturing Industries	Emissions from fuel consumed by the following industries:
		Iron and steel (steel foundries, casting and rolling mills)
		Non-ferrous metals (aluminium, magnesium, and other production)
		Chemical (fertilizer manufacturing, organic and inorganic chemical manufacturing)
		Pulp and paper (primarily pulp, paper, and paper product manufacturers)
		Cement production
		Other manufacturing industries not listed (such as automobile manufacturing, textiles, food and beverage industries)
	Construction	Emissions from fuels consumed by the construction industry – buildings, highways, etc.
	Commercial and Institutional	Emissions from fuel consumed by:
		Service industries related to mining, communication, wholesale and retail trade, finance and insurance, real estate, education, etc.
		Federal, provincial, and municipal establishments
		National Defence and Canadian Coast Guard
		Train stations, airports, and warehouses
	Residential	Emissions from fuel consumed for personal residences (homes, apartment hotels, condominiums, and farmhouses)
	Agriculture and Forestry	Emissions from fuel consumed by:
		Forestry and logging service industry
		Agricultural, hunting and trapping industry (excluding food processing, farm machinery manufacturing and repair)

Source Categories	Description
b) Transportation	Emissions resulting from combustion and/or fugitive releases due to moving passengers, freight, and commodities throughout Canada
Domestic Aviation	Emissions resulting from the consumption of fossil fuels by Canadian-registered airlines flying domestically
Road Transportation	Emissions resulting from the consumption of fossil fuels by vehicles licensed to operate on roads
Railways	Emissions resulting from the consumption of fossil fuels by Canadian railways
Domestic Marine	Emissions resulting from the consumption of fossil fuels by Canadian-registered marine vessels fuelled domestically
Others – Off-Road	Emissions resulting from the consumption of fossil fuels by combustion devices not licensed to operate on roads
Others – Pipelines	Emissions resulting from the transportation and distribution of crude oil, natural gas, and other products
c) Fugitives	Intentional and unintentional releases of greenhouse gases from the following activities:
Coal Mining	Underground and surface mining
Oil and Natural Gas	Conventional and unconventional oil and gas exploration, production, transportation, and distribution
INDUSTRIAL PROCESSES	Emissions resulting from the following process (non-combustion) activities:
a) Mineral Products	Production of cement and lime; use of soda ash, limestone and dolomite, and magnesite
b) Chemical Industry	Production of ammonia, nitric acid, and adipic acid
c) Metal Production	Production of aluminium, iron, and steel; magnesium production and casting
d) Consumption of Halocarbons and SF_6	Use of HFCs and/or PFCs in air-conditioning units, refrigeration units, fire extinguishers, aerosol cans, solvents, foam blowing, semi-conductor manufacturing, and electronics industry; use of SF_6 in electrical equipment and semi-conductors
e) Other and Undifferentiated Production	Non-energy use of fossil fuels
SOLVENT AND OTHER PRODUCT USE	Emissions resulting from the use of N_2O as an anaesthetic and propellant
AGRICULTURE	Emissions resulting from:
a) Enteric Fermentation	Livestock
b) Manure Management	Livestock waste management
c) Agricultural Soils	
Direct N_2O Emissions	Emissions resulting from synthetic fertilizer, animal manure applied on cropland, crop residue, and cultivation of organic soils, and summer-fallow and conservation tillage practices
N_2O Emissions from Manure on Pasture, Range and Paddock	Emissions resulting from manure nitrogen on pasture, range and paddock
Indirect N_2O Emissions	Emissions from volatilization, leaching, and runoff of animal manure nitrogen and synthetic fertilizer nitrogen
WASTE	Emissions resulting from:
a) Solid Waste Disposal on Land	Municipal solid waste and wood waste landfills
b) Wastewater Handling	Domestic and industrial wastewater treatment
c) Waste Incineration	Municipal solid waste and municipal wastewater treatment sludge incineration

Source: Environment Canada, 2007

3. How the indicator is used

The greenhouse gas emissions indicator is used to track progress in Canada's efforts to lower emissions and reach our environmental performance objectives. Measuring the greenhouse gas emissions indicator in conjunction with economic performance indicators such as the gross domestic product (GDP) will help to support national-level decision making on sustainable development. Sectoral and geographic breakdowns have been used to inform policy development and emissions reduction plans.

4. How the indicator is calculated

Data used to produce the greenhouse gas emissions indicator come directly from the NIR and do not undergo any further manipulation. The inventory follows the internationally approved methods developed by the IPCC to estimate emissions for the six greenhouse gases outlined in Text Table 1. The IPCC guidelines (www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm) are approved and developed through an international process that includes comments from national experts, testing of methods through preliminary inventory development, country studies, technical and regional workshops, and informal expert groups (IPCC, 1997).

4.1 Methods

In general, the same approach to estimating emissions is applied across the various gases and human activities. Emissions are estimated by multiplying activity data[3] by specific emission factors[4]. At a simple level, the calculation is:

Emissions = activity data × emission factor

The IPCC guidelines provide various methods for calculating a given emission. The methods for estimating the gases are divided into "tiers" encompassing different levels of activity and technological detail. The same general structure is used, but the level of detail at which the calculations are carried out can vary. "Tier 1" methods are generally very simple, requiring less detail and expertise than the most complicated "Tier 3" methods. For example, electricity and heat generation could be measured using three different methods. A Tier 1 method would entail mass-balance calculations based on aggregated country-wide (or regional) statistics on consumption of basic fuels. A Tier 2 method would involve emission calculation by source types, based on fuel use for each industry and sector of the economy. A Tier 3 method would utilize source-specific data and could be used for only a small number of principal emission sources.

The intention of this tiered structure is to encourage countries to work at the most detailed level possible, while ensuring that for those countries that do not have detailed

[3] Activity data refers to the quantitative amount of human activity resulting in emissions during a given period of time. The annual activity data for fuel combustion sources, for example, are the total amounts of fuel burned. In the agriculture sector, annual activity data for methane emissions from enteric fermentation are the total number of animals, by species.

[4] Based on samples of measurement data, emission factors are representative rates of emissions for a given activity level under a given set of operating conditions. They are the estimated average emission rate of a given pollutant for a given source, relative to units of activity.

data, estimates can be made. The Tier 2 and Tier 3 methods are expected to produce more accurate emission estimates, but are more resource-intensive, as they usually require collection of more detailed data and a more thorough understanding of technologies.

Text Table 3 describes the methods used to estimate some of Canada's greenhouse gas emissions. This table illustrates that the selection of IPCC method type is highly dependent on the availability of data for emission factor development.

Text Table 3: Types of methods employed in estimating selected sources for Canada's GHG emissions

Category	IPCC method type	Notes
Energy – fuel combustion	Tier 2	Emission estimations are based on detailed fuel/technology information covering stationary and mobile sources.
Energy – fugitive emissions	Tier 2/Tier 3 hybrid	A hybrid approach is appropriate in situations when specific measurement data are available for only a subset of the data (i.e. coal-specific emissions).
Industrial processes – cement production	Tier 2	Based on the use of national clinker production data and clinker-based emission factor.
Industrial processes – iron and steel production	Tier 2	Process emissions from iron production and steel production are estimated separately, based on the quantity of metallurgical coke consumed, pig iron production and crude steel production.
Industrial processes – magnesium production	Tier 3	Based on data reported by facilities.
Agriculture – enteric fermentation	Tier 1/Tier 2	Uses domestic animal population data and average emission factors for all animal categories except cattle, where country-specific emission factors are applied.
Agriculture – manure management	Tier 1/Tier 2	Uses domestic animal population data and average emission factors for manure N_2O (Tier 1), and country-specific emission factors for manure CH_4 (Tier 2) for all animal categories.
Agriculture – soil emissions of nitrous oxide	Tier 1/Tier 2	All emissions in this category are calculated using the Tier 2 emission factors, except for N_2O emissions from cultivation of organic soils, volatization and leaching of nitrogen (Tier 1).
Waste – solid waste disposal on land	Tier 2	Uses a model to produce an emission profile that reflects the pattern of the degradation of waste over time.

Source: Derived from Environment Canada (2007) and IPCC (1997)

To better understand the variation and complexities that arise in estimation methods, the following two sections provide examples of the methods used to calculate greenhouse gas emissions. The first example provides an overview of the methods used to estimate emissions from fuel combustion, while the second illustrates how methane gas is estimated for Canadian dairy and beef cattle.

4.1.1 Example of estimating emissions: fuel combustion

The energy sector includes emissions of all greenhouse gases from the production and use of fuels for the primary purpose of delivering energy. Emissions in this sector are

classified as either fuel combustion or fugitive releases[5].

Emissions from fuel combustion for all energy sub-sectors are estimated using the following equation:

Emissions = quantity of fuel combusted × emission factor per physical unit of fuel

The fuel energy-use data used to estimate the combustion emissions are taken from Statistics Canada's annual energy supply and demand report (Statistics Canada, 2005). The fuel- and technology-specific emission factors used to estimate the emissions can be found in Annex 13 of the NIR (Environment Canada, 2007). These factors are based upon the physical quantity of fuel combusted and are subdivided by the type of fuel used.

The equation above applies to all source sectors; however, more detailed methods are often used. Fuel combustion emissions attributed to the transport sector, for example, are calculated using Canada's Mobile Greenhouse Gas Emission Model (MGEM05). This model is used to disaggregate fuel statistics into 23 categories that represent the estimated amount of fuel consumed by vehicles of similar emission characteristics determined as a function of their model year, fuel, and vehicle type. A detailed discussion of this specific method can be found in Section 3.1.3 of the NIR (Environment Canada, 2007).

4.1.2 Detailed example of applying the method: methane gas from enteric fermentation

National methane gas emission estimations for dairy and beef cattle are derived using methodologies provided by the IPCC and use the following calculation:

[5] These are intentional or unintentional releases of gases from fuel production activities. In particular, they may arise from the production, processing, transmission, storage, and use of fuels and include emissions from combustion only when it does not support a primary activity, e.g., flaring of natural gases at oil and gas production facilities (Environment Canada, 2007).

Methane emission estimates for Canadian dairy and beef cattle

$$CH_4 = \sum_{l=1}^{n} (P_l \times EF_l)$$

where

CH_4	=	Enteric fermentation methane emissions for all animal categories
P_l	=	Animal population (*P*) for each specific livestock category or sub-category (*l*)
EF_l	=	Methane emissions factor for each specific livestock category (*l*)

Methane emission estimates for Canadian cattle are calculated using the following steps:

Step 1: Cattle are divided into two sub-categories based on the IPCC Tier-2 methodology, along with specific information on animal sub-category, physiological status, age, gender, weight, rate of gain, level of activity, and production environment.

Step 2: Emission factors are calculated for each cattle sub-category (dairy cows, dairy heifers, beef cows, bulls, calves <1 year, heifer replacement, heifers >1 year, and steers >1 year) by province and then combined to produce a weighted national average emission factor.

Step 3: National enteric emissions are calculated by multiplying the emission factor with its cattle sub-category population, and by summing up estimates for all cattle sub-categories.

For more detailed information on the methods used to estimate emissions in each source category, refer to Chapters 3 through 8 and Annexes 2 and 3 in the NIR (Environment Canada, 2007).

4.2 Reporting units

The greenhouse gas emissions indicator uses the same source categories as are used in the NIR, following the same sub-sector breakdown. This reporting format is agreed upon internationally, and groups emissions into the following six sectors: energy; industrial processes; solvent and other product use; agriculture; land use, land-use change and forestry; and waste. Each of these categories is further subdivided and follows UNFCCC sector and sub-sector divisions closely, with some minor differences. As previously discussed, the indicator does not include data from the land use, land-use change and forestry category. Refer to Text Table 2 for a list of all source categories for which greenhouse gas emissions are estimated by the indicator.

Greenhouse gases differ in their ability to absorb heat in the atmosphere based on their chemical properties and lifetime in the atmosphere. For example, over a period of 100 years, methane is 21 times as powerful as carbon dioxide in terms of its potential to trap heat in the atmosphere, so it is considered to have a “global warming potential” of 21. Therefore, greenhouse gas emissions are reported in terms of “carbon dioxide equivalents,” determined by multiplying the amount of emissions of a particular gas by the global warming potential of that gas. The IPCC publishes the global warming potentials for each greenhouse gas (Text Table 4).

Text Table 4: Global warming potentials and atmospheric lifetimes

Greenhouse gas	Formula	100-year global warming potential	Atmospheric lifetime (years)
Carbon dioxide	CO_2	1	variable
Methane	CH_4	21	12 ± 3
Nitrous oxide	N_2O	310	120
Sulphur hexafluoride	SF_6	23 900	3 200
Hydrofluorocarbons (HFCs)			
HFC-23	CHF_3	11 700	264
HFC-32	CH_2F_2	650	5.6
HFC-41	CH_3F	150	3.7
HFC-43-10mee	$C_5H_2F_{10}$	1 300	17.1
HFC-125	C_2HF_5	2 800	32.6
HFC-134	$C_2H_2F_4$ (CHF_2CHF_2)	1 000	10.6
HFC-134a	$C_2H_2F_4$ (CH_2FCF_3)	1 300	14.6
HFC-143	$C_2H_3F_3$ (CHF_2CH_2F)	300	1.5
HFC-143a	$C_2H_3F_3$ (CF_3CH_3)	3 800	3.8
HFC-152a	$C_2H_4F_2$ (CH_3CHF_2)	140	48.3
HFC-227ea	C_3HF_7	2 900	36.5
HFC-236fa	$C_3H_2F_6$	6 300	209
HFC-245ca	$C_3H_3F_5$	560	6.6
Perfluorocarbons (PFCs)			
Perfluoromethane	CF_4	6 500	50 000
Perfluoroethane	C_2F_6	9 200	10 000
Perfluoropropane	C_3F_8	7 000	2 600
Perfluorobutane	C_4F_{10}	7 000	2 600
Perfluorocyclobutane	c-C_4F_8	8 700	3 200
Perfluoropentane	C_5F_{12}	7 500	4 100
Perfluorohexane	C_6F_{14}	7 400	3 200

Source: Environment Canada, 2007

5. Data sources

The greenhouse gas emissions indicator comes directly from the NIR and has not undergone any further manipulation. Data used to develop the NIR come from published as well as non-published sources from various government departments, scientific papers, and internationally accepted IPCC reference documents.

The sections below provide a brief outline of the data sources that were used to calculate emissions for each source category. A comprehensive detailing of all data sources used can be found in Chapters 3 through 8 of the NIR (Environment Canada, 2007), disaggregated by sector and sub-sector.

5.1 Energy

Many of the data used to estimate stationary and mobile fuel combustion emissions are acquired from Statistics Canada.

Certain sub-sectors require data from additional sources to assess emissions more completely. Some of the data sets used to estimate emissions from road transport activities, for example, are found in Text Table 5.

Text Table 5: Data sets and sources: Road transport activities

Data set	Source
Vehicle population data	Desrosiers Automotive Consultants; Environment Canada; R.L. Polk and Co.; Statistics Canada
Fuel consumption ratios	Transport Canada; U.S. Environmental Protection Agency
Vehicle kilometres travelled	Environment Canada; Statistics Canada
Road taxed fuel	Statistics Canada

An inventory of fugitive emissions from Canadian coal mining operations is used as the basis for estimating emission factors for releases associated with the mining of solid fuels (King, 1994). These emission factors are multiplied by coal production data from Statistics Canada. Fugitive emission estimates from the oil and natural gas industry are based on two studies (Radian International, 1997; Canadian Association of Petroleum Producers, 1999), using data collected from various sources, such as the Alberta Energy and Utilities Board, Natural Resources Canada, Statistics Canada and provincial energy ministries.

5.2 Industrial processes

Activity data used to develop estimates of greenhouse gas emissions from some of Canada's industrial processes, using either default IPCC or industry-specific emission factors, are outlined in Text Table 6.

Text Table 6: Data sets and sources: Industrial processes

Data set	Source
Cement production; lime production; limestone and dolomite use	Natural Resources Canada, *Canadian Minerals Yearbook*, Annual.
Cement production	Statistics Canada, *Cement*, 1990–2004, Monthly, 44-001-XIB.
Ammonia production; nitric acid production	Statistics Canada, *Industrial Chemicals and Synthetic Resins*, 1990-2005 Monthly, 46-002-XIE; ammonia and nitric acid producers.
Soda ash use	Global Trade Information Services; U.S. Geological Survey.
Iron and steel production	Statistics Canada, *Primary Iron and Steel*, 1990–2003, Monthly, 41-001-XIB; Statistics Canada, *Steel, Tubular Products and Steel Wire*, 2004-2005, Monthly, 41-019-XIE
Iron and steel production; non-energy use of fossil fuels	Statistics Canada, *Report on Energy Supply-Demand in Canada*, 2005, Annual, 57-003-XIB.

HFC emissions from consumption of halocarbons were estimated based on data gathered from surveys conducted by the Chemical Controls Division of Environment Canada in 1996, 1998, 1999, and 2001, and from a study performed in 2005. The same Division also collected PFC use data used to calculate emissions from consumption of

PFCs. Process CO_2, PFC and SF_6 emission estimates for aluminium production were obtained directly from the Aluminium Association of Canada. Estimates of N_2O emissions from adipic acid production were provided by Canada's only adipic acid plant. SF_6 data needed for developing estimates for the categories of magnesium casters and consumption of SF_6 by other industries were gathered from casting facilities and SF_6 gas distributors, respectively.

5.3 Solvent and other product use

This sector accounts for emissions that are related to the use of N_2O as anaesthetic and propellant. When used as an anaesthetic, approximately 97.5% of the N_2O does not get metabolized and quickly leaves the body in exhaled breath (i.e. emitted) due to its poor solubility in blood and other tissues. In the case of N_2O used as propellant, none of the N_2O is reacted and hence, it is all emitted (i.e., emission rate = 100%) to the atmosphere.

To develop emission estimates, the factors of 97.5% and 100% were multiplied by the estimated N_2O sales data. As a complete set of sales data, covering 1990-2005, could not be gathered, data on domestic sales of Canadian production provided by Nitrous Oxide of Canada and N_2O import data purchased from the Statistics Canada's merchandise trade database (http://www.statcan.ca/trade/scripts/trade_search.cgi) were used to estimate the total domestic sales volumes (or consumption) of N_2O. Please refer to the 1990-2005 National Inventory Report for complete details on the emission estimation methodology used.

5.4 Agriculture

Statistics Canada livestock population data were used in conjunction with IPCC Tier 1 or Tier 2 emission factors to produce estimates of emissions from enteric fermentation and manure management. Livestock categories for which population data are available include cattle (dairy and non-dairy), buffalo, sheep and lambs, goats, horses, swine, and poultry. These data are obtained from Statistics Canada's Census of Agriculture and other annual reports.

Emissions of nitrous oxide from synthetic fertilizers, animal manure applied to soils and crop residue decomposition are calculated using annual fertilizer sales, animal manure and crop production data from Statistics Canada, combined with the country-specific emission factors. To produce emission estimates from manure on pasture, range and paddock, the same data sources as for manure management emissions, and the Tier 1 emission factors are used. The area of cultivated organic soils obtained through consultations with national and regional soil and crop specialists is applied to the IPCC default emission factor to generate emission estimates for histosols. Other sources of removals of N_20, such as summer-fallow and conservation tillage practices are also inventoried.

5.5 Waste

The waste sector includes emissions from the treatment and disposal of wastes, including solid waste disposal on land (landfills), wastewater treatment, and waste incineration.

A variety of data sources were used to collect activity data to produce solid waste emission estimates. These sources include Environment Canada (1996), Statistics Canada (2006) and Statistics Canada's *Waste Management Industry Survey* (2000, 2003, 2004, 2007), Natural Resources Canada (1997), and various other unpublished waste inventories.

Provincial-level data, including waste disposal quantities, inputs from the above-mentioned sources and the Scholl Canyon model were used to estimate CH_4 emissions from landfills (Environment Canada, 2007). This model uses a first-order decay equation to relate emission contributions to the waste that has been landfilled in previous years, as opposed to the static default method, which relates emissions to the quantity of waste landfilled in that year only. A multiple linear regression of landfilled waste quantities was performed to fit the Levelton data (1991) with data obtained from Statistics Canada's *Waste Management Industry Survey* (2000, 2003, 2004, 2007) for emission estimates from municipal solid waste (MSW) landfills. New methane generation rate constants (k) were also used for MSW and wood waste landfill emission estimates.

Wastewater handling emission estimates, from municipal and industrial wastewater treatment, were developed using specific emission rates based on the amount of organic matter generated per person in Canada. These emission rates were then multiplied by the amount of wastewater treated anaerobically in each province and then by the population of the respective province (Statistics Canada, 2006). Emissions from industrial wastewater treatment were estimated from data obtained from Environment Canada reports (1986, 1991, 1996) and from communications with industry associations.

Both MSW and sewage sludge incineration estimates were derived from Environment Canada (1996, 1999, 2003) studies and extrapolated using Statistics Canada population growth figures. This year's inventory also includes N_20 emissions.

6. Statistical analysis

6.1 Quality assurance and quality control

The application of QA/QC procedures is an essential requirement of the GHG inventory development and submission process in order to ensure and improve transparency, consistency, comparability, completeness, and confidence in the national emission and removal estimates for the purpose of meeting Canada's reporting commitments under the UNFCCC.

The data used to compile the NIR are calculated by designated experts within the Greenhouse Gas Division at Environment Canada and are reviewed internally. A draft inventory is then distributed in a formal review process to the Emissions and Projections Working Group (EPWG). The EPWG includes representatives of provincial, territorial, and federal government departments working in the field of air pollution measurement and estimation.

Emission estimates for the various sectors are also reviewed by experts who provided the source data, such as Statistics Canada (energy data, livestock and crop production statistics), Natural Resources Canada (mineral production and forest statistics), Agriculture Canada, and industrial associations. The inventory is then submitted to the UNFCCC in April of each year. Subsequently, the inventory is subject to a formal review by a UN Expert Review Team.

The review of inventories by the UNFCCC is a three-stage process and provides a thorough technical assessment of the inventory. Each stage of the review is finalized with a review report, which is published on the secretariat website (www.unfccc.int). Annual review of individual inventories became mandatory in 2003, ensuring that adequate consideration is given to recalculations and emission trends over time. International teams of sectoral inventory experts examine the data, methods, and procedures used in preparing the inventory.

7. Statistics Canada's Greenhouse Gas Emissions Account

Statistics Canada's Greenhouse Gas Emissions Account is produced following the concepts of the System of National Accounts. It uses many of the same basic data as the greenhouse gas inventory compiled by Environment Canada; however, the information is recast into the commodity and industry framework of the System of National Accounts so that the emissions data can be used for economic modelling. In particular, this linkage permits use of Statistics Canada's national input-output accounts to analyze the interplay between production and consumption of goods and services and the greenhouse gas emissions that result from those activities. Emissions from the production of goods and services are attributed via the input-output model to the final purchaser.

Statistics Canada's Greenhouse Gas Emissions Account provides emissions estimates for 119 industries and two categories of household expenditure. In addition to the detailed emissions data produced by sector, several environment-economy "intensity" indicators are derived from Statistics Canada's Greenhouse Gas Emissions Account, including the greenhouse gas intensity of gross industrial output, the greenhouse gas intensity of household consumption and the greenhouse gas intensity of net exports.

Emissions factors from Environment Canada are applied to Statistics Canada's energy use account data (which are also based on the System of National Accounts industry and commodity frameworks). The energy use data come mainly from Statistics Canada's Industrial Consumption of Energy Survey, transportation surveys, the *Report on Energy Supply-Demand in Canada* and Natural Resources Canada's *Census of Mines*. Additional estimates of emissions that are not linked to fossil fuel consumption are taken directly from the Environment Canada greenhouse gas inventory and are applied to the appropriate industries in the System of National Accounts.

The final demand categories can be defined as follows:

- **Exports:** receipts from other provinces and territories or from abroad for sales of merchandise or services. The barter, grant, and giving of goods and services as gifts would also constitute exports.

- **Gross fixed capital formation (subdivided into "Construction" and "Machinery and equipment"):** the value of a producer's acquisitions, less disposals, of fixed assets during the accounting period plus certain additions to the value of non-produced assets (such as subsoil assets or major improvements in the quantity, quality, or productivity of land) realized by the productive activity of institutional units.

- **Government net current expenditure:** economic activities of the federal government (including defence), the provincial and territorial governments, local (municipal) governments, universities, colleges, vocational and trade schools, publicly funded hospitals and residential care facilities, and publicly funded schools and school boards.

- **Inventories:** consist of stocks of outputs that are still held by the units that produced them prior to their being further processed, sold or delivered to other units, or used in other ways, and stocks of products acquired from other units that are intended to be used for intermediate consumption or for resale without further processing.

- **Personal expenditure:** represents the purchases of commodities, commodity taxes, wages and salaries, and supplementary labour income of persons employed by the personal sector. Includes individuals, families, and private non-profit organizations.

8. Future improvements

The data and methods used to develop the greenhouse gas emissions indicator described in this document are considered to be the best available at this time (Environment Canada, 2007).

Annex I Parties are required to continuously improve the quality of their national greenhouse gas inventory to further refine and increase the transparency, completeness, accuracy, consistency, and comparability. As new information and data become available and more accurate methods developed, previous estimates are updated to provide a consistent and comparable trend in emissions. Although more accurate methods are sometimes available, the lack of necessary activity data often limits the use of these methods. Some of the planned initiatives for improving data availability are outlined below.

8.1 Greenhouse Gas (GHG) Emissions Reporting Program

In an effort to improve Canada's ability to monitor, report and verify greenhouse gas emissions, the Government of Canada in March 2004 and in partnership with the provincial and territorial governments, launched a national greenhouse gas reporting system.

The program requires facilities that emit 100 000 tonnes of carbon dioxide equivalent (100 kt CO_2 eq.) or more annually to submit their GHG emission information by June 1 of each year. The program has three main objectives: to enhance the level of detail of the National Greenhouse Gas Inventory; to provide the public with timely GHG emissions information; and to support provincial/territorial GHG emissions information requirements. Portions of the collected data (totals by gas and by facility) are made available to the public.

By providing a more precise picture of the sources and quantities of Canada's GHG emissions, data from the GHG emissions reporting system can be used to improve and confirm emission estimates developed from national and provincial statistics. The extent to which the information from the reporting system can be fully integrated into the inventory is dependent upon the level of detail and type of data available. Environment Canada will continue to use these data as an important component of the overall inventory development process.

8.2 Households and the Environment Survey

In early 2006, Statistics Canada surveyed Canadian households regarding selected environmental practices, such as commuting practices and ownership of household gasoline-powered equipment, to provide additional context for the greenhouse gas emissions indicator. The results of this survey (Statistics Canada, 2007) are now available. The Households and the Environment Survey was repeated in 2007 and will be repeated every second year thereafter. The 2007 version of the survey includes more detailed questions about home heating and air conditioning, the use of gasoline-powered recreational and small household engines, as well as more information on the types of motor vehicles owned by Canadians.

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