



**environment  
& tourism**

Department:  
Environment Affairs and Tourism  
**REPUBLIC OF SOUTH AFRICA**

**GREENHOUSE  
GAS  
INVENTORY  
SOUTH  
AFRICA**

**1990  
TO  
2000**

**COMPILATION UNDER THE  
UNITED NATIONS FRAMEWORK CONVENTION ON  
CLIMATE CHANGE (UNFCCC)**

**NATIONAL  
INVENTORY  
REPORT**

**MAY 2009**

## **PREFACE**

This report is the result of work commissioned by the Department of Environmental Affairs and Tourism (DEAT) to develop the 2000 national inventory of greenhouse gases (GHGs) for South Africa.

Information on energy and industrial processes was prepared by the Energy Research Centre (ERC) of the University of Cape Town, while information on agriculture, land use changes, forestry and waste was provided by the Centre for Scientific and Industrial Research (CSIR).

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## SUMMARY

### SOUTH AFRICA'S GREENHOUSE GAS INVENTORIES

In August 1997 the Republic of South Africa joined the majority of countries in the international community in ratifying the United Nations Framework Convention on Climate Change (UNFCCC). To fulfil its obligation under the UNFCCC, a number of projects related to climate change have since been undertaken by South Africa. These include the preparation of greenhouse gas (GHG) inventories, which comprises one of the inputs to the agreed National Communications (NC) to UNFCCC.

The first national GHG inventory in South Africa was prepared in 1998, using 1990 data. It was updated to include 1994 data and published in 2004. It was developed using the 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. Its results are summarised in Tables 0-1 and 0-2.

**TABLE 0-1: GREENHOUSE GAS EMISSIONS BY GAS, 1994 (DEAT 2004)**

GHG emissions	Gg CO <sub>2</sub> equivalent	% of total
CO <sub>2</sub> (with LULUCF)	297 341.25	
CO <sub>2</sub> (without LULUCF)	315 957.22	83.2 %
CH <sub>4</sub>	43 206.03	11.4 %
N <sub>2</sub> O	20 677.0	5.4 %
HFCs	NE	
PFCs	NE	
SF <sub>6</sub>	NE	
Total (with LULUCF)	361 214.28	
Total (without LULUCF)	379 840.25	100%

LULUCF = Land use, land-use change and forestry; NE = Not estimated

**TABLE 0-2: GREENHOUSE GAS EMISSIONS BY SECTOR, 1994 (DEAT 2004)**

Sectors	Gg CO <sub>2</sub> equivalent	% of total
Energy	297 563.46	78.3 %
Industrial processes	30 386.21	8.0 %
Solvent and other product use	NE	
Agriculture	35 461.51	9.3 %
LULUCF	-18 615.97	
Waste	16 429.07	4.3 %
Other	NE	
Total (with LULUCF)	361 214.28	
Total (without LULUCF)	379 840.25	100 %

LULUCF = Land Use, Land-use Change and Forestry; NE = Not estimated

For the 2000 national inventory, a decision was made to use the recently published 2006 IPCC Guidelines to enhance accuracy and transparency, and also to familiarise researchers with the latest inventory preparation guidelines. One of the most significant changes in the 2006 IPCC Guidelines was the restructuring of inventory sectors, in particular the combining

of agriculture, forestry, and land use change into one sector and providing more comprehensive and holistic methodologies for emission calculation.

#### *Institutional framework for inventory preparation in South Africa*

South Africa is currently establishing a national system to manage its climate change obligations under the UNFCCC process. This implies institutionalizing how the country prepares its GHG inventories and how it manages data collection and all relevant climate change information for both internal and external reporting. The national system will be based on the "Single National Entity" (SNE) concept, and will be hosted at the Department of Environmental Affairs and Tourism (DEAT).

## KEY EMISSION SOURCES IN SOUTH AFRICA

An analysis of key categories using previous inventories was made in order to determine the most significant emission sources in the country, contributing to about 95% of the total GHG emission estimate in the country. Using level and trend assessment on the basis of the 1990 and 1994 GHG inventories, the most significant emission sources contributing to more than 95% of total South Africa's emissions were identified. The full list of key emission sources is presented in Table 1-2. The first five emission sources in the list of key emission sources in South Africa, together accounting for 62.5% of emissions, were as follows:

1. Public electricity and heat production
2. Road transport
3. Iron and steel energy consumption
4. Iron and steel production (process emissions)
5. Enteric fermentation

## OVERVIEW OF THE 2000 INVENTORY

The total emissions for the 2000 inventory was 436,257 Gg CO<sub>2</sub>e (or 437.3 million tonnes CO<sub>2</sub>e). Four fifths (78.9%) were associated with energy supply and consumption, with smaller contributions from industrial processes (14.1%), agriculture (4.9%) and waste 2.1%) (see Table 0-4). These figures do not include emissions or sinks caused by agriculture, land use change and forestry activities. Activities in agriculture, land use and forestry contributed 40,772.94 Gg CO<sub>2</sub>e as sources, but provided a sink of 20,279.43 Gg CO<sub>2</sub>e, to provide a net source of emissions of 20,493.51 Gg CO<sub>2</sub>e. If this is taken into account, the net emissions total from South Africa is reduced to 435 461.62 Gg CO<sub>2</sub>e.

**TABLE 0-3: NATIONAL GHG INVENTORY RESULTS, 2000**

GHG source and sink category	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	Total
	CO <sub>2</sub> equivalent (Gg)						
Total (net emissions)	333 363.70	76 114.36	23 764.51	0.00	2 219.05	0.00	435 461.62
1. Energy	301 068.85	40 914.14	2 123.23				344 106.22
A. Fuel combustion (sectoral approach)	301 044.52	527.83	2 123.23				303 695.58
Energy industries	212 226.48	78.23	1 070.09				213 374.81
Manufacturing industries and construction	38 879.34	65.61	145.87				39 090.83
Transport	38 623.88	258.19	629.23				39 511.31
Commercial/institutional	1 901.59	0.43	9.28				1 911.30
Residential	5 547.25	122.25	258.89				5 928.40

GHG source and sink category	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	Total
	CO <sub>2</sub> equivalent (Gg)						
Agriculture/forestry/fishing	3 705.54	3.06	9.74				3 718.34
Other	160.42	0.06	0.11				160.60
B. Fugitive emissions from fuels	24.33	40 386.31	NA NO				40 410.64
Solid fuels	24.33	40 366.25	NA NO				40 390.58
Oil and natural gas	0.00	20.07	NO				20.07
2. Industrial processes and product use	52 574.28	4287.377593	2 388.39	NA NO	2 219.05	NA NO	61 469.09
A. Mineral products	6 863.20	NA	NA				6 863.20
B. Chemical industry	23 751.68	4 284.08	2 388.39	NO	NO	NO	30 424.14
C. Metal production	21 959.40	3.30	0.00	NA	2 219.05	NA NO	24 181.75
3. Agriculture, forestry and land use	-20 279.43	22 136.94	18 636.00				20 493.51
A. Enteric fermentation		18 969.09					18 969.09
B. Manure management		1 904.70	415.40				2 320.10
C. Forest land	-13 020.52	NA NO					-13 020.52
D. Cropland	-7 730.15						-7 730.15
F. Wetlands		190.89					190.89
I. GHG Emissions from biomass burning	471.24	1072.26	793.6				2 337.10
M. Indirect N <sub>2</sub> O emissions from managed soils			17427				17 427.00
4. Waste	0.00	8 775.90	616.90				9 392.80
A. Solid waste disposal on land		8 085.00					8 085.00
B. Waste-water handling		690.90	616.90				1 307.80
Memo Items:							
International bunkers	11 645.83	17.11	95.56				11 758.50
Aviation	2 906.25	0.43	25.20				2 931.87
Marine	8 739.59	16.68	70.36				8 826.62
CO <sub>2</sub> emissions from biomass	4 700.00						4 700.00
Total CO <sub>2</sub> equivalent emissions without land use, land-use change and forestry							436 257.30
Total CO <sub>2</sub> equivalent emissions with land use, land-use change and forestry							435 461.62

## OVERVIEW OF ESTIMATES AND TRENDS FROM 1990

The general trend in sector GHG emissions showed both increasing and decreasing trends between years 1990 and 2000. Agriculture and waste sectors showed significant decrease of emissions from 1990, whereas industrial processes and other product use emissions showed an increase of over 100% between 1990 to 2000. Energy sector emissions showed an increasing trend from 1990 to 2000. Some of these changes are attributable to changes in emission calculation methodologies and allocation of source categories, rather than significant change in activity data.

**TABLE 0-4: SECTOR EMISSION TRENDS AND PERCENTAGE CHANGES FROM 1990**

Sector	GHG emissions CO <sub>2</sub> e Gg							
	1990 (CO <sub>2</sub> e Gg)	% of total	1994 (CO <sub>2</sub> e Gg)	% of total	2000 (CO <sub>2</sub> e Gg)	% of total	2000 % change from 1994	2000 % change from 1990
Energy	260 886	75.1	297 564	78.3	344 106	78.9	15.6	31.9
Industrial processes and product use	30 792	8.9	30 386	8.0	61 469	14.1	102.3	99.6
Agriculture	40 474	11.6	35 462	9.3	21 289	4.9	-40.0	-47.4
Waste	15 194	4.4	16 430	4.3	9 393	2.1	-42.8	-38.2
Total (without LULUCF)	347 346		379 842		436 257		14.8	25.6

The trends for individual gases gave a different picture. There was a uniform increase in emissions for all types of greenhouse gases, with no decreases. Methane showed the highest increase, recording an increase of more than 76% from 1990 to 2000. Nitrous oxide showed the lowest increase from 1990 to 2000, of 2.7%.

**TABLE 0-5: GAS EMISSION TRENDS AND PERCENTAGE CHANGES FROM 1990**

GHG emissions CO <sub>2</sub> eGg	1990 Gg	% of total	1994 Gg	% of total	2000 Gg	% of total	1994 % change from 1990	2000 % change from 1994	2000 % change from 1990
CO <sub>2</sub>	280 932	80.9	315 957	83.2	353 643	81.1	12.5	11.9	18.6
CH <sub>4</sub>	2 053	12.4	2 057	11.4	3 624	17.2	0.2	76.2	76.5
N <sub>2</sub> O	75	6.7	67	5.4	76.7	1.3	-10.7	14.5	2.7
CF <sub>4</sub>	-		-	-	0.303	0.5		-	-
C <sub>2</sub> F <sub>6</sub>	-		-	-	0.027	0.06		-	-
Totals CO <sub>2</sub> eqGg (without LULUCF)	347 346		379 842		436 257		9.4	14.8	25.6

## CONCLUSIONS AND RECOMMENDATIONS

The 2000 GHG emission estimation continues to show a continued rise in GHG emissions in South Africa.

The GHG inventory process continues to face a number of challenges, the most significant of which is the availability of activity data for computation of the emissions.

The most challenging sectors for data collection were AFOLU (Agriculture, Forestry and Other Land Use) and IPPU (Industrial Processes and other Product Use). For the AFOLU sector, spatial data, in-depth research and modelling studies are required in order to create a robust database for land use and land use changes. Data for the agriculture sector had to be obtained from international sources (FAO) for this 2000 inventory.

For the IPPU sector, one reason given for the difficulty in collecting data was lack of cooperation by some industrial companies connected to the protection of confidentiality. There is an urgent need for government assistance here. Government can consolidate the agreements it has entered into with industry so that industry provides the required data, and in a format that is commensurate with the data requirements for preparations of national GHG inventories.

Similarly, agreements are necessary with data custodians in other sectors (Forestry, Agriculture, etc.). A clear regulatory framework for the provision of data for GHG inventory purposes would be helpful in this regard.

Consistency of inventory preparation is another area that requires urgent attention. In a number of cases it was observed that emissions estimated were not consistent with reality on the ground. For example, there was apparently a decrease in transport sector emissions between 1994 and 2000, even though an increase in transport fuel consumption was observed in the same time period. This suggests that the decrease in transport sector emissions was related more to improper allocation of fuel consumption in this sector rather than to an actual decrease in transport emissions. To address the consistency problem, recalculation and reallocation need to be undertaken when preparing future GHG inventories.

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## LIST OF ABBREVIATIONS AND TERMS

AFOLU	Agriculture, forestry and other land use
C	Carbon
C <sub>2</sub> F <sub>6</sub>	Carbon hexafluoroethane
CDSM	Chief Directorate of Surveys and Mapping
CF <sub>4</sub>	Carbon tetrafluoromethane
CFC	Chlorofluorocarbons
CH <sub>4</sub>	Methane
CO <sub>2</sub>	Carbon dioxide
CP	Conference of parties
CSIR	Council for Industrial And Scientific Research
DEAT	Department of Environmental Affairs And Tourism
DLA	Department of Land Affairs
DME	Department of Minerals And Energy
DWAF	Department of Water Affairs & Forestry
ERC	Energy Research Centre
FAR	Fourth Assessment Report
FAO	Food And Agriculture Organization
FCCC	Framework Convention on Climate Change
FOD	First order decay
FSA	Forestry South Africa
GEF	Global environmental facility
GHG	Greenhouse gas
GHGI	Greenhouse gas inventory
GWH	Gigawatt hour
GWP	Global warming potential
HFC	Hydrofluorocarbons
INC	Initial national communication
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial processes and other product use
ISO	International organization for standardization
KT	Kilotonne
LFG	Landfill gas
LPG	Liquified petroleum gas
LTMS	Long term mitigation scenarios
LTO	Landing/take off
LULUCF	Land use, land-use change, and forestry
MCF	Methane correction factor
MW	Megawatt
MWH	Megawatt hours
NA	Not applicable
NC	National communication
NCCC	National Climate Change Committee
NDA	National Department Of Agriculture
NE	Not estimated
NER	National electricity regulator
NIR	National inventory report
NLC	National land cover
NO	Not occurring
PAMSA	Paper manufacturers association of south africa
PFC	Perfluorocarbons
PPM	Parts per million

PSA	Forestry south africa
QA/QC	Quality assurance/quality control
RSA	Republic of South Sfrica
SAISI	South Africa Iron and Steel Institute
SANS	South Africa National Standards
SAPIA	South African Petroleum Industries Association
SAR	Second assessment report
SF <sub>6</sub>	Sulphur hexafluoride
SNE	Single national entity
UCT	University of Cape town
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nations Environmental Programme

## UNITS, FACTORS AND ABBREVIATIONS

### *Multiplication factors, abbreviations, prefixes and symbols*

<b>Multiplication factor</b>	<b>Abbreviation</b>	<b>Prefix</b>	<b>Symbol</b>
1 000 000 000 000 000	10 <sup>15</sup>	Peta	P
1 000 000 000 000	10 <sup>12</sup>	Tera	T
1 000 000 000	10 <sup>9</sup>	Giga	G
1 000 000	10 <sup>6</sup>	Mega	M
1 000	10 <sup>3</sup>	kilo	k
100	10 <sup>2</sup>	hecto	h
0,1	10 <sup>-1</sup>	deci	d
0,01	10 <sup>-2</sup>	centi	c
0,001	10 <sup>-3</sup>	milli	m
0,000, 001	10 <sup>-6</sup>	micro	μ

### *Units and abbreviations*

<b>Abbreviation</b>	<b>Units</b>
°C	Degrees Celsius
a	Year (annum)
cal	Calorie
g	Gram
h	Hour
ha	Hectare
J	Joule
m <sup>3</sup>	Cubic metre
t	Tonne
W	Watt

### *Standard conversions*

<b>Unit</b>	<b>Equivalency</b>
1 tonne (t)	1 Megagram (Mg)
1 Kilotonne	1 Gigagram (Gg)
1 Megatonne	1 Teragram (Tg)

# 1 INTRODUCTION

## 1.1 Climate change and greenhouse gas inventories

In August 1997 the Republic of South Africa joined the vast majority of countries in the international community in ratifying the United Nations Framework Convention on Climate Change (UNFCCC). Since the ratification of the convention, the government of South Africa has strived to meet the fundamental objective of the UNFCCC: to achieve stabilisation of the concentrations of the greenhouse gases in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, while allowing ecosystems to adapt, not threatening food security and enabling economic development to proceed in a sustainable manner. In July 2002, five years after ratification of the convention, the South African government signed the Kyoto Protocol.

In order to fulfil its obligations under the UNFCCC, including those under Articles 4.1 and 12.1, South Africa embarked upon a number of projects related to a broad understanding of issues around climate change, including projects related to climate change capacity building. The first major national climate change project under the umbrella of commitment to the UNFCCC was the Enabling Activities for First National Communication to the UNFCCC, funded by the Global Environmental Facility (GEF) through the United Nations Environmental Programme (UNEP). The project was implemented under the auspices of the Department of Environmental Affairs and Tourism (DEAT) of South Africa. The Enabling Activities project led to the submission of South Africa's first national communication to the Conference of Parties (COP), the Initial National Communication (INC). Amongst other things, the first national communication reported on national inventories of greenhouse gases for 1990 and 1994.

The current report presents the third national estimation of greenhouse gases, using year 2000 as the base. It will eventually be included as a chapter in the Second National Communication to the Conference of Parties.

Decision 3/CP.5 of the COP resolved that all Parties listed in Annex I of the UNFCCC would be required to prepare and submit an annual National Inventory Report (NIR) containing detailed and complete information on the entire process of preparation of greenhouse gas inventories. The purpose of such reports is to ensure the transparency, consistency and comparability of inventories and support the independent review process. The NIR reports will facilitate a continuous and smooth process in responding to reporting requirements of the UNFCCC under Articles 4.1(a) and 12.1(a). Regular inventories would also provide a solid information base for any future commitments under the Convention and any other associated protocols. South Africa, although a non-Annex 1 country, took the initiative to prepare a National Inventory Report as part of the institutionalization of its national communication process.

South Africa is submitting this inventory report both for the Convention process and for public consumption, together with inventory tables for 2000. The GHG inventories have been prepared using to a large extent the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. As the inventory software accompanying the 2006 IPCC Guidelines was not ready when the inventories were prepared, the GHG inventory team used appropriately adjusted computation spreadsheets based on the software that accompanied the 1996 IPCC Guidelines for most computations. Tables in the report have been prepared in accordance with the UNFCCC guidelines based on the IPCC format.

Chapter 1 of the report gives a general background on climate change and on greenhouse gas inventories, as well as a general overview of South Africa's reporting obligations and a description of the institutional framework for inventory preparation in South Africa.

Chapter 2 provides a general overview of emissions of greenhouse gases and their storage in sinks.

Chapters 3 to 9 provide detailed information about the main groups of emissions sources and sinks in South Africa.

### **1.1.1 The greenhouse effect**

Scientists worldwide have come to the conclusion that human-induced emissions of greenhouse gases are mainly responsible for the earth's current above-normal changes in weather conditions. Greenhouse gases, which include carbon dioxide (CO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O), methane (CH<sub>4</sub>), ozone, and water vapour, allow the energy-rich radiation falling onto the earth from the sun to pass through them almost unhindered, while at the same time they partially absorb the long-wave radiation emitted by the heated earth. Greenhouse gases then re-emit the absorbed energy in the form of infrared radiation, which in turn warms the earth's surface. The intensity of this warming depends on the concentration of the GHGs in the atmosphere.

Greenhouse gases play an important natural role in life on earth. Without greenhouse gases, life on our planet would not be possible, as the earth's average temperature would be about -20°C instead of the approximately 15°C that makes the earth habitable by both animal and plant species.

### **1.1.2 Climate change**

The industrial revolution of the 19<sup>th</sup> century marked a significant change in the concentration of carbon dioxide and other greenhouse gases in the atmosphere. We now live in a world where concentrations of CO<sub>2</sub> have risen by approximately 30% compared with levels in pre-industrial times, whilst those of methane (CH<sub>4</sub>) have increased by 145% and those of nitrous oxide (N<sub>2</sub>O) by 15%. To compound the problem, a number of new substances such as chlorofluorocarbons (CFCs), halons, perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF<sub>6</sub>) have entered the atmospheric equation. These gases do not occur in nature and are generated almost exclusively by anthropogenic activities.

In its most recent Fourth Assessment Report (AR4) of 2007, the IPCC re-emphasized the increase in average global air temperature over the past hundred years. It showed that the preceding few years were amongst the warmest of the last hundred years.

### **1.1.3 Reduction obligations and reporting of greenhouse gases**

The Rio de Janeiro Summit of 1992 led to the establishment of the United Nations Framework Convention on Climate Change (UNFCCC), which was adopted by most nations of the world. Since then there has been a multilateral effort to reduce the concentration of greenhouse gases in the atmosphere.

The Articles of the Convention acknowledge the different circumstances of countries seeking to address the twin challenges of climate change – mitigation or greenhouse gas reduction, and adaptation, or response to the impacts of climate change. Parties to the Convention have been divided into two main groups. The first principle in the Convention requires Parties to protect the climate system ... on the basis of "equity and common but differentiated responsibilities and respective capabilities", drawing the conclusion that developed countries should "take the lead in combating climate change and the adverse effects thereof" (Art 3.1). The countries listed in Annex I are required to submit annual inventories of greenhouse gases each year, a requirement

which does not apply directly to Non-Annex 1 countries like South Africa. However, Article 4.1(a) of the UNFCCC requires all parties to develop, periodically update, publish and make available to the Conference of Parties, national inventories of anthropogenic emissions by sources, and removals by sinks of all greenhouse gases, using comparable methodologies to be agreed upon by the Conference of the Parties.

Some of the Annex 1 parties are also required, under the Kyoto Protocol, to reduce their emissions to levels comparable to year 1990 by specific amounts. South Africa, though a signatory of the Kyoto Protocol, does not fall directly under this obligation. However, South Africa has indicated its willingness to take nationally appropriate mitigation actions, the implications of which would be considerable for many organisations and companies within South Africa. Cabinet has indicated that South Africa's emissions should (2002)). Cabinet stated clearly that emissions need to peak (at the latest by 2020-25), then plateau for a decade or so, and then decline. The South African government as a whole indicated at the 2009 Climate Change Summit that it seeks long-term change, making a major transition from an energy-intensive to a low-carbon economy. The Summit included participants from a wide range of stakeholder groups and the conference statement reconfirmed that the process will "culminate in the introduction of legislative, regulatory and fiscal packages to give effect to the strategic direction and policy by 2012" (Climate Summit 2009).

#### **1.1.4 Country background**

In 2000 South Africa had a population of about 43 686 million, of which some 22,7 million were women. Its economy hinges to a large extent on energy production and use, with energy-intensive sectors such as mining, minerals processing, a coal-based electricity and liquid fuel supply sector and energy-intensive beneficiation. Fossil fuels dominate the energy sector, with coal providing 75% of the fossil fuel demand and accounting for more than 90% of electricity generation.

The land area of South Africa is 1.2 million square kilometres. It borders a wide expanse of both the Indian and Atlantic oceans, with a combined coastline stretch of 3 751 kilometres. Its climate is generally warm and dry, with winter temperatures seldom falling below 0°C, and maximum summer temperatures above 35°C in many places.

#### **1.1.5 The institutional framework for inventory preparation in South Africa**

Because activities relevant to the UNFCCC Convention fall within the responsibility of many different government departments and at all levels of government, South Africa has set up a National Climate Change Committee (NCCC). The NCCC is designed to be an advisory body to the Minister of Environmental Affairs and Tourism and to guide the government on issues of climate change, at both international and national levels. It includes representatives from relevant government departments, business and industry, universities and research institutions, mining, labour, community based organisations (CBOs) and non-governmental organisations (NGOs).

To avoid fragmented administration, the government has designated the Department of Environmental Affairs and Tourism (DEAT) to be the lead department responsible for coordination and the implementation of South Africa's commitments under the Convention. DEAT is currently in the process of establishing a national system to deal with climate change obligations. This process will not be limited to preparation of GHG inventories, but will manage all relevant climate change information for both internal and external reporting, as well as for data collection. The national system is based on the "Single National Entity" (SNE) concept, and will be hosted at the Department of Environmental Affairs and Tourism. It will function as a network of all government departments, research institutes, associations and other organisations that can help improve the inventory calculations.

## 1.2 Data sources and inventory methodology

The selection of calculation methods for estimating GHG emissions can have significant effects on total emissions reported. For this reason it was decided at the beginning of the 2000 inventory process that the 2006 IPCC Guidelines would be used, in order to enhance accuracy and transparency of the inventory. The decision “trees” in the IPCC Guidelines provide guidance on what methods are to be used for the various source categories. In general, the selection of method depends on whether or not the source category is considered a key category. Depending on the level of disaggregation of available data, the methods of higher tier levels of emission estimation usually provide more accurate results than the methods of lower tier levels.

Although a simple analysis of key categories was undertaken for the 1994 inventory, data disaggregation was a key challenge in using higher tier levels for most of the sectors. It was also difficult to make an informative review of data sources because most of the data were available at national aggregated levels rather than point sources. Questionnaires were prepared for data providers to be able to submit information on data quality, but very few data providers were able to respond to questions of data quality. However, in many cases, the data sources used have been relied on for a number of years, for example, the national energy balance.

### 1.2.1 Data sources and data collection

Data collection and documentation was the responsibility of individual experts in each sector. Data came mostly from government institutions, local and international literature and to a smaller extent from individual plants and professional associations. Whether data were collected from official statistics or industry associations, the expert would still be responsible for quality checks by following up on data sources. One way of ensuring consistency was to collect data one year before and one year after the baseline year 2000. For AFOLU and Waste sectors the data was collected for much longer periods, sometimes for decades. This enabled experts to spot trends and identify significant anomalies. Collection of temporal data also enabled uncertainty analysis to be carried out.

Data access remains a challenging issue in South Africa, and consequently it cannot be said that the 2000 inventory is complete. Some source or sink categories might have been omitted due to lack of appropriate and relevant data. Examples include the electronics industry, the health sector, and some industrial production activities. A future system of regular data provision has been planned and is currently under development.

#### 1.2.1.1 Energy

The most important source of data for the energy sector was the Department of Energy (DME). Data was obtained by way of publications and website links, in particular the energy balance published as the *Digest of South African Energy Statistics*. The South African energy balance provided in the *Digest* provides an overview of the links within South Africa’s energy sector, giving breakdowns in accordance with fuels and source categories. The energy balance receives data from a wide range of sources, but efforts to follow up on these data sources were not successful.

Other energy data were obtained from the South African Petroleum Association (SAPIA) and (for coal mining emissions) from the Chamber of Mines. SAPIA data, published in SAPIA’s annual reports, were used to supplement energy balance data on transport fuel and crude production in South Africa.

Coal-industry statistics in South Africa are prepared by the Department of Minerals and Energy, and are available on the DME website. The DME coal statistics were used for data quality checks against data obtained from the Chamber of Mines.

#### ***1.2.1.2 Industrial processes and other product use***

The main sources of data for the Industrial Processes and Other Product Use (IPPU) sector were industry associations, the Department of Minerals and Energy (DME), and Statistics South Africa. In a few cases data were obtained by direct meetings with plant personnel and/or e-mail communications.

#### ***1.2.1.3 Agriculture, Forestry, and Land use (AFOLU)***

Livestock data for estimation of agriculture sector emission estimates were obtained from the United Nations Food Organization (FAO) website (<http://faostat.fao.org/site/605/default.aspx>). These data were verified using commercial farming data from the South African Department of Agriculture (DoA 2006).

Various sources of data were used for GHG emissions and sinks. Forest land data were obtained from Forestry South Africa (FSA), which keeps annual statistical data on plantations in South Africa dating back to the 1970s. Grassland areas data were obtained from the literature as well as from National Land Cover (NLC) datasets.

Wetlands data were obtained from the Department of Land Affairs (DLA) Chief Directorate of Surveys and Mapping (CDSM) and the Department of Water Affairs and Forestry (DWAF) and data on settlements were extracted from NLC datasets.

Data for biomass burning were obtained from satellite data, FSA and various literature sources.

#### ***1.2.1.4 Waste***

Data on waste generation were based on the annual South Africa population statistics, which were adopted from the United Nations Statistics web-link (<http://esa.un.org/unpp>). The UN estimates were found to be more suitable than the Statistics South Africa values, as they consistently covered the entire period under investigation.

### **1.2.2 Inventory methodology**

The methodology for estimating GHG emissions can have a significant effect on the figures for total emissions. The Intergovernmental Panel on Climate Change published guidelines for the choice of method in 1996 and again in 2006. For this 2000 national inventory, it was decided to use the 2006 IPCC Guidelines to enhance accuracy and transparency. The 2006 IPCC Guidelines include several changes made since the 1996 IPCC Guidelines. For example, the number of inventory sectors has been reduced to four, which was made possible by combining agriculture, forestry and land use change into one sector. The four inventory sectors are now:

- Energy
- Industrial processes and product use (IPPU)
- Agriculture, forestry and land use (AFOLU)
- Waste

The 2006 IPCC Guidelines provide more updated, comprehensive and holistic methodologies than 1996 IPCC Guidelines.

In accordance with the UNFCCC reporting requirements, the Global Warming Potentials (GWP) used for calculation of the CO<sub>2</sub>equivalent emissions were those of the IPCC Second Assessment Report (SAR), as shown in Table 1-1

Once data had been received and the necessary checks and units conversions (which sometimes involved further consultation with data sources) had been made, the emissions were calculated by inventory experts based on the following principle:

$$\text{Emission} = \text{activity rate} \times \text{emission factor}$$

As required by the 2006 IPCC Guidelines for AFOLU and Waste sectors more complex calculations or models were used.

In each sector, the relevant expert was responsible for quality control and checks. Once the national system has been established, this role can be undertaken at the Single Entity level.

The most accurate emission factors are those from national sources. Where national country-specific factors are not available, emission factors are taken from international sources, the latter being essentially the IPCC default factors. IPCC default factors were used predominantly in sectors for which disaggregated data could not be obtained and consequently where a Tier 1 approach had to be used, e.g. the energy sector. More detailed pertinent information is presented in the descriptions of methods for the various sectors and source categories.

Conversion of greenhouse gases into CO<sub>2</sub> equivalents was made on the basis of decision FCCC/CP/2002/8. This inventory gathered data on the following gases: CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub> were only recorded in the production of aluminium. The Global Warming Potentials (GWP) used are those published in the Second Assessment Report (SAR) and listed in Table 1-1, even though the Third Assessment Report has updated some of them.

**TABLE 1.1: GLOBAL WARMING POTENTIAL OF GREENHOUSE GASES**

Greenhouse gas	Chemical formula	1995 IPCC GWP
Carbon dioxide	CO <sub>2</sub>	1
Methane	CH <sub>4</sub>	21
Nitrous oxide	N <sub>2</sub> O	310
<b>Hydrofluorocarbons (HFCs)</b>		
HFC-23	CHF <sub>3</sub>	11 700
HFC-32	CH <sub>2</sub> F <sub>2</sub>	650
HFC-41	CH <sub>2</sub> F	150
HFC-43	C <sub>5</sub> H <sub>2</sub> F <sub>10</sub>	1 300
<b>Perfluorocarbons (PFCs)</b>		
Perfluoromethane	CF <sub>4</sub>	6 500
Perfluoroethane	C <sub>2</sub> F <sub>6</sub>	9 200
Perfluoropropane	C <sub>3</sub> F <sub>8</sub>	7 000
Perfluorobutane	C <sub>4</sub> F <sub>10</sub>	7 000
Perfluorocyclobutane	c-C <sub>4</sub> F <sub>8</sub>	8 700
Perfluoropentane	C <sub>5</sub> F <sub>12</sub>	7 500
Perfluorohexane	C <sub>6</sub> F <sub>14</sub>	7 400
<b>Sulphur hexafluoride</b>		
Sulphur hexafluoride	SF <sub>6</sub>	23 900

Source: FCCC/CP/2002/8, p.15

### 1.2.3 Report preparation

The following steps were used to prepare this national inventory:

- Collection of activity and calculation of equivalent emissions for different GHG gases, according to 2006 IPCC Guidelines

- Calculation of CO<sub>2</sub> equivalents for the greenhouse-gas emissions, using methodologies as described above
- Compilation of submitted reports from experts to form a draft national inventory report (NIR)
- Work progress review by Project Management Team
- Submission of the draft inventory report to the GHG Project Steering Committee for review
- Finalization of the report
- Final review by the GHG Project Steering Committee
- Hand over of final report to DEAT for inclusion in the second national communication and archiving

Due to the unavailability of 2006 IPCC GHG software, it was not possible for a number of the reporting tables to be generated automatically, and it was thus necessary to create most of the tables manually. Further, it was necessary in some cases to perform manual aggregations as these were not carried out automatically by the software.

### **1.3 Brief description of key categories**

Key categories refer to the most significant emission sources in the country, those which contribute about 95% of the total GHG emissions. Key category analysis can be made by using two methods, level and trend analysis. If only one inventory year emissions is available, only level key category analysis can be done. South Africa's key category analysis was done using 1990 and 1994 emission estimates, and both level and trend analysis of key categories were made, with results shown in Table 1-2 and 1-3. The shaded portions of the tables represent sources adding up cumulatively to the 95% level. Table 1-2 is sorted by contribution to trend, while Table 1-3 is sorted by contribution to level (both from highest to lowest).

**TABLE 1-2: LEVEL AND TREND KEY CATEGORY ANALYSIS (WITHOUT LULUCF)**

A Category	B Direct GHGs	1990	1994	Assessment				
		C Base year estimate (Gg CO <sub>2</sub> eq)	D Current year estimate (Gg O <sub>2</sub> eq)	E Level Assess- ment	F % Contri- bution to level	G Trend Assess- ment	H % Contri- bution to trend	Cumu- lative
1A2a Iron and steel energy	CO <sub>2</sub>	186.79	19 194.98	0.051	5.1%	0.0480	12.7%	12.7%
1A1c Manufacture of solid fuels and other energy industries	CO <sub>2</sub>	27 270.13	10 551.52	0.028	2.8%	0.0451	11.9%	24.6%
1A4c Others Agriculture/forestry/fishing	CO <sub>2</sub>	2 957.73	15 953.54	0.042	4.2%	0.0325	8.6%	33.2%
1A2c Chemicals	CO <sub>2</sub>	3 496.93	16 240.98	0.043	4.3%	0.0318	8.4%	41.6%
1A4a Others Commercial/institutional	CO <sub>2</sub>	11 496.81	780.26	0.002	0.2%	0.0283	7.5%	49.1%
1A1a Public electricity and heat production	CO <sub>2</sub>	136 731.50	152 505.12	0.402	40.2%	0.0252	6.7%	55.7%
1A2f Others	CO <sub>2</sub>	19 517.35	10 554.73	0.028	2.8%	0.0247	6.5%	62.3%
1A3d Navigation	CO <sub>2</sub>	11.11	8 627.07	0.023	2.3%	0.0218	5.7%	68.0%
2C1 Iron and steel production	CO <sub>2</sub>	10 011.14	18 034.60	0.047	4.7%	0.0192	5.1%	73.1%
6A Solid waste disposal	CH <sub>4</sub>	7 529.76	15 156.54	0.040	4.0%	0.0185	4.9%	78.0%
1B2a Oil fugitive	CH <sub>4</sub>	4 341.12	13.26	0.000	0.0%	0.0114	3.0%	81.0%
1B1a Coal mining fugitive	CH <sub>4</sub>	9 805.53	6 654.90	0.018	1.8%	0.0090	2.4%	83.4%
4D Agricultural soils	N <sub>2</sub> O	17 657.60	15 515.50	0.041	4.1%	0.0073	1.9%	85.3%
4A Enteric fermentation	CH <sub>4</sub>	19 247.55	17 724.21	0.047	4.7%	0.0059	1.6%	86.8%
1A3a Civil aviation	CO <sub>2</sub>	999.43	2 961.08	0.008	0.8%	0.0048	1.3%	88.1%
2B2 Nitric acid production	N <sub>2</sub> O	765.70	2 253.70	0.006	0.6%	0.0037	1.0%	89.1%
1A4b Others Residential	CH <sub>4</sub>	1 387.26	12.61	0.000	0.0%	0.0036	1.0%	90.1%
1A2b Non ferrous metals energy	CO <sub>2</sub>	19.13	1 450.37	0.004	0.4%	0.0036	1.0%	91.0%
1A5 Others Mining and Quarrying	CO <sub>2</sub>	959.56	2 273.35	0.006	0.6%	0.0032	0.8%	91.9%
4E Prescribed savannah burning	CH <sub>4</sub>	1 306.20	265.23	0.001	0.1%	0.0028	0.7%	92.6%
1A3b Road transport	CO <sub>2</sub>	29 579.04	29 816.63	0.078	7.8%	0.0026	0.7%	93.3%
2B1 Ammonia production	CO <sub>2</sub>	2 688.53	1 867.08	0.005	0.5%	0.0024	0.6%	93.9%
1A3c Railways	N <sub>2</sub> O	930.00	153.95	0.000	0.0%	0.0021	0.5%	94.4%
1A2d Pulp, paper and print	CO <sub>2</sub>	2 196.20	1 583.89	0.004	0.4%	0.0018	0.5%	94.9%
2A1 Cement production	CO <sub>2</sub>	4 457.12	3 952.22	0.010	1.0%	0.0018	0.5%	95.4%
1A4b Others Residential	CO <sub>2</sub>	7 761.27	7 397.49	0.019	1.9%	0.0017	0.5%	95.8%
1A4b Others Residential	N <sub>2</sub> O	654.10	25.73	0.000	0.0%	0.0017	0.4%	96.3%

**TABLE 1-3: N-LEVEL KEY CATEGORY ANALYSIS (WITHOUT LULUCF)**

A Category	B Direct GHGs	1990	1994	Assessment		
		C Base year estimate (Gg CO <sub>2</sub> eq)	D Current year estimate (Gg CO <sub>2</sub> eq)	E Level assess- ment	F % Contri- bution to level	G Cumula- tive
1A1a Public electricity and heat production	CO <sub>2</sub>	136 731.50	152 505.12	0.402	40.2%	40.2%
1A3b Road transport	CO <sub>2</sub>	29 579.04	29 816.63	0.078	7.8%	48.0%
1A2a Iron and steel energy	CO <sub>2</sub>	186.79	19 194.98	0.051	5.1%	53.1%
2C1 Iron and steel production	CO <sub>2</sub>	10 011.14	18 034.60	0.047	4.7%	57.8%
4A Enteric fermentation	CH <sub>4</sub>	19 247.55	17 724.21	0.047	4.7%	62.5%
1A2c Chemicals	CO <sub>2</sub>	3 496.93	16 240.98	0.043	4.3%	66.7%
1A4c Others Agriculture/forestry/fishing	CO <sub>2</sub>	2 957.73	15 953.54	0.042	4.2%	70.9%
4D Agricultural soils	N <sub>2</sub> O	17 657.60	15 515.50	0.041	4.1%	75.0%
6A Solid waste disposal	CH <sub>4</sub>	7 529.76	15 156.54	0.040	4.0%	79.0%
1A2f Others	CO <sub>2</sub>	19 517.35	10 554.73	0.028	2.8%	81.8%
1A1c Manufacture of solid fuels and other energy industries	CO <sub>2</sub>	27 270.13	10 551.52	0.028	2.8%	84.6%
1A3d Navigation	CO <sub>2</sub>	11.11	8 627.07	0.023	2.3%	86.8%
1A4b Others Residential	CO <sub>2</sub>	7 761.27	7 397.49	0.019	1.9%	88.8%
1B1a Coal mining fugitive	CH <sub>4</sub>	9 805.53	6 654.90	0.018	1.8%	90.5%
1A1b Petroleum refining	CO <sub>2</sub>	3 960.35	4 760.00	0.013	1.3%	91.8%
2A1 Cement production	CO <sub>2</sub>	4 457.12	3 952.22	0.010	1.0%	92.8%
1A3a Civil aviation	CO <sub>2</sub>	999.43	2 961.08	0.008	0.8%	93.6%
2C2 Ferroalloys production	CO <sub>2</sub>	2 698.17	2 539.81	0.007	0.7%	94.3%
1A5 Others Mining and Quarrying	CO <sub>2</sub>	959.56	2 273.35	0.006	0.6%	94.9%
2B2 Nitric acid production	N <sub>2</sub> O	765.70	2 253.70	0.006	0.6%	95.5%
1A2e Food processing, beverage & tobacco	CO <sub>2</sub>	0.00	1 888.04	0.005	0.5%	96.0%
2B1 Ammonia production	CO <sub>2</sub>	2 688.53	1 867.08	0.005	0.5%	96.5%
4B Manure management	CH <sub>4</sub>	1 751.82	1 647.87	0.004	0.4%	96.9%
1A2d Pulp, paper and print	CO <sub>2</sub>	2 196.20	1 583.89	0.004	0.4%	97.3%
1A2b Non ferrous metals energy	CO <sub>2</sub>	19.13	1 450.37	0.004	0.4%	97.7%

Using level key category analysis, the most significant sources of greenhouse emissions in South Africa were electricity generation, road transport, and consumption of energy in iron and steel production.

## **1.4 Quality control and quality assurance**

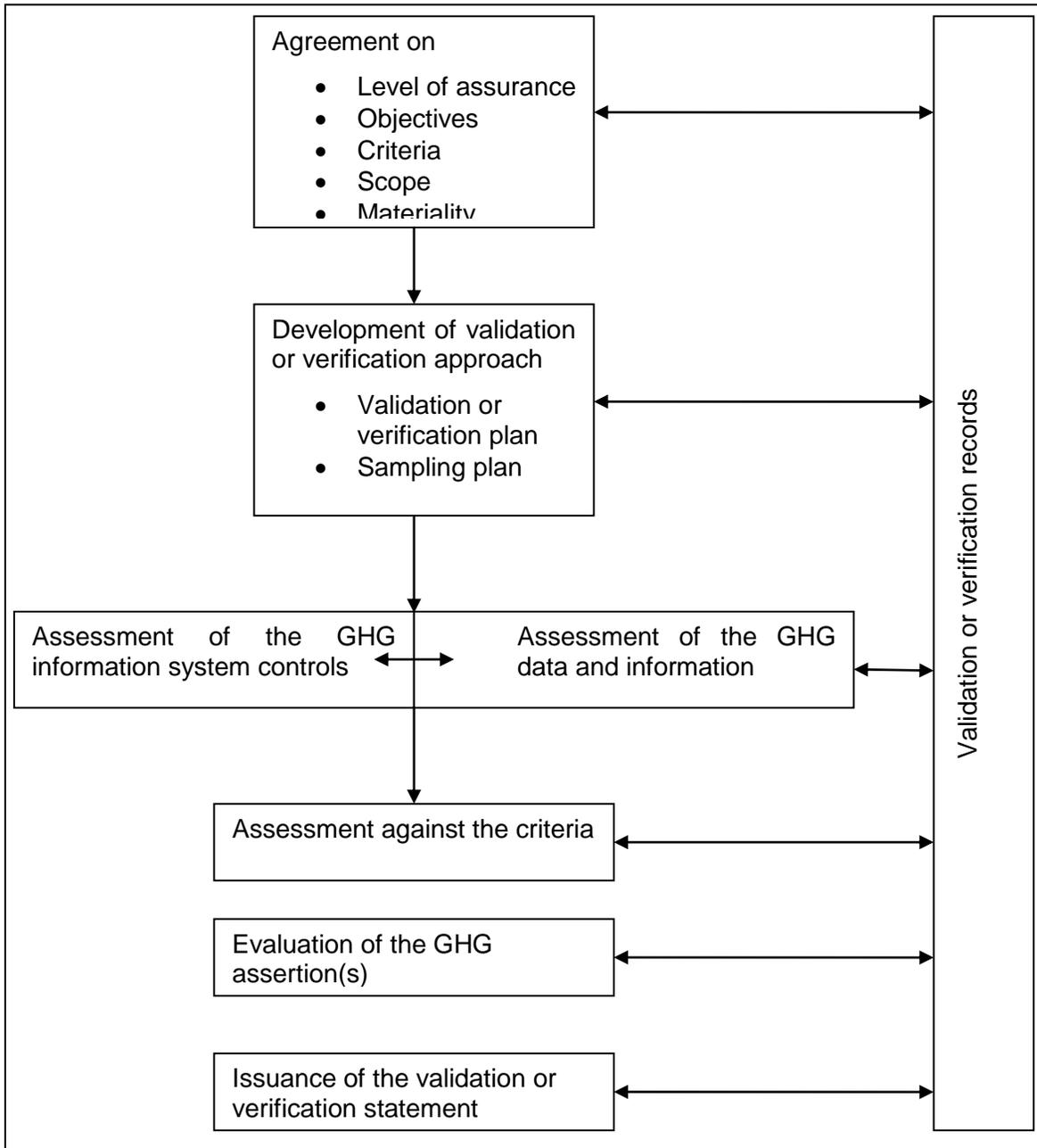
In accordance with IPCC requirements for national GHG inventory preparation, the necessary quality control and quality assurance (QC/QA) measures for emissions reporting should be summarised in a QC/QA plan. The primary purpose of a QC/QA plan is to organise, plan and monitor QC/QA measures.

The basic requirements of quality control and quality assurance measures for national GHG inventories are defined in the 2006 IPCC Guidelines, Vol. 1, Chapter 6. A QA/QC verification system contributes to the objectives of good practice in inventory development, namely to improve transparency, consistency, comparability, completeness, and accuracy of national greenhouse gas inventories. The 2006 IPCC Guidelines are emphatic that QA/QC and verification activities should be integral parts of the inventory process.

In addition to the IPCC Guidelines, South Africa has developed its own validation and verification procedure for “GHG assertions”. A GHG assertion is defined as a declaration or factual and objective statement made by a person or persons responsible for the greenhouse gas inventory and the supporting GHG information. It is a standard adopted from the International Organization for Standardization (ISO) series programme for data documentation and audits as part of a quality management system.

In the South African context, QA/QC measures are defined by Part 3 of the South African National Standard for Greenhouse Gases, SANS 14064-3:2006 (Specification with guidance for the validation and verification of greenhouse gas assertions). This standard specifies the requirements for selecting GHG validators/verifiers, establishing the level of assurance, objectives, criteria and scope, determining the validation/verification approach, assessing GHG data, information, information systems and controls, evaluating assertions, and preparing validation/verification statements.

The South African GHG validation and verification standard specifies a process for completing a validation or verification of GHG information, as shown in Figure 1-1.



**FIGURE 1-1: SOUTH AFRICA GHG ASSERTION VALIDATION AND VERIFICATION PROCESS (FROM ISO STANDARD)**

South Africa is in the process of preparing a "Manual for preparation of national GHG inventory", which will include a QA/QC plan.

For the 2000 inventory, the systematic evaluation of all inventory data with regard to their quality in 2000 was not carried out as a specific project, but rather on the basis of expert cross-checking and trend analysis over a period of three years. For quality assurance, external reviews are to be performed.

## 1.5 Uncertainty evaluation

Uncertainty analysis is regarded by the IPCC Guidelines as an essential element of any complete GHG inventory. It is a necessary step for identifying areas of further improvement in the inventory preparation process, as well as for selecting methods and carrying out recalculations for previous inventories. Its objective is to minimise uncertainties to the greatest possible degree.

Uncertainty analysis for the South Africa inventory involved quantifying the uncertainties for all source categories and sinks. The analysis involved determination a probability-density function for a number of parameters, using approaches and values provided in the 2006 IPCC Guidelines. Thus the uncertainty analysis included a statistical evaluation of individual data items, and experts' assessments as guided by the IPCC Guidelines.

In general, there are two methods for determining uncertainties. The Tier 1 method combines, in a simple way, the uncertainties in activity rates and emission factors for each source category and greenhouse gas. It then aggregates these uncertainties to obtain the total uncertainty for the inventory.

The Tier 2 method is the same in principle, but it goes further by considering the distribution function for each uncertainty, and then carries out aggregation using Monte Carlo simulation.

Given the absence of quantitative, and in some cases even qualitative uncertainty data, it is not possible to make an overall statement of uncertainty. It is recommended that it be necessary to add to the rigour of descriptive uncertainty in the compilation of future inventories. More detailed data collection is required to speculate about levels of quantitative uncertainty. In embarking on the compilation of the inventory it is necessary to bear uncertainty in mind prior to embarking on the data gathering, so that uncertainty analysis can be performed consistently and in line with IPCC Guidelines.

### 1.5.1 Procedure for uncertainty analysis

Chapter 3 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories describes the need and methodology for estimating and reporting uncertainties associated with annual estimates of emissions and removals, including emission and removal trends over time. Broadly speaking, the approach involves combining the category uncertainties into estimates of uncertainty for total national net emissions and their associated trends.

The reporting of uncertainties requires a complete understanding of the processes of compiling the inventory, so that potential sources of inaccuracy can be qualified and where possible quantified. The aim of this reporting is to suggest methods of compiling uncertainty estimates and suggest approaches that would enable the prioritisation of national efforts to reduce future uncertainties. Such reporting will serve to guide methodological choices in future inventories to improve accuracy, reduce bias, and transparently report on the presence and levels of uncertainty.

The following seven broad ways of reducing uncertainty can be used to improve the quality of data:

- Improving conceptualisation
- Improving models
- Improving representativeness
- Using more precise measurement methods
- Collecting more measured data
- Eliminating known risk of bias
- Improving state of knowledge

### 1.5.2 Results of uncertainty assessment

It should be noted that the IPCC 2008 set of compilation spreadsheets has the capability to include the uncertainty calculations.

In chapters 3 to 6 of this report), the default IPCC uncertainty values for conversion of activity levels to emissions or removals were quoted in the sections on quality control, but not incorporated into the final reporting through any calculation procedure. It is recommended that as a bare minimum, future reporting should utilise the uncertainty calculation spreadsheet to calculate:

- a) the trend uncertainties between base year and current year
- b) the combined uncertainty of activity data uncertainty (where available) and emission factor uncertainty (using IPCC defaults which can be found in the relevant sections of the IPCC Guidelines – sectoral Vols 2 to 5)

In this report, the sources of data uncertainty have been made clear, and many of the assumptions made in the compilation have been reported. Some examples of the assumptions that could lead to biases, inaccuracies or lack of precision in the compilation are:

- a) Extrapolation uncertainty in the case of emissions resulting from soda ash use. The extrapolation was based on an annual percentage growth in the use of soda ash.
- b) Activity levels in the Energy sector and Industrial Processes and Product Use sector have been sourced from a variety of reporting entities (DME, SAPIA, and individual companies) leading to some conflicting data in certain instances.
- c) Conversion level uncertainties through energy conversion of carriers with variable calorific values and combustion uncertainty. The IPCC provides tables with guidelines for the suggested lower and upper values of conversion factors for all of the compiled emission and removal processes.
- d) Missing information on activity levels, for example in the Pulp and Paper Industries.
- e) The inconsistency between SAPIA and DME with regard to diesel and petrol final use needs to be resolved. For this report, the higher value was taken. In addition, the road transport emission conversion factor was applied uniformly to the total figure.
- f) Regarding coal type, the proportions of bituminous and non-bituminous coal are unknown. For the current inventory it has been assumed that all coal used for electricity generation is sub-bituminous, with all other uses classified as bituminous.
- g) There is a data transparency issue with regard to fugitive emissions. This is discussed in the following section.

**TABLE 1-4: OVERALL UNCERTAINTY FIGURES**

Default uncertainty estimates for data and emission factors			
Sector	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
Public Power, co-generation and district heating		50-150%	Order of magnitude, i.e. an uncertainty range from one-tenth mean value to ten times mean value
Civil aviation emissions	±5 %	-57% to +100%.	-57% to +100%.
Transport emissions	Less than 2%		

Default uncertainty estimates for data and emission factors			
Sector	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
Coal fugitive emissions		Factor of 3 greater or lower for surface mines	
Cement production emissions	Range of 2% to 7% if a 95% clinker inclusion in portland cement is assumed.		
Limestone and dolomite use	Uncertainty of the activity data in the range of 1% to 3%.		
Other land converted to forest land	-11% to +3%.		
Grasslands	Up to 50%		
Wetlands		More than 50% for countries where national databases are not available	
Total municipal solid waste		30% is a typical value for countries which collect waste generation data on regular basis. For countries with poor quality data: more than a factor of two.	
Fraction of MSWT sent to SWDS		For countries with poor quality data: more than a factor of two	
Waste composition – bulk waste used as no data on waste composition was available for the study period		For countries with poor quality data: more than a factor of two	
Carbon decomposed (DOCf)-selected IPCC default value =0.5		± 20%	
Methane correction factor (MCF) – selected value=1		-10%, +0%	
Fraction of CH <sub>4</sub> in generated Landfill Gas (F)- selected IPCC default value: = 0.5		±5%	

Default uncertainty estimates for data and emission factors			
Sector	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
Methane Recovery (R) –selected value =0		The uncertainty range depends on how the amounts of CH <sub>4</sub> recovered and flared or utilised are estimated: ± 50% if metering is not in place.	
Oxidation Factor (OX) ) –selected value =0		OX should be included in the uncertainty analysis if a value other than zero has been used for OX itself	
Domestic waste water N <sub>2</sub> O emissions			
Emission factor, (kg N <sub>2</sub> O-N/kg –N)			0.0005 - 0.25
Emission factor, (g N <sub>2</sub> O/person/year)			2 – 8
Annual per capita protein consumption			± 10 %
Fraction of nitrogen in protein (kg N/kg protein)			0.15 - 0.17
Degree of utilization of large WWT plants			± 20 %
Factor to adjust for non-consumed protein			1.0 – 1.5
Factor to allow for co-discharge of industrial nitrogen into sewers			1.0 - 1.5

## 2 TRENDS IN GREENHOUSE GAS EMISSIONS

Table 2-1 shows the contributions of individual sectors and changes to the total greenhouse gas emissions for the years 1990, 1994 and 2000. In total, emissions of greenhouse gases, calculated as CO<sub>2</sub>-equivalent emissions, were up by more than 25% compared to the base year of 1990 (347,346 Gg CO<sub>2</sub>e) to a level of 436,357 Gg CO<sub>2</sub>e in 2000. Against 1994 levels, this represents an increase of 14.8%. The general picture shows both an increase and decrease of emissions between 1990 and 2000, depending on the sector. Agriculture and waste sectors showed significant decrease of emissions from 1990, whereas industrial processes and other product use (IPPU) emissions showed an increase of above 100% from 1990 to 2000. Energy sector emissions showed an increasing trend from 1990 to 2000, although the increase from 1994 to 2000 was half the increase from 1990 to 1994.

Table 2-2 shows the emissions and changes in emissions of the major greenhouse gases for the years 1990, 1994 and 2000. The general trend is one of increasing emissions for all types of greenhouse gases, without any decreases. Methane showed the highest increase, of more than 76% from 1990 to 2000. Nitrous oxide showed the lowest increase from 1990 to 2000, an increase of 2.7%.

**TABLE 2-1: SECTOR EMISSION TRENDS AND PERCENTAGE CHANGES FROM 1990**

Sector	GHG emissions CO <sub>2</sub> e Gg							
	1990 (CO <sub>2</sub> e Gg)	% of total	1994 (CO <sub>2</sub> e Gg)	% of total	2000 (CO <sub>2</sub> e Gg)	% of total	2000 % change from 1994	2000 % change from 1990
Energy	260 886	75.1	297 564	78.3	344 106	78.9	15.6	31.9
Industrial processes and product use	30 792	8.9	30 386	8.0	61 469	14.1	102.3	99.6
Agriculture	40 474	11.6	35 462	9.3	21 289	4.9	-40.0	-47.4
Waste	15 194	4.4	16 430	4.3	9 393	2.1	-42.8	-38.2
Total (without LULUCF)	347 346		379 842		436 257		14.8	25.6

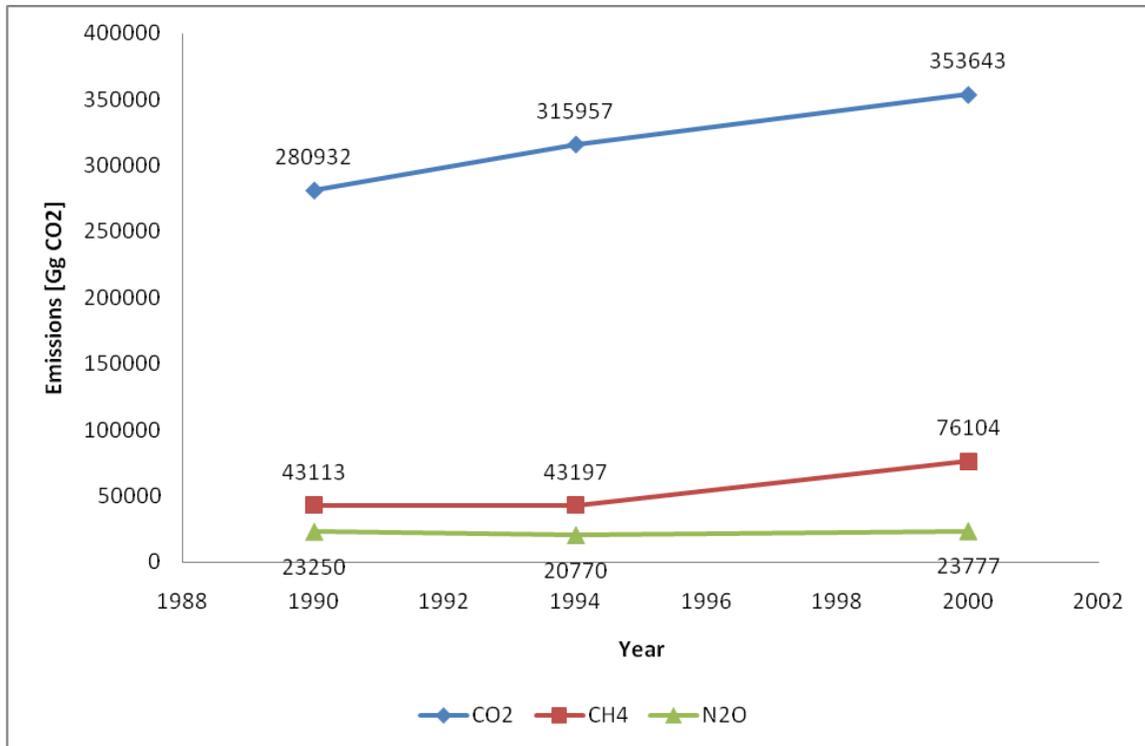
**TABLE 2-2: GHG EMISSIONS TRENDS AND PERCENTAGE CHANGES SINCE 1990**

GHG emissions (CO <sub>2</sub> eGg)	1990 (Gg)	% of total	1994 (Gg)	% of total	2000 (Gg)	% of total	1994 % change from 1990	2000 % change from 1994	2000 % change from 1990
CO <sub>2</sub>	280 932	80.9	315 957	83.2	35 3643	81.1	12.5	11.9	18.6
CH <sub>4</sub>	2 053	12.4	2 057	11.4	3 624	17.2	0.2	76.2	76.5
N <sub>2</sub> O	75	6.7	67	5.4	76.7	1.3	-10.7	14.5	2.7
CF <sub>4</sub>	-		-	-	0.303	0.5		-	-
C <sub>2</sub> F <sub>6</sub>	-		-	-	0.027	0.06		-	-
Totals CO <sub>2</sub> eGg) (without LULUCF)	347 346		379 842		436 257		9.4	14.8	25.6

## 2.1 Analysis of trends

While total GHG emissions clearly increased compared to previous inventories, there was variation in sectors. There are could be a number of reasons behind the sector emission increase or decrease in Table 2-1. One likely reason is the approaches used in compiling the 1990, 1994 and 2000 inventories, because depending on the approach, certain emission sources are defined as being located in different sectors or subsectors. This phenomenon is referred to as a location issue. While a location issue can suggest a false increase or decrease in the emissions of the relevant sectors, it does not affect the overall total emissions. Nevertheless, consistency in how and where emission sources are located in the different sectors is very important in order to accurately interpret sector emission trends.

Given the circumstances affecting sectors, an analysis of trends of emissions of individual greenhouse gases gives a more understandable picture. The emissions trends by gases for the years 1990, 1994 and 2000 is shown in Figure 2-1.



**FIGURE 2-1: EMISSIONS TRENDS BY GAS**

Figure 2-1 shows that emission of the major greenhouse gases increased over the period between 1990 and 2000. This increase can be explained by the higher growth in the South African economy following the democratic elections of 1994. The democratic elections in South Africa opened previously restricted markets outside the borders of the country, and this could have been one of the factors contributing to an increased level of activities that contributed to greenhouse gas emissions. Population growth in South Africa has been at relatively low levels, and is not likely a major driver of GHG emissions.

### 3 ENERGY

For most countries, including South Africa, the energy sector is the largest contributor to greenhouse gas emissions, generating over 90% of all carbon dioxide (CO<sub>2</sub>) emissions.

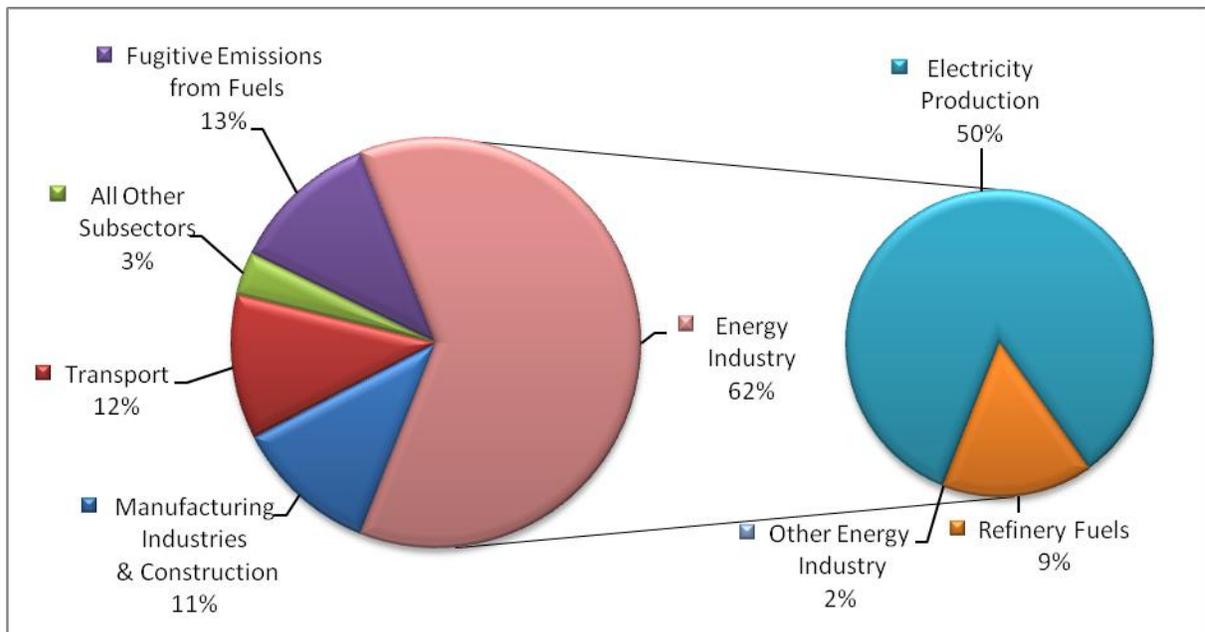
Within South Africa's energy sector, the largest source of emissions is the combustion of fossil fuels. Emission products of fossil fuel combustion processes include CO<sub>2</sub>, nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>).

Using the IPCC 2006 Guidelines, energy sector emissions sources can be classified as:

- Exploitation of primary energy sources, e.g. coal mining
- Conversion of primary energy sources into more useable energy forms, e.g. refineries and power-plants
- Use of fuels in stationary applications, e.g. manufacturing industries
- Use of fuels in mobile applications, e.g. the transport sector

For both the previous (1994) and the current (2000) GHG inventory for South Africa the energy sector was the largest contributor to GHG emissions. In 1994 it contributed 78.3% of total GHG (DEAT 2004), while in 2000, energy sector emissions amounted to 78.9% (344 106 Gg CO<sub>2</sub>eq) of total GHG emissions. Total emissions from the energy sector increased by 15.6% between 1994 and 2000.

The largest contributors to energy sector GHGs in the 2000 inventory were energy industries (by source) and CO<sub>2</sub> (by gas), the latter making up 87.5% of total energy GHG emissions.



**FIGURE 3-1: ENERGY SECTOR EMISSION DISTRIBUTION (2000)**

The rise in emissions in the sector has been driven by the energy industry (i.e. public electricity production and refineries), which accounted for 62% of energy emissions in 2000 – an increase of 26.5% compared to 1994.

Fugitive emissions from fuels (in coal mining and oil and gas activities) accounted for 12% of the sector's emissions in 2000, representing a huge increase of 488.3% compared to 1994. However this very large increase is deceptive, as it was mainly due to a more detailed and accurate fugitive emissions study for the 2000 inventory, rather than to actual emission production differences.

Transport emissions contributed 13% of the 2000 energy emissions: a decrease of 9.4% from 1994 to 2000. This seems to contradict reports that consumption of diesel and gasoline fuel increased from 1994 to 2000, by 22.4% and 7.9% respectively (SAPIA 2006). When transport emissions were recalculated using 1994 energy balance data for the transport sector, they were observed to have increased from 1994 to 2000 by 32 222.08 CO<sub>2</sub>e Gg, or 22.3%. It was concluded that the decrease in transport emissions from 1994 to 2000, based on the inventory reports, was related to the location of fuel consumption emissions in the inventory rather than to an actual decrease of emissions in the sub-sector. It is very likely that non-transport fuel consumption emissions, for example gasoline and diesel consumption in the manufacturing sector, were included in the 1994 inventory under transport emissions rather than under their relevant sub-sectors. This is a typical location mis-allocation, which does not affect the overall total emission figure, but can be a problem in the analysis of sub-sector emission trends. A breakdown of the energy sector emissions is given in Table 3-1.

**TABLE 3-1: ENERGY SECTOR EMISSIONS, 2000**

1. Energy	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	Total
	CO <sub>2</sub> equivalent (Gg )			
A. Fuel combustion (sectoral approach)	301 076	485	1 913	303 473
1. Energy industries	212 226	91	986	213 303
2. Manufacturing industries & construction	38 879	10	146	39 036
3. Transport	38 655	258	503	39 416
4. Commercial/institutional	1 902	0	9	1 911
5. Residential	5 547	122	259	5 928
6. Agriculture/forestry/fishing	3 706	3	10	3 718
5. Other	160	0	0	161
B. Fugitive emissions from fuels	24	40 386	NA,NO	40 411
1. Solid fuels	24	40 366	NA,NO	40 391
2. Oil and natural gas	0	20	NO	20
<b>Total</b>	<b>301 100</b>	<b>40 871</b>	<b>1 913</b>	<b>343 884</b>

Energy balances published by the Department of Minerals and Energy (DME) are the main source of energy data for the 2000 South Africa GHG inventory. DME used independent consultants to collect and prepare these balances.

### 3.1 Combustion of fossil fuels

The combustion of fossil fuels includes both stationary and mobile sources, with their respective combustion-related emissions. In South Africa's 2000 DME energy balance, this refers to:

- Energy industries
  - Public and autoproducer electricity generation
  - Oil refineries
- Manufacturing and construction activities
- Transport sector
  - International civil and marine aviation (for record only)
  - Domestic air transport
  - Road
  - Rail
- Other sectors
  - Agriculture/fishing/forestry
  - Commerce and public service
  - Residential

#### 3.1.1 Energy industries

Fossil fuel emissions from the energy industry in South Africa come from fuels combusted by the large fuel-extraction and energy-producing industries – electricity producers and petroleum refineries. Emissions from manufacture of solid or liquid fuels are included under refinery emissions.

**TABLE 3-2: ENERGY INDUSTRY ACTIVITY DATA AND EMISSION FACTORS**

Energy transformation	Amount	Amount (TJ)	Emission factors (kg/TJ)		
			CH <sub>4</sub>	N <sub>2</sub> O	CO <sub>2</sub>
Sub bituminous coal for public electr.	9 3845kt	1 773 676	1	1.5	96 250
Autoproducers	4298kt	81 232	1	1.5	96 250
Refinery fuel oil		27 804	3	0.6	77 400
Refinery fuel gas		30 175	1	0.1	57 600
Refinery FCC coke use		5 883	3	0.6	97 500
Refinery coal	1 437 7560t	301 928	3	0.6	94 600
Refinery others		9 060	3	0.6	73 300
Other solid biomass		47 000	30	4	
Gas works gas		27	1	0.1	73 300
<b>Total</b>		<b>2 276 787</b>			

##### 3.1.1.1 Public and autoproducer electricity production

###### 3.1.1.1.1 Source-category description

Public electricity plants are plants that feed produced electricity into the public grid, while autoproducers are industrial companies that operate their own power stations. The energy balance (DME 2002) reports on type of fuel and quantity used, which is mainly sub-bituminous coal.

Electricity generation is the biggest emission source in South Africa. Its main fuel, coal, is abundantly available in South Africa, and makes up over 92% of fuel used in electricity generation. Nuclear power generation accounts for about 5.8% and hydroelectric power generation about 1% in 2000. In accordance with IPCC 2006 Guidelines, neither of these is included as a source of GHG emissions in the 2000 inventory.

South Africa's net maximum electricity generation capacity in 2000 was 35 324 MW, with an associated national consumption of 198 206 GWh (NER 2000). Electricity production from the national power utility company accounts for more than 90% of total electricity generated.

#### 3.1.1.1.2 Data sources

Data on coal consumption for electricity generation were obtained from the 2002 national energy balances (DME 2005) compiled by the Department of Minerals and Energy (DME), and also from the national power utility (Eskom 2008). The national energy balances did provide data on coal used for electricity production, but coal consumption data from the national power utility was assumed to be of better quality. The national energy balances also provided data on electricity autoproducers.

#### 3.1.1.1.3 Methodological issues

Being a key emission source, electricity production requires the use of higher-tier levels of emission calculations, which require country-specific emission factors and plant-level emission estimations. For this 2000 inventory a country-specific carbon dioxide emission factor was used for coal, and IPCC default factors were used to calculate non-carbon dioxide emissions.

The emission calculations were based on aggregated consumption of coal for electricity generation, with a separation of public and autoproducer electricity generation.

The study for the country-specific emission factors was undertaken by the Energy Research Centre at the University of Cape Town, contracted by the national power utility, Eskom. In its annual reports, Eskom has published environmental indicators for its coal power stations. These are summarised in Table 3-2.

**TABLE 3-3: ENVIRONMENTAL INDICATORS FROM ESKOM**

Indicator	Factor	If electricity is measured in		
		KWh	MWh	GWh
Coal use	0.53	Kilogram	Tonnes	Thousand tonnes
Water use	1.26	Litre	Kilolitre	Megalitre
Ash produced	157	Gram	Kilogram	Tonnes
Particulate emissions	0.28	Gram	Kilogram	Tonnes
CO <sub>2</sub> emissions	0.963	Kilogram	Tonnes	Thousand tonnes
SO <sub>2</sub> emissions	8.793	Gram	Kilogram	Tonnes
NO <sub>x</sub> emissions	3.872	Gram	Kilogram	Tonnes

Given the net power consumption figure of 198 206 GWh in 2000, and the total electricity production emissions of 170 716.3 Gg CO<sub>2</sub>, the average electricity emission rate was calculated to be 861 CO<sub>2</sub>kg/MWh, which is lower than the figure of 963 kg/MWh indicated by the national

power utility. The difference could be explained by electricity exports, transmission losses and/or the emission factors used.

#### 3.1.1.1.4 *Quality control and uncertainties*

It is acknowledged that there are a number of uncertainties about the quality of data in the energy balance (DME 2002). Data quality can be assessed quickly by observing trends over three years, and checking for significant outliers.

No information was available from which to estimate uncertainties for the country-specific carbon dioxide emission factors. The IPCC Guidelines note that coal mines produce coal with a very wide range of carbon content. The term "black coal" can have a range of CO<sub>2</sub> emission factors.

The IPCC 2006 Guidelines note that emission factors for CH<sub>4</sub> and especially for N<sub>2</sub>O are highly uncertain. This may be ascribed to lack of relevant measurements, or uncertainties regarding measurements, or insufficient understanding of the emission generating process. Since default emission factors were used, it is important to note the range of CH<sub>4</sub> and N<sub>2</sub>O uncertainty, which is shown in Table 3-3.

**TABLE 3-4: PUBLIC ELECTRICITY AND HEAT EMISSION FACTOR UNCERTAINTY FOR CH<sub>4</sub> AND N<sub>2</sub>O**

Default uncertainty estimates for stationary combustion emission factors		
Sector	CH <sub>4</sub>	N <sub>2</sub> O
Public power, co-generation and district heating	50-150%	Order of magnitude, i.e. an uncertainty range from one-tenth mean value to ten times mean value

Source: 2006 IPCC Guidelines

The IPCC 2006 Guidelines note that while default uncertainties can be used for the existing emission factors, there may be additional uncertainties associated with applying emission factors that are not country-specific.

#### 3.1.1.1.5 *Planned improvements*

Rather than relying on a single source such as the energy balance, a regulatory framework that required the provision of data for GHG inventories from organisations and entities in specific sectors and sub-sectors could improve data quality in future.

Given that there is only one major producer of electricity in South Africa, it should be relatively easy to disaggregate electricity production data. This would need to involve gathering fuel consumption data from the national power utility, and from all other electricity producers in the country. Since the para-statal utility in 2000 provided 96% of the net electricity sent out in South Africa (NER 2002), reliable and verifiable data from this source would significantly improve data quality in this sector.

In the longer term, data precision would require determining the N<sub>2</sub>O and CH<sub>4</sub> emissions behaviour of power plants. Power utilities do not currently provide environmental indicators for these two gases, so research studies would have to be undertaken.

Another improvement would be reporting at the facility level, for example obtaining data for power plants above a certain MW or kt CO<sub>2</sub>-eq threshold.

Local emission factors for coal used in electricity generation were used in the 2000 inventory. These could be submitted to the IPCC for inclusion in its database of emission factors.

### **3.1.1.2 Petroleum refining**

#### *3.1.1.2.1 Source-category description*

Petroleum refining in South Africa includes crude oil refining and the manufacturing of synthetic fuels from coal, the latter making refinery activity one of the most significant sources of emissions in the country. In 2000, the total crude oil distillation capacity of South Africa's petroleum refineries was 700 000 bbl/day, and production of oil amounted to 689 000 tonnes (SAPIA 2006).

#### *3.1.1.2.2 Data sources*

The South Africa energy balance provides hardly any information on fuel consumption by refineries, its only entry being a 27TJ consumption of gasworks gas. The main sources of refinery data were refinery companies and the SAPIA 2006 annual report.

#### *3.1.1.2.3 Methodological issues*

Refinery emission estimation was approached in two ways. In cases where data was made available by refineries, appropriate default emission factors were used. Where no data could be obtained from refinery companies, the assumption was made that 8.0% of the processed crude oil was the equivalent energy used for refinery processes.

#### *3.1.1.2.4 Quality control and uncertainty*

The refinery companies explained the high level of their data quality being due to the developed systems used by the industry for data recording and archiving. Default IPCC emissions factors were used to estimate emissions.

#### *3.1.1.2.5 Planned improvements*

An improvement for this key source category would be to format and correct data in a way that could provide more transparency in the preparation of GHG inventories. Most refineries were willing to provide the required data, but this would need to be followed up by setting up appropriate communication channels with refinery managements to ensure ongoing submission of data in the required formats. This could be enabled by a regulatory framework for the provision of data for GHG inventory purposes.

## **3.1.2 Manufacturing industries and construction**

### *3.1.2.1 Source-category description*

According to the IPCC 2006 Guidelines, this category consists of several fuel combustion emission sources, mostly in the industry sector, including production of cement, iron and steel, and metal production. Emissions from fossil fuel consumption in the construction sector are also included in this category. It was noted in the energy balance that fossil fuels in the construction sector include liquefied petroleum gas (LPG), gasoline, diesel, and other kerosene.

**TABLE 3-5: MANUFACTURING INDUSTRY ACTIVITY DATA AND EMISSION FACTORS**

Manufacturing and construction	Amount	Amount (TJ)	Emission factors (kg/TJ)		
			CH <sub>4</sub>	N <sub>2</sub> O	CO <sub>2</sub>
Gasoline		155	3	0.6	69 300
Other kerosene		6 656	3	0.6	71 900
Gas/Diesel oil		31 262	3	0.6	74 100
RFO		2 030	3	0.6	74 100
LPG	36 5337kl	9 754	1	0.1	63 100
Other bituminous coal		257 694	1	1.5	94600
Coke oven coke	1221.534kt	34 447	1	1.5	107 000
Gas works gas	39 532TJ	39 532	1	0.1	44 400
Coke oven gas		14 867	1	0.1	44 400
Blast furnace gas		18 545	1	0.1	260 000
<b>Total</b>		<b>414 944</b>			

### 3.1.2.2 Data sources

Data on fuel consumption in the manufacturing and construction industry were obtained from the DME energy balances (DME 2002). Some data came from key industry sources, but this data could not be used, as some of it was most likely included in the aggregate energy balance figures.

### 3.1.2.3 Methodological issues

It is important to ensure that emissions under this source category pertain to fuel combustion only, rather than production processes. In certain cases, such as in iron and steel production, fuel is used both for producing energy and as part of chemical processes. IPCC Guidelines require, where possible, a separation between energy and process emissions, in order to avoid double counting between the energy and industry sectors.

In circumstances where it is impossible to separate energy and process emissions, IPCC Guidelines make provision for locating both process and energy emissions under one sector. This was the case for South Africa's iron and steel industry, where energy and process emissions could not be separated due to lack of relevant information from the industry. Thus Tier 1 methodology and IPCC default emission factors for stationary sources had to be used in the emissions computation.

### 3.1.2.4 Quality control and uncertainty

Quality control was limited to checking the consistency of data trends within the three-year period 1999-2001, and cross-checking data entries. In some cases, comparisons were made between data from the energy balance and data from key industries in the sector, in order to check the consistency of data magnitude.

### 3.1.2.5 Planned improvements

The energy balance (DME 2002) provides a good disaggregation of fuel consumption of sub-source categories for the manufacturing industries and the construction sector. There is room for further disaggregation in significant sectors such as metal production, aluminium smelting and cement production. A further improvement would be a separation between process- and energy-related emissions.

### **3.1.3 Transport**

Emissions of greenhouse gases from mobile combustion are estimated according to transport activity: road, air, rail, and water navigation. The diversity of sources and combustion factors have to take into account age of fleet, maintenance, sulphur content of fuel, and patterns of use of the various transport modes.

A national GHG inventory for transport emissions should include emissions from combustion and evaporation of fuel for all transport activity. However IPCC Guidelines indicate that some activities, such as agricultural machinery, fishing boats and military transport, should where possible be excluded from the transport sector and reported separately. Further, emissions from fuel sold to any air or marine vessel engaged in international transport should not be included in the national total emissions and should be reported separately.

#### ***3.1.3.1 Civil aviation***

##### *3.1.3.1.1 Source-category description*

Civil aviation emissions come from both international and domestic aircraft, including takeoffs and landings. They include civil commercial use of airplanes, scheduled and charter traffic for passengers and freight, air taxiing, agricultural airplanes, private jets and helicopters. Emissions from military aviation are separately reported under 'Other' or under the memo item 'Multilateral Operations'.

##### *3.1.3.1.2 Data sources*

The energy balances by DME was the major source of data. Civil aviation fuels in the DME South Africa energy balance include gasworks gas, aviation gas and jet fuel.

##### *3.1.3.1.3 Methodological issues*

The challenge of dealing with this source category is how to split fuel consumption for international and domestic flights. A proposed methodology is based on departure and landing locations for each flight stage, however a consensus has yet to be reached on this. It was noted that the energy balance (DME 2002) had made the split between international and domestic flights, although the methodological approach for doing this was not mentioned.

The energy balance does not give any detail on whether aviation fuel consumption figures include military aviation activities. Understandably, military aviation fuel consumptions might have been omitted for reasons of confidentiality.

The Tier 1 method was used to estimate all aviation emissions, as aircraft operational use data were not available. The Tier 1 approach makes use of consumption of fuel and fuel emission factors.

##### *3.1.3.1.4 Quality control and uncertainties*

Quality control was limited to checking the consistency of data trends within the three-year period 1999-2001, and cross-checking data entries.

As was the case for other energy sector source categories, analysis on the uncertainty of activity data was limited. According to the IPCC 2006 Guidelines, uncertainty on emission factors may be significant. For non-CO<sub>2</sub> emission factors, uncertainty is in the range -57% to +100%. Carbon dioxide emission factors are reported within a range of  $\pm 5$  %, as they are dependent only on the carbon content of the fuel and the fraction oxidised.

*3.1.3.1.5 Planned improvements*

Improvement of emission estimation for this category would require the understanding of a number of aviation parameters, including the number of landing/take-off cycles (LTOs), fuel use, and an understanding of the approaches used to distinguish between domestic and international flights. These refinements would enable the use of higher-tier levels for a more accurate emission estimation.

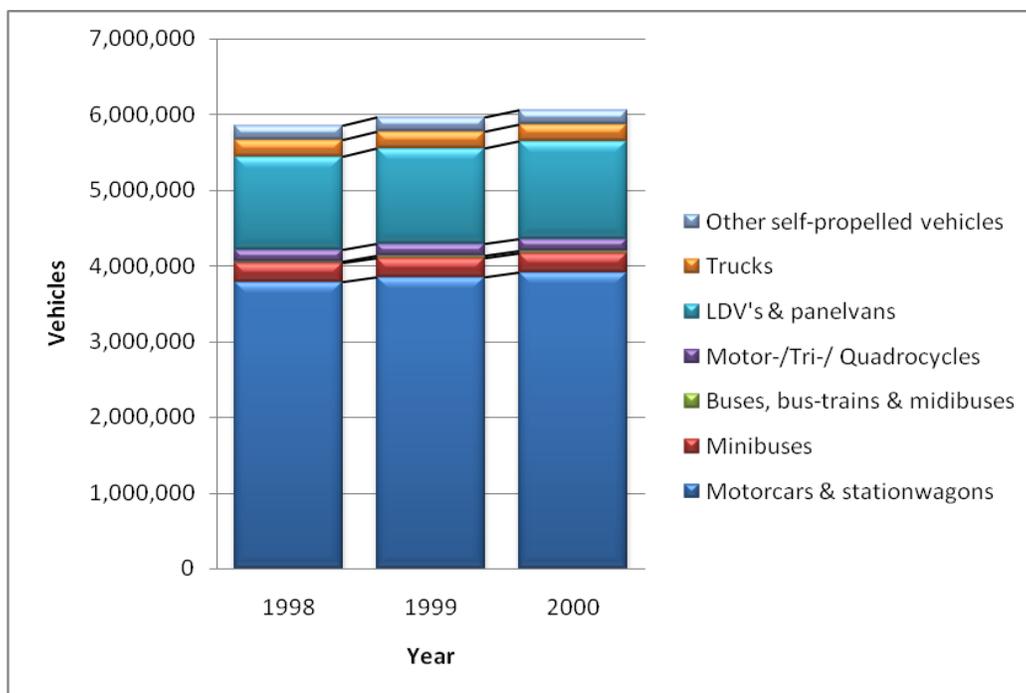
*3.1.3.2 Road transportation**3.1.3.2.1 Source-category description*

According to the IPCC 2006 Guidelines, road transportation emissions include fuel consumption by all types of light-duty vehicles (cars and light delivery vehicles - LDVs), heavy-duty vehicles (trucks, buses, and tractors) and motorcycles (including mopeds, scooters, and three-wheelers). All emissions from fuel use by agricultural vehicles on paved roads should be included under this source category.

The 2000 energy balance lists fuels under road transport as being only gasoline and diesel.

**TABLE 3-6: TRANSPORT ACTIVITY DATA AND EMISSION FACTORS**

Transport	Amount (TJ)	Emission factors (kg/TJ)		
		CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
Av jet kerosene	27 097	0.5	2	71 500
Av other kerosene	245	0.5	2	71 500
Av gas	835	0.5	2	69 300
Av gas works gas	29	0.5	2	69 300
Road LPG	53	62	0.2	63 100
Road gasoline	352 259	33	3.2	69 300
Other gasoline from SAPIA difference)	302	3	0.6	69 300
Road Gas works	29	1	0.1	69 300
Road gas/diesel	155 058	3.9	1.3	74 300
Rail gas/diesel	8 282	4.15	28.6	74 100
Other gas/diesel from SAPIA difference	910	3	0.6	74 100
<b>Total</b>	<b>544 193</b>			
<b>International bunkers</b>				
Marine gas/diesel	13 228	7	2	74 100
Marine RFO	100 249	7	2	77 400
Av jet kerosene	40 646	0.5	2	71 500
<b>Total</b>	<b>154 125</b>			

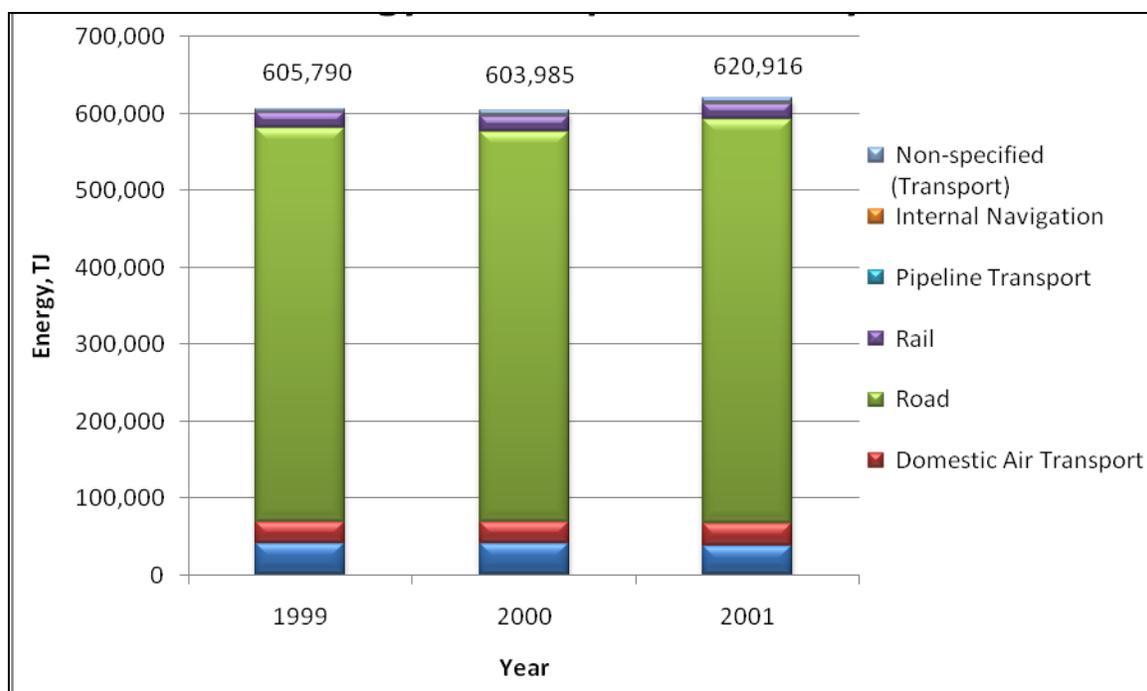


**FIGURE 3-2: NUMBER OF “LIVE” (REGISTERED) VEHICLES IN SOUTH AFRICA, 1998-2000**  
(DOT 2001)

#### 3.1.3.2.2 Data sources

The DME energy balance (DME 2002) was the main source of fuel data for the transport sector. However, the energy balance did not provide sufficient information for a thorough understanding of fuel consumption. For example, it did not state whether aviation fuel consumption figures included military aviation activities (which might have been excluded for security reasons).

The second source of data for transport emissions was the SAPIA 2006 Annual Report, which provided data on fuel consumption, both diesel and gasoline. It was noted that SAPIA 2006 reported consumption figures for diesel and gasoline that were higher than those reported in the DME energy balance. The difference in diesel and gasoline consumption between SAPIA and the DME was included in the calculation of GHG emissions under road transport.



**FIGURE 3-3: TOTAL ENERGY IN TRANSPORT SECTOR BY MODE**

#### 3.1.3.2.3 Methodological issues

In order to use higher-tier levels for calculating road transportation emissions, a better understanding of fuel sold and vehicle kilometres travelled is needed for the entire South Africa vehicle fleet. The IPCC 2006 Guidelines suggest that in general the fuel approach (fuel sold) is appropriate for CO<sub>2</sub> whereas the kilometre approach (distance travelled by vehicle type and road type) is appropriate for CH<sub>4</sub> and N<sub>2</sub>O.

Some activities that involve consumption of fuel by mobile equipment were excluded from the transport sector and reported separately in this 2000 inventory. Among these were fuel consumption from agricultural machinery, fishing boats, and military transport. Also reported separately were emissions from fuel sold to air or marine vessels engaged in international transport. It was noted that fuel consumption for these activities might have been included in the transport sector emissions, resulting in the comparatively higher transport emissions reported in the 1994 inventory.

A Tier 2 approach, based on fuel consumption and default emission factors, was used to estimate road transport emissions for this 2000 inventory.

#### 3.1.3.2.4 Quality control and uncertainty

Quality control for transport sector emission estimates was limited to checking the consistency of data trends within the three-year period 1999-2001, as well as cross-checking data entries and comparing energy balance data (DME 2002) with SAPIA 2006 data.

The IPCC Guidelines explain that CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O normally contribute about 97%, 2-3% and 1% respectively of CO<sub>2</sub>-equivalent emissions from the road transportation sector. Although uncertainties in N<sub>2</sub>O and CH<sub>4</sub> estimates are much higher, the uncertainty in the CO<sub>2</sub> emission factor is typically less than 2% when national values are used. Hence the use of locally-estimated data reduces uncertainties, particularly with bottom-up estimates.

Fuel quality is regarded as a factor that can lead to inaccurate estimation of road transport emissions. The IPCC Guidelines explain that fuel adulteration can have impacts on uncertainties in emission factors for CH<sub>4</sub> and N<sub>2</sub>O emissions only. Other factors that may have impacts on non-CO<sub>2</sub> emissions, according to the 2006 IPCC Guidelines, include:

- Uncertainties in fuel composition and sulphur content
- Uncertainties in fleet age distribution and other fleet characteristics such as cross-border effects
- Uncertainties in maintenance patterns of the vehicle stock
- Uncertainties in combustion conditions (climate, altitude) and driving practices, such as speed, proportion of running distances to cold starts, or load factors (CH<sub>4</sub> and N<sub>2</sub>O)
- Uncertainties in application rates of post-combustion emission control technologies (e.g. three-way catalysts)
- Uncertainties in the use of additives to minimise the aging effect of catalysts
- Uncertainties in operating temperatures (N<sub>2</sub>O)
- Uncertainties regarding test equipment and emission measurement equipment.

#### *3.1.3.2.5 Planned improvements*

For road transport, improvements could include the ability to compare emission estimates using fuel consumption and kilometre-based travel data. This implies more knowledge is needed about South Africa's fleet profile, and about how much fuel is consumed in the road transportation sector as a whole.

Development of localised emission factors will also enhance the accuracy of the emission estimation. Research will be necessary to establish country-specific emission factors. A regulatory framework for the provision of data for GHG inventory purposes would need to gather data from several sources in the transport sector.

### **3.1.3.3 Railways**

#### *3.1.3.3.1 Source-category description*

Railway transport, both freight and passenger railway traffic, generates emissions as locomotives use fossil fuel as their energy source. South Africa's railway sector uses electricity as its main energy source, with diesel being the only other energy source (DME 2002).

#### *3.1.3.3.2 Methodological issues*

The IPCC 2006 Guidelines provide a Tier 1 approach for CO<sub>2</sub> emissions from railway transport, and Tier 1 and Tier 2 approaches for estimating CH<sub>4</sub> and N<sub>2</sub>O emissions. The relevant emissions are calculated by multiplying fuel consumption by the relevant emission factors. Use of higher tier levels depends on the availability of fuel consumption by locomotive type, and/or country-specific emission factors.

The Tier 1 method was used to estimate railways transport emissions for this 2000 inventory.

### **3.1.3.4 Navigation**

#### *3.1.3.4.1 Source-category description*

The 2006 IPCC Guidelines define the navigation source category as emissions from the use of fossil fuels in all waterborne transport, from recreational craft to large ocean-going cargo ships. These vessels are driven primarily by large, slow- to medium-speed diesel engines and occasionally by steam or gas turbines.

The emissions include carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O), as well as carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), sulphur dioxide (SO<sub>2</sub>), particulate matter (PM) and oxides of nitrogen (NO<sub>x</sub>).

Navigation fuels in the South Africa 2000 energy balance included diesel, residual fuel oil, LPG, and other kerosene.

#### 3.1.3.4.2 *Methodological issues*

The two approaches used in estimating navigation emissions apply emission factors to fuel consumption activity data. It is important to ensure that emissions are estimated separately for domestic and international water-borne navigation.

The South Africa energy balance for 2000 (DME 2002) differentiated between international and domestic navigation fuel consumption, although no details were given on the calculations and approaches used to do this.

#### 3.1.3.4.3 *Quality control and uncertainties*

According to the 2006 IPCC Guidelines, CO<sub>2</sub> emission factors for fuels are generally well determined, as they are primarily dependent on the carbon content of the fuel. Thus most of the uncertainty in waterborne navigation emission estimates is related to the difficulty of distinguishing between domestic and international fuel consumption.

### 3.1.4 **Other: residential, commercial/institutional, agriculture, forestry and fishing**

#### 3.1.4.1 *Source-category description*

This source category includes emissions from fuel combustion in commercial and institutional buildings, agriculture, forestry, fishing, and fishing industries such as fish farms. Fuels included under this category in the 2000 energy balance (DME 2002) include bituminous coal, gasworks gas, solid biomass, LPG and gasoline. Emissions not associated with fuel combustion are included elsewhere: for example non-energy emissions from agriculture are listed in the AFOLU sector.

**TABLE 3-7: RESIDENTIAL, COMMERCIAL, AGRICULTURE AND FISHING ACTIVITY DATA AND EMISSION FACTORS**

	Amount (TJ)	Emission factors (kg/TJ)		
		CH <sub>4</sub>	N <sub>2</sub> O	CO <sub>2</sub>
<b>Commercial/institutional, agriculture and fishing</b>				
Other kerosene	141	3	0.6	71 900
LPG	11	1	0.3	63 100
Other bituminous coal	19 877	1	1.5	94 600
Gas Works gas	231	1	0.1	44 400
<b>Total</b>	<b>20 261</b>			

	Amount (TJ)	Emission factors (kg/TJ)		
		CH <sub>4</sub>	N <sub>2</sub> O	CO <sub>2</sub>
<b>Residential</b>				
Other kerosene	22 202	3	0.6	71 900
LPG	3 012	1	0.2	63 100
Other bituminous coal	39 755	1	1.5	94 600
Other solid biomass	190 400	30	4	0
<b>Total</b>	<b>255 369</b>			
<b>Agriculture/forestry/fishing</b>				
Gasoline	2 821	3	0.6	69 300
Other kerosene	2 437	3	0.6	71 900
Gas/Diesel oil	42 609	3	0.6	74 100
LPG	141	1	0.1	63 100
Other bituminous coal	1 781	1	1.5	94 600
<b>Total</b>	<b>49 790</b>			

#### **3.1.4.2 Data sources**

Data on fuel consumption in the residential, commercial/institutional, agriculture, forestry and fishing sectors were obtained from the DME 2000 energy balances (DME 2002).

#### **3.1.4.3 Methodological issues**

A Tier 1 approach was used in estimating emissions, by applying emission factors to fuel consumption activity data.

#### **3.1.4.4 Quality control and uncertainties**

An area of uncertainty was the biomass fuel data, which was relatively constant over the three-year period. Comparison with data from the Food and Agriculture Organization (FAO) revealed a significant discrepancy between the local and international data sources, with the international data indicating much higher quantities of biomass use levels than those indicated in the South African DME energy balances.

#### **3.1.4.5 Planned improvements**

Studies of residential energy consumption in South Africa are urgently required for an accurate estimation of the associated emissions. Given the many households, unified reporting requirements would only be possible by aggregation, for example, by collection of data by local government in major cities.

For commercial and institutional buildings, regulatory framework for the provision of data for GHG inventory purposes could specify reporting requirements.

Biomass consumption data is significantly uncertain and based on outdated studies.

### **3.1.5 Sectoral emissions comparison with the CO<sub>2</sub> reference approach**

A quick estimate of the total CO<sub>2</sub> emitted in a country can be made by using a first-order estimate of national greenhouse gas emissions based on the energy supplied to a country. This is called the reference approach. It is based on the assumption that once carbon is brought into a national

economy in the form of a fuel, it is either released into the atmosphere in the form of a greenhouse gas, or it is diverted and does not enter the atmosphere as a greenhouse gas (2006 IPCC Guidelines).

The reference approach can be used to estimate a country's CO<sub>2</sub> emissions from fuel combustion and can be compared with the results of the combined sectoral emission estimates. If there is a significant difference between the reference and sectoral approaches, this would indicate possible problems in the compilation of the GHG inventory. In some cases it may indicate of fuel pilferage (i.e. smuggling) out of the country.

For this 2000 inventory, the total CO<sub>2</sub> emissions using the reference approach was 413 914 Gg (taking activity data mainly from the energy balance). Using the sectoral approach, total CO<sub>2</sub> emissions was 301,069 Gg. There was thus a difference of 27% (112,845 Gg) between the two approaches. This difference is quite significant, suggesting that some activities may not have been accounted for in the sectoral approach or data source inconsistencies. Some of the difference could also be attributed to fuel that has left South Africa without being recorded as exports.

## 3.2 Fugitive emissions from fuels

### 3.2.1 Solid fuels

Fugitive emissions from solid fuel activities refers to all intentional and unintentional emissions from the extraction, processing, storage and transport of solid fuel to its point of final use. For coal mining activities, the major sources of fugitive emissions are:

- Coal mining, both underground and surface
- Processing of coal
- Storage of coal and coal wastes

Methane is the most important fugitive emission emanating from solid fuels.

#### 3.2.1.1 Coal mining and handling

##### 3.2.1.1.1 Source category description – coal mining and handling

Methane releases take place from coal and the rock surrounding it during coal production, transport and storage. The amount of methane released depends primarily on the amount of methane stored in the coal. In the mining sector, a distinction is made between open-pit mines, where material is extracted from pits open to the surface, and closed-pit mines, where seams are mined underground.

In underground mines, ventilation systems pump significant amounts of methane into the atmosphere. This is the main source of fugitive methane emissions in hard coal mining activities. In contrast, methane release from surface coal mining operations is negligible.

**TABLE 3-8: COAL MINING FUGITIVE ACTIVITY DATA AND EMISSION FACTORS**

Mining method		Amount of coal produced (tonne)	CH <sub>4</sub> emission factor (m <sup>3</sup> tonne <sup>-1</sup> )
Underground	Mining	139 949 198	2.5
	Post-mining	139 949 198	2.5
Surface	Mining	150 282 060	1.2
	Post-mining	150 282 060	0.1

#### *3.2.1.1.2 Data sources*

Data was obtained from studies on coal fugitive emissions (Lloyd & Cook 2005) and a DME report (DME 2001a).

#### *3.2.1.1.3 Methodological issues*

Fugitive emission estimates were based on coal production data. The emission estimation was done for underground and surface mining only, as data on abandoned mines could not be obtained.

The Tier 1 method was used for emission estimation, applying IPCC default emission factors to production data. The IPCC 2006 Guidelines require that countries using the Tier 1 approach use country-specific variables, such as the depth of major coal seams, to determine the emission factor to be used, as the gas content of coal normally increases with depth. For South African underground mines, the assumption was made that the average coal mine depth is between 200m and 400m. This gives an average emission factor of 2.5m<sup>3</sup> per tonne. A similar assumption was made for surface mines, so that the average overburden depth was assumed to be between 25m and 50m. This gives an average emission factor of 1.2 m<sup>3</sup>/tonne.

An IPCC conversion factor of  $0.67 \times 10^{-6}$  Gg m<sup>-3</sup> (the density of methane at 20°C and 1 atmosphere pressure) was used to convert volume of CH<sub>4</sub> to mass of CH<sub>4</sub>.

Post-mining emissions for both underground and surface coal were estimated. Given the choice of emission factors between low, average and high, average emission factors were selected, as there was no underlying information to support either low or high emission factors. The average emission factor used for underground coal was 2.5 m<sup>3</sup> tonne<sup>-1</sup> and for surface coal 0.1 m<sup>3</sup> tonne<sup>-1</sup>.

No emission estimates from coal waste dumps (spontaneous oxidation) were made because IPCC Guidelines indicate that such emissions are usually insignificant. No methods are provided to estimate this.

#### *3.2.1.1.4 Data quality and uncertainties*

A comparison of coal production data for fugitive emissions revealed that there were discrepancies between data taken from the energy balance and data obtained from industry and individual studies. Coal production data from individual studies were higher than data from the energy balance, with a clear separation between underground and surface mining. It was decided to adopt the individual studies data for the 2000 inventory.

Significant errors can be associated with estimations of fugitive methane emissions, mainly because of the highly sporadic nature of these emissions. To reduce the relative standard deviations to significantly lower levels would require continuous measurement of the methane releases over extended periods. Such measurement would need to be of high precision ( $\pm 10$  ppm) at low methane concentrations (of the order of 200ppm), which would require expensive instrumentation. The effort does not seem justified in view of the relatively low quantities of methane involved.

According to the IPCC 2006 Guidelines, the use of the Tier 1 approach for surface mining has uncertainty factors of between 2 and 3 on emission factors.

#### *Planned improvements*

A special effort is needed to include fugitive emissions from abandoned mines. These were not included in the current inventory due to lack of data from the Department of Minerals and Energy on abandoned mines.

## 3.2.2 Oil and gas

### 3.2.2.1 Source category description

Oil and gas fugitive emissions are made up of emissions from all oil and natural gas activities. The major sources of these emissions are equipment leaks, evaporation losses, venting, flaring, and accidental releases.

**TABLE 3-9: OIL REFINING FUGITIVE EMISSIONS**

Fugitive refinery total (SAPIA data)	Crude processed	Crude 10 <sup>3</sup> (m <sup>3</sup> )	CH <sub>4</sub> EF
	19 662 000t	22 984.878	0.000041/ m <sup>3</sup>

### 3.2.2.2 Methodological issues

Oil and gas fugitive emission estimations were made from refinery activity data, on the basis of the volume of crude oil processed by each refinery. IPCC default emission factors were applied for venting and flaring.

### 3.2.2.3 Data sources

Data on crude oil processes were obtained directly from refineries and from the South Africa Petroleum Industry Association (SAPIA 2006).

### 3.2.2.4 Planned improvements

Since the coal mining sector is one of the most significant sources of GHG emissions in the country, it is strongly recommended that country-specific emission factors for coal fugitive emissions be developed.

## 4 INDUSTRIAL PROCESSES AND OTHER PRODUCT USE

In 1994 the Industrial Processes and other Product Use (IPPU) sector was the third largest source of emissions in South Africa's GHG inventory after energy and agriculture. By the time of the 2000 inventory it had become the second largest source of emissions after the energy sector. Gases generated by the IPPU sector include CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub> and PFCs. The main emissions sources for this category are:

- Manufacture of mineral products, mainly cement
- Manufacture of chemical products, such as nitric acid and adipic acid
- Metal production, mainly iron and steel

Industry associations and the Department of Minerals and Energy (DME) were the primary data sources for the IPPU sector for this 2000 inventory. In a few cases, data were obtained by direct meetings or e-mail communications with plant management.

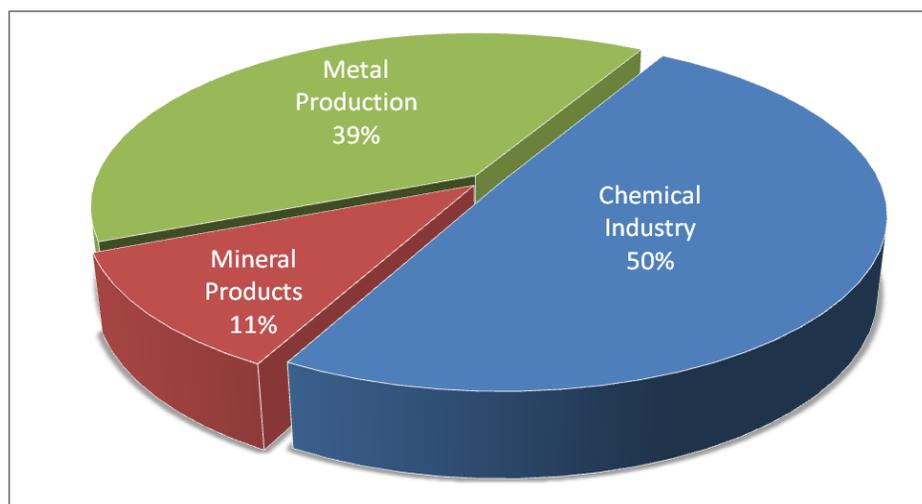
The IPPU contribution to total emissions showed a substantial increase from the 1994 inventory to the 2000 inventory. In 1994, industrial process emissions were 8.0% of South Africa's GHG emissions, and by 2000 they had grown to 14% (61 469 Gg CO<sub>2</sub>eq) – an increase of 102.3% compared to 1994.

**TABLE 4-1: IPPU EMISSIONS, 2000**

Industrial processes & product use	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	HFCs	PFCs	SF <sub>6</sub>	Total
	CO <sub>2</sub> equivalent (Gg)						
A. Mineral products	6 863	NA	NA	NA	NA	NA	6 863
B. Chemical industry	23 751	4284	2 388	NO	NO	NO	30 424
C. Metal production	21 959	3 30	0.00	NA	2 219	NA,NO	24 181
D. Other production	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
E. Production of halocarbons and SF <sub>6</sub>	NA	NA	NA	NA,NO	NA,NO	NA,NO	NA,NO
F. Consumption of halocarbons and SF <sub>6</sub>	NA	NA	NA	NA,NE	NA,NE	NA,NE	NA,NE
G. Other product manufacture and use	NA,NE	NA,NE	NA,NE	NA,NE	NA,NE	NA,NE	NA,NE
Total	52 574	4 287	2 388	NA,NO	2 219	NA,NO	61 469

NA = Not Applicable; NE = Not Estimated; NO = Not Occurring

The main source contributing to the rise in industrial emissions was the chemicals industry, which increased its emissions by 618.9% between 1994 and 2000. The chemicals industry accounted for 50% of IPPU emissions in 2000, while metal production emissions accounted for 39% (an increase of 16.1% from 1994), and mineral production emissions accounted for 11% (an increase of 28.7% from 1994).

**FIGURE 4-1: INDUSTRIAL PROCESSES AND PRODUCT USE (IPPU) EMISSION DISTRIBUTION**

#### 4.1 Mineral products

Mineral products emissions (source category 2.A in the IPCC 2006 Guidelines) is divided into five sub-categories – cement production, lime production, glass production, process uses of carbonates, and other mineral products processes.

Mineral products emissions are mainly process-related carbon dioxide emissions resulting from the use of carbonate raw materials. For the 2000 inventory this source sub-category included production of cement, other non-aggregate uses of limestone and dolomite (including glass production, lime production and ceramics production), and the use of soda ash.

The most significant emissions came from cement production (contributing 64.7% of emissions for mineral products – one of the largest sources of emissions in South Africa), followed by other non-aggregate uses of limestone and dolomite at 33.1%.

**TABLE 4-2: MINERAL PRODUCTS ACTIVITY DATA AND EMISSION FACTORS**

Mineral industry	Production (Tonnes)	IPCC EFs (tonnes CO <sub>2</sub> /tonne)
Clinker production	6 932 617	0.52000
Other non-aggregate limestone & dolomite uses	5 104 000	0.4453515
Soda ash use	355 200	0.41490

#### 4.1.1 Mineral products: Cement production

The South African cement industry's cement plants vary widely in age, ranging from five to over 70 years (DME 2008). The most common materials used for cement production are limestone, shells, and chalk or marl combined with shale, clay, slate or blast furnace slag, silica sand, iron ore and gypsum. For certain cement plants, low-grade limestone appears to be the only raw material feedstock for clinker production (DME 2008).

South African cement plants produce Portland cement and blended cement products such as CEM I, and more recently CEM II and CEM III. For the purpose of the 2000 GHG inventory, production was assumed to be all Portland cement, with clinker content level at 95%.

Cement produced in South Africa is sold locally and to other countries in the region – Namibia, Botswana, Lesotho and Swaziland.

##### 4.1.1.1 Source-category description

The main GHG emission in cement manufacture is CO<sub>2</sub> emitted during the production of clinker, an intermediate stage in the cement production process. Non-carbonate materials may also be used in cement production, which reduce the amount of CO<sub>2</sub> emitted. However the amounts of non-carbonate materials used are generally very small and not reported in cement production processes in South Africa. An example of non-carbonate materials would be impurities in primary limestone raw materials.

##### 4.1.1.2 Data sources

Data on cement production in South Africa was obtained from the Department of Minerals and Energy's South Africa's Mineral Industry publication (SAMI) (DME 2001b). and the Association of Cementitious Materials Producers (ACMP). Data from SAMI was the larger of the two and was, therefore, the one used in the inventory.

##### 4.1.1.3 Methodological issues

As a key emission source, cement production requires higher-tier level emission estimation, but this was not possible because of the lack of plant-specific data.

The Tier 2 method stipulates that if sufficient country-specific data on calcium oxide (CaO) content of clinker and inputs of non-carbonate CaO sources are available, a country-specific CO<sub>2</sub> emission factor for clinker should be calculated. Data obtained from DME was insufficient for the country-specific emission factor to be calculated. A clinker inclusion of 95% was assumed in cement and then an IPCC default emission factor of 0.52 tonnes CO<sub>2</sub>/tonne clinker was applied.

#### ***4.1.1.4 Data quality and uncertainties***

Only aggregated industry data for cement production were available, so no comparison was made of data across different plants. For purposes of quality assurance, all data obtained from DME's SAMI publication was checked for consistency. According to the IPCC 2006 Guidelines, if a 95% clinker inclusion in portland cement is assumed the uncertainty is in the range of 2% to 7%.

#### ***4.1.1.5 Planned improvements***

An improvement would be the determination of country-specific data by collecting data from all cement plants in South Africa. These data need to include the CaO content of the clinker and the fraction of this CaO from carbonate. CaO from non-carbonate sources (e.g. slag and fly ash) should be subtracted from CaO content of the clinker when calculating emissions.

### **4.1.2 Mineral products: other non-aggregate limestone and dolomite uses**

This sub-section reports all CO<sub>2</sub> emissions from non-aggregate uses of limestone and dolomite, excluding emissions from cement production. Non-aggregate limestone and dolomite uses are all uses of these carbonates where they are calcined to produce CaO and CO<sub>2</sub>, and these include lime production, glass production and production of ceramics.

#### ***4.1.2.1 Methodological issues***

It was not possible to obtain production statistics for each source category in this sub-section, instead the emissions were determined from the quantities of limestone and dolomite used in those categories, and these were obtained from the Department of Minerals and Energy's South Africa's Mineral Industry publication (DME 2001b). This publication reports an aggregate national value of the quantity of limestone and dolomite produced, the amount that was used in cement production and the amount used in non-aggregate form for other purposes. This latter value was the one used in calculating emissions of this sub-section. Based on the IPCC's default method, an emission factor that assumes 85% to 15% ratio of limestone to dolomite was used

#### ***4.1.2.2 Data quality and uncertainties***

According to the IPCC 2006 Guidelines, the uncertainty of the activity data that accompanies the method used here is in the range of 1% to 3%.

### **4.1.3 Mineral products: soda ash use**

It was difficult to obtain data on soda ash consumption, since all soda ash used in the country is imported. The data used came from a report published in *Mining Weekly* (Venter 2008). Tier 1 methodology was used to calculate emissions.

### **4.1.4 Quality control and uncertainty estimates**

There are several challenges in ensuring good quality activity data, especially for soda ash use. A number of reports were analysed, including DME reports on the mineral industry. Some production data were analysed in order to detect any significant abnormalities in data trends.

## **4.2 Chemical industry**

### **4.2.1 All categories**

This category estimates emissions resulting from the production of both inorganic and organic chemicals in South Africa. Production processes covered for the 2000 inventory include those of:

- Nitric acid
- Adipic acid

- Calcium carbide
- Carbon black
- Acetylene carbon black
- Fertiliser

Methane emissions from certain petrochemical gas processes were also included under this category.

**TABLE 4-3: CHEMICAL INDUSTRY ACTIVITY DATA AND EMISSION FACTORS**

Chemical industry	Production	IPCC EFs (ton/ton)		
		CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
Nitric acid production(t)	441 000.00			0.009
Adipic acid(t)	1 484.90			0.300
Calcium carbide(t)	59 244.34	1.09000		
Carbon black production(t)	59 278.00	2.62000	0.00006	
Acetylene carbon black production(t)	59 278.00	2.62000	0.00006	
Fertilizer production(t)	470 000.00			0.007
Gas production processes				
Gas processes methane emissions				

#### 4.2.1.1 Data sources

Sources of data for chemical industry emission estimates were sparse. They included the chemical producing companies themselves and a research report (Lauriente 2007). Production data of calcium carbide and acetylene carbon black were obtained from SA Calcium Carbide (2009) while carbon black production data was obtained from Evonik Degussa (2008) formerly known as Algorax. These companies are the sole producers of these chemicals in the country. Data on adipic acid production were obtained from the United Nations statistics division

Emission figures from the production of fertiliser were obtained from one manufacturer. It was not known whether these figures included emissions from nitric acid production which is an intermediate step in fertiliser production. If so this could create a possible problem of double counting. Carbon dioxide and methane emissions from synfuels processes were obtained from a report by SASOL where the company carried out its own greenhouse gas inventory for the year 2000 (SASOL 2008).

Due to difficulties encountered in obtaining nitric acid data for 2000 the production figures for nitric acid were derived by applying growth in demand factors to 1990 data. A similar approach was used for soda ash use data using 2008 data and applying demand growth rate backwards to derive the 2000 figure..

##### 4.2.1.1.1 Methodological issues

Tier 1 was the main approach used in calculating chemical industry emissions using production data and relevant emission factors. IPCC 2006 default emission factors were used in all emission estimations except for a few cases when emission estimates were obtained directly from industry.

In some cases assumptions had to be made without the necessary background information. For example for nitric acid production it was assumed that no abatement measures were implemented and that the production process was medium high pressure.

#### 4.2.1.1.2 *Quality control and uncertainties*

There was not sufficient access to data on chemical industry activities which limited the scope for checking the quality of data. In some cases confidentiality required that only emission figures rather than full activity data be available from a particular plant.

#### 4.2.1.1.3 *Recommended improvements*

The most important issue to be addressed in chemical industry estimates is completeness. All chemical process plants in the country should be included. In some cases data were obtained from particular industry associations but it could not be ascertained if all producers in South Africa were members of the association.

Another important issue is data quality. For example when emission figures are obtained directly from industry it is difficult to ascertain their accuracy.

Once these issues have been addressed it will be possible to focus on improving emission factors with an objective of deriving national-specific emission factors.

## 4.3 Metal industry

### 4.3.1 All categories

#### 4.3.1.1 *Source category description*

This subcategory relates to emissions resulting from the production of metals. Processes covered for the 2000 inventory include production of:

- Iron and steel
- Ferro-alloys
- Aluminium
- Lead
- Zinc

Estimates were made for emissions of carbon dioxide (CO<sub>2</sub>) from the manufacturing of all the metals methane (CH<sub>4</sub>) from ferro-alloy production and perfluorocarbons (CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub>) from aluminium production.

**TABLE 4-4: METAL INDUSTRY ACTIVITY DATA AND EMISSION FACTORS**

Metal industry	Production	IPCC EFs (ton/ton)				
		CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	CF <sub>4</sub>	C <sub>2</sub> F <sub>6</sub>
Iron production - DRI (t)	1 552 553.00	0.70000				
Iron production - Blast furnaces (t)	5 410 207.00	1.35000				
Steel production electric arc (t)	3 724 914.00	0.08000				
Steel production oxygen furnace (t)	4 674 511.00	1.46000				
Ferro-alloy - FeCr (t)	2 574 000.00	1.30000				
Ferro- alloy - FeMn (t)	596 873.00	1.50000				

Metal industry	Production	IPCC EFs (ton/ton)				
		CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	CF <sub>4</sub>	C <sub>2</sub> F <sub>6</sub>
Ferro-alloy - FeSiMn (t)	238 127.00	1.40000				
Ferro-alloy - FeSi (t)	108 500.00	4.80000	0.001			
Silicon (t)	40 600.00	5.00000	0.0012			
Aluminium production - CWPB (t)	589 917.00	1.60000			0.0004	0.00004
Aluminium production - VSS (t)	84 082.87	1.70000			0.0008	0.00004
Lead production (t)	75 000.00	0.52000				
Zinc production (t)	63 000.00	1.72000				

#### ***4.3.1.2 Methodological issues***

The Tier 1 approach was used to calculate emissions using production data and relevant emission factors. The emission factors used were IPCC 2006 default factors.

Two important assumptions were made regarding the activity data used. For aluminium production the data were assumed to be for primary aluminium only without any re-smelting. For iron and steel emission estimation no separation was made between energy and process emissions emanating from the use of coke. This was due to lack of disaggregated information on coke consumption.

#### ***4.3.1.3 Data sources***

Metal industry emission estimates were based on data from two main sources: The South Africa Iron and Steel Institute (SAISI 2008) provided data for iron and steel production while production data for all the other metals were obtained from DME's South Africa's Mineral Industry publication (DME 2001b).

#### ***4.3.1.4 Quality control***

The necessary quality control measures were used to minimise estimation errors. The Tier 1 approach for metal production emission estimates generates a number of uncertainties. For example the IPCC 2006 Guidelines explain that applying Tier 1 to default emission factors for iron and steel production may have an uncertainty of  $\pm 25\%$ . The same range of uncertainty is associated with the Tier 1 approach for ferro-alloy production emission factors.

#### ***4.3.1.5 Recommended improvements***

As with most other subcategories completeness of data is urgently needed for metal production activities. Other improvements would be ensuring that accurate activity data are collected and aiming to arrive at nationally-derived emission factors.

## 5 AGRICULTURE, FORESTRY AND OTHER LAND USE

### 5.1 Sector description

Based on subcategory descriptions in the IPCC 2006 (Vol. 4) Guidelines a number of activities in South Africa's Agriculture Forestry and Other Land Use (AFOLU) sector should be included when estimating emissions. These are:

#### *Livestock*

- Enteric fermentation (IPCC section 3A1)
- Manure management (IPCC section 3A2)

#### *Lands*

- Forest land (IPCC section 3B1)
- Cropland (IPCC section 3B2)
- Grasslands (IPCC section 3B3)
- Wetlands (IPCC section 3B4)
- Settlements (IPCC section 3B5)
- Other land (IPCC section 3B6)

#### *Aggregate sources and non-CO<sub>2</sub> emissions on land*

- Biomass burning (IPCC section 3C1)
- Liming (IPCC section 3C2)
- Urea application (IPCC section 3C3)
- Direct N<sub>2</sub>O emission from managed soils (IPCC section 3C4)
- Indirect N<sub>2</sub>O emission from managed soils (IPCC section 3C5)
- Indirect N<sub>2</sub>O emission from manure management (IPCC section 3C6)
- Rice cultivation (IPCC section 3C7)
- Harvested products (IPCC section 3D1)

The AFOLU sector has some unique characteristics which call for different inventory methods from other sectors. The sector has many long-term processes leading to both emissions and removals of greenhouse gases which can be widely dispersed in space and also highly variable in time (with diurnal seasonal and annual variations). The factors governing emissions and removals can be both natural and anthropogenic (direct and indirect) and it is often difficult to clearly distinguish between causal factors.

### 5.2 Methodology and approach

The 1990 Greenhouse Gas Inventory (GHGI) for South Africa used the Revised 1996 Guidelines of the Intergovernmental Panel on Climate Change (IPCC 1997) for the Land Use Land Use and Change and Forestry (LULUCF) sector (Van der Merwe & Scholes 1998).

For this 2000 Inventory although it was not a requirement the IPCC 2006 Guidelines (IPCC 2006) were followed as closely as possible. The new AFOLU guidelines (IPCC 2006 Vol.4 Chapter 1.1) restructure the LULUCF sector to improve transparency and completeness and reduce double accounting. The somewhat arbitrary distinctions between LULUCF categories have been removed allowing for more consistent use of data especially when applying detailed methods. The new categorisation also allows for a more consistent treatment of land conversions.

Spatial data for all managed land is now required but it is a good practice to monitor unmanaged lands as well. More technical details on the data collection and processing are provided in the Technical Guide for Land Use Data AFOLU sector (Taviv et al. 2008). The IPCC provides detailed guidelines for the three approaches to spatial data use (IPCC 2006 Vol. 4 Chapter 3.3.1):

- Approach 1 identifies the total area for each category of land use within a country but does not provide detailed information on conversions between different categories of land use.
- Approach 2 incorporates Approach 1 but introduces the tracking of conversions between land use categories.
- Approach 3 extends the information available from Approach 2 by allowing land use conversions to be tracked in a spatially explicit way.

Approach 3 provides the most thorough reporting of surface area use and ideally it should have been used in the 2000 South Africa GHG inventory. Unfortunately the available spatial data was too limited and inconsistent especially regarding land use. There is not enough information on total land use per year over time or on conversions between land uses over time.

A further complicating factor has been the use of different methodologies and different scales in the two National Land Cover (NLC) data sets NLC1996 and NLC2000. This has made it difficult to detect changes in land class and in some instances it has led to illogical land class conversions. The required consistency for future NLC data is discussed in the Technical Guide for Land Use Data AFOLU sector (Taviv et al. 2008). A similar problem was experienced when the USA attempted to implement the IPCC 2006 Guidelines (USEPA 2008).

This 2000 inventory for South Africa uses a combined approach creating a continuous “wall-to-wall” surface area land use in South Africa for the year 2000 as required by Approach 1 and where possible applying Approach 2. This is a significant improvement on the 1994 South African GHG Inventory.

### **5.3 Livestock and other agricultural sub-sectors**

GHG emissions from livestock come primarily from two sources: enteric fermentation and manure management. The methods for their calculation are provided in the IPCC Guidelines (2006 Vol. 4 Chapter 10). The emissions from enteric fermentation in South Africa are significant and this source is therefore identified as a key category (DEAT 2007) to which higher-tier methodologies should be applied.

Some local emission factors have been estimated using IPCC 1996 Guidelines. The National Department of Agriculture (NDA) initiated a sector inventory which should be completed by the end of 2009 and it is recommended that the NDA apply Tier 2 methodology as described in the IPCC 2006 Guidelines. This 2000 inventory uses IPCC 1996 methodology and combines the livestock with other agricultural sub-sectors in a similar way to the previous inventory. This will serve to provide interim information until the NDA sector inventory is completed. Table 5-1 summarises the emissions for the sector.

**TABLE 5-1: EMISSIONS FROM AGRICULTURAL SECTOR 2000**

Sub-sectors	CH <sub>4</sub> (Gg)	N <sub>2</sub> O (Gg)	CO <sub>2</sub> eq (Gg)
A Enteric fermentation	903.3	NA	<b>18969.0</b>
B Manure management	90.7	1.3	<b>2320.6</b>
C Others (indirect N <sub>2</sub> O emissions)	NA	56.2	<b>17427.0</b>
<b>Total agriculture</b>	<b>994.0</b>	<b>57.6</b>	<b>38716.7</b>

Key: NA = Not Applicable

### 5.3.1 Source-category description

In the 1994 inventory (DEAT 2004) it was estimated that enteric fermentation contributed about 4.7% of national CO<sub>2</sub> equivalent emissions. The methane emissions from livestock are dependent on the animal population in different livestock categories and their feed intake.

The N<sub>2</sub>O and CH<sub>4</sub> emissions from manure management are dependent on management practices. Indirect N<sub>2</sub>O emissions from agricultural lands are dependent on the quantity of fertilisers and manure applied as well as on inputs from nitrogen-fixing crops.

### 5.3.2 Methodological issues

The IPCC 1996 Guidelines were applied (Van der Merwe & Scholes 1998).

### 5.3.3 Data sources

FAO data (<http://faostat.fao.org/site/605/default.aspx>) for the year 2000 for livestock were used and verified using commercial farming data from the Department of Agriculture (DoA 2006).

### 5.3.4 Quality control

At this stage no quality control procedures were applied. The provided values will soon be replaced by the complete sector inventory.

The data for some of the livestock categories used in the 1990 inventory (DEAT 2004) appear to be too high compared to data used for the 1994 data and the FAO data for the year 2000 – for example the total number of horses was estimated as 770 000 for 1990 then 77 000 for 1994 then 270 000 for 2000 (FAO 2008).

The data for non-commercial farming in South Africa need to be accurately quantified – international data sources which are often only estimates or calculated values have been used for the 1994 and 2000 inventories.

### 5.3.5 Planned improvements

At this stage no recommendations are provided as improvements are expected to be part of the complete sector inventory.

## 5.4 Lands

### 5.4.1 Selection of land classes

The IPCC 2006 AFOLU Guidelines divide land use into six classes: Forestry Croplands Settlements Wetlands Grasslands and Other lands (IPCC 2006 Vol.4 Ch. 2). For these classes the definitions of land use categories may be based on land cover type or land use or a combination of the two (IPCC 2006 Vol.4.Ch. 3 p 3.5).

South Africa's current land use dataset is incomplete in both its spatial cover and its coverage of the relevant time period. Two recent National Land Cover (NLC) datasets are available but reclassifying the NLC categories into the six IPCC 2006 classes would give an inaccurate reflection. This is because about half (49%) of South Africa is covered by vegetation with unique GHG emission and removal characteristics made up of Savanna (16%) Arid Shrublands (26%) and Fynbos/Shrubland (7%) biomes. These biomes were included in the 2000 inventory as additional classes in order to quantify their unique contribution. Where necessary the NLC land cover classes were refined to biome classes using the biome boundaries of Mucina and Rutherford (2006). More detailed explanations are provided in Taviv et al. (2008).

The inclusion of additional biome classes provides continuity from the 1990 inventory. Although the earlier IPCC Guidelines (IPCC 1997) did not require emissions to be reported for any biome other than Savanna for the 1990 inventory Van der Merwe and Scholes (1998) calculated the total quantity of biomass burnt in the Grasslands Nama Karoo Succulent Karoo Fynbos and Thicket biomes. The IPCC 2006 Guidelines makes reporting of fires in all land uses a requirement. Thus the 2000 inventory determines emissions in all selected land classes including biomes.

Nine land classes were used for reporting in the 2000 inventory namely Forestry, Croplands, Settlements, Wetlands, Grasslands, Other lands, the Savanna biome, the Arid shrublands biome, and the Fynbos /shrubland biome. Each of these land classes is discussed in the sections that follow which include definitions available statistics and results. The AFOLU categories by area are summarised in Table 5-2.

**TABLE 5-2: AREA OF AFOLU CLASSES FOR THE YEAR 2000**

AFOLU Classes	Sub classes	NLC2000 (Ha)
Forestry	Plantation forest	1 734 900
	Indigenous forest	527 048
	Woodlands	10 839 102
	Thicket	3 782 900
Cultivated land	Cultivated land	12 602 400
Settlements		1 832 725
Wetlands	Wetlands	2 268 400
	Waterbodies	528 550
Grasslands		25 759 325
Other land		995 300
Savanna		19 884 675
Arid shrublands		32 500 450
Fynbos and shrubland		9 242 350
Total		122 498 125

*Source: DOT 2001*

#### 5.4.2 Cross-cutting issues

According to the IPCC definition of the AFOLU sector anthropogenic greenhouse gas emissions and removals take place on "managed land" which is defined as "land where human interventions and practices have been applied to perform production ecological or social

functions” (IPCC 2006 Vol.4 Ch.1 p1.5). Although most land in South Africa is managed to some degree it has been assumed for the purposes of the 2000 inventory that certain lands are close to their natural state and have zero changes in carbon balance. These “natural” lands include some categories in the Forestry class as well as Grasslands Savanna Arid Shrublands Fynbos/Shrubland and Other Lands classes. For Woodlands and indigenous forests biomass growth is specifically accounted for.

As required by the IPCC (2006) some classes are further divided into sub-classes. For example the Forestry class is divided into the “Forestry remaining Forestry” and “Land converted into Forestry”. A class can also be divided into further categories: for example Savanna can be divided into woody and grassy categories.

The areas for “natural” lands classified under this inventory are smaller in extent than the areas in the latest biome classification for South Africa (Mucina & Rutherford 2006). This is because the AFOLU classification also includes the land use classes (Croplands Wetlands and Settlements) while the Mucina and Rutherford (2006) classification divides the whole surface area of South Africa into biomes. For example some of the lands classified by Mucina and Rutherford as Grasslands could be Croplands under the AFOLU classification. This makes the total Grasslands area under AFOLU smaller than Grasslands according to Mucina and Rutherford (2006). There could be some further differences as a result of misclassification of certain types of Shrublands.

Details of the description of the differences between Tiers 1 2 and 3 methods of estimating emissions are provided in the IPCC 2006 (Vol.4 Ch.1 p 1.11). Tier 1 and 2 methods for the AFOLU sector do not represent annual variability in emissions except for activity data. The same emission factor is used over time and encompasses limited spatial variability. No Tier 3 methods are applied in the 2000 South Africa inventory because the contribution from AFOLU categories is too small to justify development of local complex and intensive models which would require approval of the IPCC and attention to quality control and verification.

Greenhouse gas fluxes in the AFOLU sector can be estimated in two ways:

- 1) as net changes in carbon stocks over time (this is used for CO<sub>2</sub> fluxes)
- 2) directly as gas flux rates to and from the atmosphere (this is used for estimating non-CO<sub>2</sub> emissions and some CO<sub>2</sub> emissions and removals)

The IPCC 2006 Guidelines require inclusion of four carbon stocks/pools: carbon in biomass above ground carbon in biomass below ground dead wood and litter/debris and soil carbon pool. Carbon stock in organic soil can only be estimated using Tier 3 methods while Tier 1 and 2 methods can calculate annual flux from soil.

Where possible the emission calculations used the formats suggested in Annex 1 of IPCC 2006. Spreadsheets with these formats were downloaded from the IPCC web-site ([http://www.ipcc-nggip.iges.or.jp/public/2006gl/worksheets/2006GL\\_Worksheets.zip](http://www.ipcc-nggip.iges.or.jp/public/2006gl/worksheets/2006GL_Worksheets.zip)) populated with data and equations and updated or enhanced where necessary. An additional spreadsheet was created to summarise all classes. Some notes were provided in the original IPCC spreadsheet templates. Some of the data sources for the factors and values used in the spreadsheets were indicated as notes or comments and are described in more detail in Taviv et al. (2008).

The preparation for next NLC mapping for South Africa NLC2005 has already included a consultation workshop with users to ascertain the data needs of the categories and data consistency. The spatial data will need significant improvement if Approach 2 is to be considered for the next inventory. The proposed categories will have to be evaluated by the custodian of the GHG inventory data to ensure that the final results are suitable and accurate enough for Approach

2. An agreed and acceptable categorisation of the National Land Cover data suitable for all data users (including the custodian of the GHG inventory data) is critical.

### 5.4.3 Forest lands

This class is made up of four categories: Plantation forest Indigenous forest Woodlands and Thicket. Standards South Africa (SSA) defines Plantation forest as all areas of systematically planted man-managed tree resources and composed of primarily exotic species including hybrids. This category includes all plantations from young to mature which have been established for commercial timber production seedling trials or woodlots/windbreaks. The plantations have to be of sufficient size to be identifiable on satellite imagery (SSA 2004).

SSA defines Indigenous forest as all wooded areas with over 70% tree canopy. Indigenous forest is a multi-strata community with interlocking canopies composed of canopy sub-canopy shrub and herb layers. The canopy is composed mainly of self-supporting single stemmed woody plants over 5 metres in height. These are essentially indigenous species growing under natural or semi-natural conditions although some areas of self-seeded exotic species may be included. The category excludes planted forests and woodlots (SSA 2004).

The Food and Agriculture Organization (FAO) defines indigenous forest as forest that includes natural forests and forest plantations with a tree canopy cover of more than 10% and an area of more than 0.5 ha. The trees should be able to reach a minimum height of 5 metres. However young stands that have not yet reached a crown density of 10% and tree height of 5m are included as are temporarily unstocked areas. According to the FAO definition forests are determined not only by the presence of trees but also by the absence of other predominant land uses. Forests can be used for purposes of production protection multiple use or conservation (i.e. forest in national parks nature reserves and other protected areas) and they can include forest stands on agricultural lands (e.g. windbreaks and shelter belts with a width of more than 20m). The term forest specifically excludes stands of trees established primarily for agricultural production for example fruit tree plantations. It also excludes trees planted in agroforestry systems (FAO 2008).

Under the FAO definition indigenous forests can include Woodlands defined as all wooded areas with a tree canopy between 10% and 70% typically consisting of a single tree canopy layer and a grass layer (SSA 2004). The canopy of a Woodland is composed mainly of self-supporting single stemmed woody plants over 5m in height of essentially indigenous species growing under natural or semi-natural conditions (which may include some areas of self-seeded exotic species). Planted forests and woodlots are therefore excluded. Canopy cover density classes may be mapped as sparse (< 40%) open (40%-70%) closed (> 70%) and “degraded forest and woodlands” (SSA 2004).

The definition of Woodlands overlaps with the definition of Woody Savanna (see Section 6.11 on Savanna below). However the geographical distribution of these two land classes is different and this spatial differentiation is used to distinguish between Woodlands and Woody Savanna.

SSA defines Thicket as vegetation which replaces forest where a degree of fire protection is still evident but rainfall is too low. Thicket does not fit within the Forest type as it does not have the required height or the many strata below the canopy. Nor is it a Savanna type because it does not have a conspicuous grassy ground layer (SSA 2004).

The Thicket biome has only been formally recognised recently (Powell et al. 2006) and insufficient data is available to quantify its carbon stock and fluxes. Although preliminary trial work has shown that one of the species has an unusual ability to fix carbon the results vary from 0.12 to 0.42 kgC/m<sup>2</sup>/a between sites (Mills & Cowling 2006) and cannot be extrapolated to the whole biome. The Thicket category has been excluded from the calculation of emissions until more representative data becomes available.

**TABLE 5-3: COMPARISONS BETWEEN FAO AND SSA DEFINITIONS OF INDIGENOUS FORESTS**

FAO	SSA
Includes natural forests and plantation forests	Indigenous species growing under natural or semi-natural conditions. Excludes planted forests
Tree canopy cover over 10% and area over 0.5 ha	Tree canopy > 70%
Crown density of 10% and tree height of at least 5m	Self-supporting single stemmed woody plants over 5m in height

In the 1990 and 1994 inventories (DEAT 2004) the Forest class was a carbon sink (e.g. in 1990 it had removed 13 641 Gg of CO<sub>2</sub>). This has not changed much in the 2000 inventory although more accurate methodology slightly different assumptions and more detailed data have been used. The total change in carbon stock is still positive which means that forestry sector remains a sink for carbon emissions.

**TABLE 5-4: FOREST LANDS CLASS EMISSIONS**

Annual increase in carbon stocks by biomass	C (tonnes/yr)	CO <sub>2</sub> (Gg )
Forest remaining forest	8 777 428	32 183 902
Land converted to forest	5 147 054	18 872 532
Wooded savanna	0	
<b>Total growth (increase in carbon stock)</b>	<b>13 924 482</b>	<b>51 056 434</b>
Loss of carbon from wood removals (harvested products)	4 598 284	16 860 376
Loss of carbon from fuelwood removal	5 771 565	21 162 406
Loss of carbon from disturbance	3 582	13 132
<b>Total loss (decrease in carbon stock)</b>	<b>10 373 431</b>	<b>38 035 914</b>
<b>Total annual carbon stock change</b>	<b>3 551 051</b>	<b>13 020 519</b>

#### 5.4.3.1 Forest land remaining forest land

##### 5.4.3.1.1 Source-category description

This sub-class represents lands that have been Forest Lands for longer than the transition period required to reach new soil carbon levels (IPCC 2006 Vol.4 Ch.4.1). The default transition period is 20 years. Therefore for the 2000 inventory the calculations are based on the area of Plantation forest planted in 1980 or before and two “natural” categories: Indigenous forests and Woodlands.

The Plantation category is further split into species: Acacia (wattle) Eucalyptus Pinus (softwoods) and others. The Eucalyptus and Pinus can be further split into plantations producing sawlogs and plantations producing pulp as their rotation periods are very different. However for the 2000 inventory this differentiation was not necessary as a Tier 1 methodology was followed.

#### 5.4.3.1.2 Carbon pools

##### *Biomass*

In the 2000 inventory the biomass pool for the Forestry class includes both above ground and below ground biomass. The 1994 inventory included only carbon in biomass above ground.

According to IPCC (2006) the spatial distribution of forest biomass is an important factor when calculating the sources of carbon caused by conversion of forest land to clear land or vice versa. Change in forest biomass resulting from management and re-growth is other factor that affects the long term net flux of carbon between atmosphere and terrestrial ecosystems (Houghton 2005).

The Tier 1 calculation assumes zero changes in below ground biomass (IPCC 2006 Vol.4 Ch.4.2.1.2). In this 2000 inventory Tier 2 calculations are made only for the Plantation category. The Tier 1 methodology is applied to “natural” categories where no local factors were available.

Changes in biomass also include wood removal fuel wood collection and losses due to disturbances. The latter was added in the IPCC 2006 requirements and was not included in the 1990 and 1994 inventories. Biomass losses due to disturbances are reported by Forestry South Africa (FSA 2008) for plantations and divided into two groups: fire and other damage. They were analysed for the period 1993 to 2003 by the Institute for Natural Resources (2005). The total area of plantation damaged did not change significantly over this time but the proportion damaged by fire increased. This conclusion was used for estimating emissions from biomass burning (see Section 5.3.1 below). In 1993 the greatest contributor to “other causes of damage” was drought.

To avoid double-counting fire emissions they are reported as part of the emissions from biomass burning while emissions from the burning of fuelwood for energy purposes are reported as part of the energy sector.

##### *Dead wood debris and soils*

For the Tier 1 calculations an assumption could be made that the dead wood and litter/debris pool is in balance (IPCC 2006 Vol.4 Ch. 4.2.2). However to account for the dead wood available for fuel wood collection the dead wood pool was included.

There is still insufficient information in South Africa to estimate the magnitude of change in soil carbon as a result of land conversion or even to assess whether it is positive or negative (Christie & Scholes 1995).

#### 5.4.3.1.3 Other greenhouse gas emissions from forest fires

The IPCC 2006 Guidelines require calculation of non-CO<sub>2</sub> GHGs from fires but for the Forest class the CO<sub>2</sub> emissions from fire also need to be accounted for (IPCC 2006 Vol.4 Ch. 4.2.4). Therefore unlike the 1994 inventory which assumed a zero net balance (in which re-growth counteracts the amount of carbon lost to the atmosphere) in the 2000 inventory the CO<sub>2</sub> emissions from fire in the Forestry class are also accounted for. These emissions are described in Section 6.14.2 on biomass burning.

#### 5.4.3.2 Methodological issues

The Tier 1 biomass gain-loss method as described in IPCC 2006 Vol. 4 Ch.4.2.1 was applied except in the Plantation categories. In these categories the Tier 2 methodology was used because of the availability of local factors.

The gains in biomass stock growth are calculated in sheet “Biomass 1 of 4” as follows:

$$ACG = \sum A_i * GW_i * (I+R_i+D_i) * CF_i \qquad \text{eq. 2.9 and 2.10 (IPCC 2006 Vol. 2)}$$

where

$A_i$  - Area of forest category i

$GW_i$  - Average annual above-ground biomass growth for forest category I (t dm/(ha\*a))

$R_i$  - Ratio of below-ground biomass to above-ground biomass for forest category i  
(t below-ground dm)/(t above-ground dm)

$D_i$  Ratio of dead wood biomass to above-ground biomass for forest category i (t dead wood dry matter (dm))/(t above-ground dm)

$CF_i$  - Carbon fraction of dry matter for forest category i (t carbon/t dm)

The losses are calculated for three components:

- Loss of carbon from wood removals (sheet Biomass 2 of 4)
- Loss of carbon from fuelwood removals (sheet Biomass 3 of 4)
- Loss of carbon from disturbance (sheet Biomass 4 of 4)

Loss of carbon from wood removals is calculated as follows:

$$L_{wood-removals} = H_j * BCEF_{sj} * (1+R_j) * CF_j \quad \text{eq.2.12 (IPCC 2006 Vol. 2)}$$

where

$H_j$  – Harvested wood stock of category j (m<sup>3</sup>/a)

$BCEF_{sj}$  - Biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark) for category j (t/m<sup>3</sup>)

$R_j$  - Ratio of below-ground biomass to above-ground biomass for product category j (t below-ground dm/t above-ground dm)

$CF_i$  - Carbon fraction of dry matter for product category j (t carbon/(t dm))

Loss of carbon from fuelwood removals is calculated as follows:

$$L_{fuelwood} = (FG_{trees} * BCEF_R * (1+R) + FG_{part} * D) * CF \quad \text{eq.2.13 (IPCC 2006 Vol. 2)}$$

where

$FG_{trees}$  - Annual volume of fuelwood removal of whole trees

$FG_{part}$  - Annual volume of fuelwood removal as tree parts

$BCEF_R$  - Biomass conversion and expansion factor for conversion of removals in volume to total biomass removals (including bark) for category j (t/m<sup>3</sup>)

D and CF are described above

Finally the loss of carbon from disturbance is calculated as follows:

$$L_{disturbances} = A * BW * (1+R) * CF * fd \quad \text{eq.2.14 (IPCC 2006 Vol. 2)}$$

where

A - Area affected by disturbances

Bw - Average above-ground biomass of areas affected

fd - fraction of biomass lost in disturbance; a stand-replacing disturbance will kill all (fd = 1) biomass while an insect disturbance may only remove a portion (e.g. fd = 0.3) of the average biomass C density.

R and CF are described above

The total carbon flux can then be calculated as follows:

$$\Delta C = \Delta CG - L_{wood-removals} - L_{fuelwood} - L_{disturbances}$$

#### Data sources

Forestry South Africa (FSA) keeps annual statistical data on plantations in South Africa dating back to the 1970s. FSA provided the annual data on total area of Plantation forests from 1980 to 2006 (FSA 2008) together with other relevant data. Supplementary information was obtained from the literature (Taviv et al. 2008).

In 2005 a comprehensive Forestry Assessment was prepared by the Department of Water Affairs and Forestry (DWAF) for the FAO (FAO 2005) which describes the various data sources and their quality. It should be noted that the “other forested land” class used in the FAO report has been excluded from the Forest land class in this 2000 inventory as it was included in the Savanna and Fynbos/Shrubland land classes.

The ratio (R) of below ground to above ground biomass for Pinus and Eucalyptus is sourced from Christie and Scholes (1995) while for other forest categories they are assumed to be the same as in FAO (2005).

D the ratio of dead wood biomass to above-ground biomass of 0.14 which is used in the FAO (2005) report Ch.6.3 is applied for all categories.

The  $BCEF_{sj}$  factors applied for the 1994 inventory were again applied for the 2000 inventory. These factors are lower than the default factors provided by the IPCC 2006 (Vol.4 Ch.4 Table 4.5). These factors were discussed with local experts and were originally based on the conversion of merchantable volume into dry weight. The IPCC 2006 factor includes both conversion and expansion and includes conversion of the merchantable volume (roundwood) to total biomass to account for non-merchantable parts of the tree. However in South Africa the non-merchantable parts are not removed they are simply moved from the live biomass pool into the dead wood pool. It was therefore decided not to account for merchantable volume when calculating losses. It was also decided to keep the factors used in the 1990 inventory which assists data continuity.

For calculation of carbon stock in biomass the Carbon Fraction (CF) default of 0.47 is used (IPCC 2006 Vol. 4 Table 4.3) which falls between the value of 0.5 used in FAO (2005) and the value of 0.45 used for the 1990 inventory (Van der Merwe & Scholes 1998).

Fuel wood consumption in South Africa is not sustainable except for some areas in the northern part of the country (Scholes & Biggs 2005). Since the fuel wood sector is mainly informal available estimates vary significantly (see the South Africa Manual for preparation of the GHG inventory). No information is available about how firewood removed can be divided between total tree and tree parts. It was assumed that fuel wood removal does not affect below ground biomass. For this 2000 inventory the FAO (2005) estimate for fuel wood removal from categories other than plantations was used.

### **5.4.4 Other land converted to forest land**

#### ***5.4.4.1 Source-category description***

This sub-class represents lands that have become Forest Lands since 1980. The change in area from 1980 to 2000 for each plantation category is calculated from the FSA dataset (FSA 2008). The area under acacia reduced slightly over this period by about 38 000 ha. Since Approach 3 could not yet be implemented it is not known into which land use class these lands were converted. It is assumed that abandoned plantations become one of the natural land classes in which the biomass pool is in balance. Therefore for acacia the carbon change was assumed to be zero.

In South Africa the rotation period for forests is relatively short (10 to 25 years) and it is assumed that the biomass growth in land converted to forests is the same as in existing plantations (Forest

remaining Forest). This is supported by analysis of the IPCC data. The IPCC 2006 defaults show that young forest (less than 20 years old) of Africa Eucalyptus has a biomass growth of 13 t dm/ha/a (IPCC 2006 Vol.4 Table 4.9) which is similar to value of 13.2 used for plantations more than 20 years old. The IPCC default for young Africa Pinus is 8 t dm/ha/a which is lower than the value of 10 t dm/ha/a for older forests (IPCC 2006 Vol.4 Table 4.9). The South African value for mature Pinus species is already lower than the IPCC default (4.58 t dm/ha/a) so it does not make sense to reduce it further. Therefore the same values were used as in the Forest remaining Forest sub-class.

#### 5.4.4.2 Emissions calculations / results

According to the 1994 inventory the amount of CO<sub>2</sub> taken up by forestry in 1990 was 17.27Tg CO<sub>2</sub> (Van der Merwe & Scholes 1998). This was based on the assumption that the surface area of land under forests especially plantation forests would continue to increase. It was also expected that this value would increase for the 2000 inventory. However the change in methodology together with new data resulted in a smaller increase of the carbon pool.

**TABLE 5-5: FOREST LANDS CLASS EMISSIONS**

<b>Annual increase in carbon stocks by biomass</b>	<b>C (tonnes/yr)</b>	<b>CO<sub>2</sub> (Gg )</b>
Forest remaining forest	8 777 428	32 183 902
Land converted to forest	5 147 054	18 872 532
Wooded savanna	0	
<b>Total growth (increase in carbon stock)</b>	<b>13 924 482</b>	<b>51 056 434</b>
Loss of carbon from wood removals (harvested products)	4 598 284	16 860 376
Loss of carbon from fuelwood removal	5 771 565	21 162 406
Loss of carbon from disturbance	3 582	13 132
<b>Total loss (decrease in carbon stock)</b>	<b>10 373 431</b>	<b>38 035 914</b>
<b>Total annual carbon stock change</b>	<b>3 551 051</b>	<b>13 020 519</b>

This is partly explained by limitations caused by the static nature of the Tier 1 approach followed. To minimise temporal variations an average harvest for five years (1998 to 2002) was used to represent the year 2000. The net balance of carbon for a given year was calculated as the difference between carbon lost when trees were harvested and carbon gained that year due to area increases or growth increases on existing plots. If the harvest were more than the gain the carbon balance would be negative (i.e. a loss).

The applied Tier 1 methodology assumes that all harvested products lose all their carbon in the same year whereas in reality most of them store carbon over a long time. In the 1994 inventory (Van der Merwe & Scholes 1998) it was estimated that carbon sequestration on long-lived products could be 3.67 Tg CO<sub>2</sub>/a. The IPCC 2006 Guidelines include a new carbon pool called harvested wood products. The changes in carbon stock for these products are calculated in a similar way to solid waste using a first order decay model. Although the model for this calculation is available from IPCC it would have required new data and expertise. It is therefore suggested that the model be used in the next inventory.

A study by Scholes and Biggs has suggested that fuel wood consumption in South Africa is not sustainable (Scholes & Biggs 2005). The calculations in this 2000 inventory demonstrate that fuel wood removal from woodlands is greater than its growth. However some of the fuel wood is collected in woodland savanna. This contribution is not accounted for and needs to be added for completeness.

#### ***5.4.4.3 Uncertainties***

The statistics from FSA were valuable (FSA 2008) with a high confidence rating of 80% (Vorster 2008). They were used to calculate the Forest land that remained forest and the Forest land converted to forest. The FSA data were chosen because they covered the complete time series. Temporal changes were assessed and no outliers were found.

Different sources of data rarely use the same definitions – for example there is a slight overlap in the definitions of woodlands and indigenous forests from two sources (see Taviv et al. 2008 for details). This leads to different surface areas depending on the source used.

The statistics from FSA (2008) were therefore used as well as information from the RSA yearbook (South Africa Yearbook 2007). The biggest difference in surface areas between the FSA and RSA yearbook estimates was for 1997/98 when the FSA value was 11% lower than the RSA yearbook value. In 1994/95 the FSA value was 3% higher than the RSA yearbook value. Therefore the uncertainty range is from -11% to +3%. This is within the confidence level estimate of 80% (Vorster 2008) but the error range would need to be reduced if South Africa intended to match the 3% error range of the industrialised countries (IPCC 2006 Vol. 4 Ch.4). A smaller error range could be achieved by improving the data collection methodologies of the different data suppliers.

Uncertainty could not be estimated for other sub-categories due to the lack of data provided by data suppliers but it would be safe to assume that uncertainty would be higher than for the Forest sub-category.

The uncertainty for the Carbon Fraction (CF) is not high. The range of default values suggested by the IPCC (2006 Vol. 4 Table 4.3) is between 0.43 and 0.49 for tropical and subtropical forests.

The variations in R are the largest for dry forest. The range of default values suggested by the IPCC (2006 Vol. 4 Table 4.4) is between 0.28 and 0.68.

The variations in BCER are the largest for forest categories with the smallest growing stock and can reach up to 30% (IPCC 2006 Vol. 4 Table 4.5).

The values of R and BCER used for South Africa are in the lower range of default values suggested by the IPCC and need to be further verified.

#### ***5.4.4.4 Planned improvements***

Forestry monitoring is complex and needs a combination of remotely sensed data complemented and verified by terrestrial inventories. The status of the data and proposed improvements are described in a number of papers presented in the Natural Forests and Savanna Woodland Symposium IV organised by the Department of Water Affairs and Forestry particularly the paper by Köttsch (2007).

The preparation of the GHG inventory for the Forest class needs to be closely aligned with DWAF's preparation of the Global Forest Assessment required by the FAO. For estimations of biomass and carbon stocks the Forest Assessment process relies on the methodological framework developed by the IPCC and documented in the 2006 IPCC Guidelines (FAO 2007). Harmonising these processes will reduce the reporting burden for DWAF and DEAT.

More research is needed to verify local factors used and to replace IPCC default ratios for above ground to below ground biomass for dead wood by locally derived factors.

Local data is required for young forests particularly the above ground biomass growth for different types of plantations and possibly also for the carbon fraction.

### 5.4.5 Croplands

The Standards South Africa definition of cultivated land is: Land which has been ploughed and/or prepared for the raising of crops (excluding timber production). Unless otherwise stated it includes areas currently under crop fallow land and land being prepared for planting. Class boundaries are broadly defined to encompass the main areas of agricultural activity and are not defined along exact field boundaries. As such all sub-classes may include small inter-field cover types (e.g. hedges grass strips small windbreaks) as well as farm infrastructure (SSA 2004).

#### 5.4.5.1 Source-category description

The 1994 inventory reported that (i) abandonment of managed agricultural lands is one of the important land use practices by humans that result in emission and uptake of CO<sub>2</sub> (Van der Merwe & Scholes 1998) and (ii) agricultural soils in South Africa were a net sink of CO<sub>2</sub> (Du Toit 1992). Sugar cane is listed as the only agricultural residue that is burned before harvesting and was assumed to have the same emission factors as dry grass and Savanna (Van der Merwe & Scholes 1998).

There are several sub-categories that make up cultivated land all of which emit different amounts of GHGs:

- Cultivated permanent commercial irrigated
- Cultivated permanent commercial dryland
- Cultivated permanent commercial sugarcane
- Cultivated temporary commercial irrigated
- Cultivated temporary commercial dryland
- Cultivated temporary subsistence dryland
- Cultivated temporary subsistence irrigated

In the 2000 inventory the emissions from croplands were not estimated as data on land conversions were required for the calculation of emissions from this sector. These data are not available in the public domain.

The only data available (provided in Table 5-6) comes from the 1990 and 1994 inventories. They show agricultural soils being a sink for CO<sub>2</sub>. It is critical to update the data for this sub-sector as it has mitigation potential that could be important for South Africa. Van der Merwe & Scholes (1998) compared the IPCC 1996 methodology results with locally developed calculations which show that croplands in South Africa could be a source of CO<sub>2</sub> emissions. The appropriate methodology and data for croplands will be addressed by the forthcoming agricultural sector inventory.

**TABLE 5-6: CROPLANDS EMISSION**

Year	CO <sub>2</sub> (Gg)
1990	-3 341.5
1994	-7 730.2

Source: DEAT 2004 Appendix 1 and 2

## 5.4.6 Grasslands

### 5.4.6.1 Source-category description

Grasslands cover about one-quarter of the earth's land surface and span a range of climatic conditions from arid to humid (IPCC 2006 Vol.4 Ch. 6). The IPCC (2006) definition states: "Grasslands vary greatly in their degree and intensity of management. Grasslands generally have vegetation dominated by perennial grasses and grazing is the predominant land use. Many Shrublands with high proportions of perennial woody biomass may be considered to be a type of grassland and countries may elect to account for some or all of these Shrublands in the Grassland category."

For the South Africa 2000 inventory Shrublands were separated and only natural and planted grassland were included under Grassland. The AFOLU classification gives the following definitions for these two sub-categories:

- 'Natural grassland' is all areas of grassland with less than 10% tree and/or shrub canopy cover and more than 0.1% total vegetation cover. This class is dominated by grass-like non-woody rooted herbaceous plants which are essentially indigenous species growing under natural or semi-natural conditions.
- 'Planted grassland' is defined in the same way except that it is grown under human-managed (including irrigated) conditions for grazing hay or turf production or recreation (e.g. golf courses). Planted grassland can be either indigenous or exotic species (SSA 2004).

The Grassland biome is one of the most threatened biomes in South Africa with 40% irreversibly transformed and only 2.8% formally conserved. It is estimated that 22.7% of the Grassland biome is currently under cultivation with virtually the entire remainder used as rangeland (O'Connor & Associates 2005). Additional threats are overgrazing temperature increase and reduction in precipitation and increased CO<sub>2</sub> concentrations. In addition fire control can lead to the expansion of woody species.

### 5.4.6.2 Methodological issues

Although the Grassland biome is changing for the GHG emission calculation it is assumed that the carbon in the lands not converted to croplands is in balance with the exception of the impact of fire. A Tier 1 approach has been used which according to the IPCC 2006 (Vol. 4 Ch.6 p.6.6) assumes no change in biomass or soil carbon.

### 5.4.6.3 Data sources

Grassland areas were obtained from the literature as well as NLC land cover datasets. The value from NLC2000 of 25 759 325 ha is similar to the value quoted in Engelbrecht et al. (2004) of 24 million ha and the value of 240 189 km<sup>2</sup> used in the 1994 inventory (van der Merwe & Scholes 1998). The NLC 2000 value was used for this 2000 inventory.

### 5.4.6.4 Uncertainties

The variations in definition of Grassland results in different surface areas being cited by different sources. The use of international sources such as FAO can cause an uncertainty of up to 50% (IPCC 2006 Vol. 4 Ch.6 p.6.13). The overall accuracy of the NLC 2000 is about 66% (ARC & CSIR 2005).

### 5.4.6.5 Planned improvements

No improvement is planned for this class.

## 5.4.7 Wetlands

### 5.4.7.1 Source-category description

Wetlands store 35% of global terrestrial carbon (RAMSAR 2007). For the 2000 inventory three types of wetlands were considered – Wetlands Waterbodies and Peatlands.

### 5.4.7.2 Definitions

The Standards South Africa definition of Wetlands is: Natural or artificial areas where the water level is permanently or temporarily at (or very near) the land surface typically covered in either herbaceous or woody vegetation cover. The category includes fresh brackish and salt-water conditions. Examples include pans (with non-permanent water cover) and reed-marsh or papyrus-swamp. Dry pans are included in this category unless they are permanently dry (SSA 2004).

O'Connor and associates (2005) adds to this definition that Wetlands are characterised by a high water table hygrophilous plants impeded drainage anaerobic conditions for at least part of the year and soils shaped by water-based processes.

The Standards South Africa definition of Waterbodies is: Areas occupied by (generally permanent) open water. The category includes both natural and man-made waterbodies which are either static or flowing and fresh brackish and salt-water conditions. This category includes features such as rivers major reservoirs farm-level irrigation dams permanent pans lakes and lagoons (SSA 2004).

According to the IPCC 2006 requirements (IPCC 2006 Vol.4 Ch.7 p7.5) two types of wetlands have to be considered namely Peatlands and Flooded Lands.

Peatlands are wetlands in which the annual generation of dead organic matter exceeds the amount that decays. Most peat deposits have been accumulating for several thousand years. The IPCC 2006 methodology for emissions from peatlands is essentially the same as that of the IPCC 2003 report on Good Practice Guidance for Land use Land-Use Change and Forestry (IPCC 2003 GPG-LULUCF) the only difference being that emissions from the use of horticultural peat are added.

Emissions from Wetlands vary spatially and over time as they are controlled by the degree of water saturation (which determines anaerobic conditions) as well as by climate and nutrient availability. Generally Wetlands are a natural source of CH<sub>4</sub> while N<sub>2</sub>O emissions are relatively low unless there is a supply of exogenous nitrogen.

### 5.4.7.3 Data sources

The Department of Land Affairs (DLA) Chief Directorate of Surveys & Mapping (CDSM) and DWAF provided the spatial data for Wetlands and Waterbodies for the 2000 inventory though neither is an appointed custodian (see Taviv et al. 2008). The data for dams was supplemented by information provided by Mallory (pers. comm. 2008) which enabled the capturing of the extent of dams from the SPOT data (SAC 2006).

The IPCC 2006 guidelines recommend the estimation of emissions from land converted to Flooded Land. This requires information on the areas of land converted annually to Flooded Land which could not be obtained.

### 5.4.7.4 Methodological issues

Guidelines on the calculation of emissions from Wetlands are provided in IPCC 2006 Guidelines Vol. 4 Chapter 7.

#### 5.4.7.5 Emissions from peatlands

The total area of peatlands in South Africa as provided by the IPCC is 950 000 ha (IPCC 2003 Ch.3 App. 3a3 p 3.282). This value was sourced from *Global Peat Resources* (Lappalainen 1996) and includes “coastal mangroves and other wetlands without any information about the thickness of peat or other organic soils”. The local study by Marneweck et al. (2001) which also includes a spatial analysis shows that the total area of peatlands in South Africa amounts to about 30 000 ha. The difference between the IPCC default and the local data shows how important is to obtain the local value rather than use defaults. Accepting the Marneweck et al. (2001) assumption that the depth of peatlands is about 1 metre this gives a peat volume of about 300 million m<sup>3</sup>. The same study gives values for peatlands mined: “current volume of peat utilized in the country varies between 40 000 and 60 000 m<sup>3</sup>... the demand for peat has declined over the past 10-15 years”. The mined area is less than 0.02% of the total peatlands and is so small that it can be ignored in the emission calculations.

#### 5.4.7.6 Emissions from flooded lands

Methane emissions were calculated using the methodology from IPCC 2006 (Appendix 3. CH<sub>4</sub> Emissions from Flooded Land: Basis for Future Methodological Development) which shows how to estimate emissions from Flooded Land Remaining Flooded Land.

The “fuel” for CH<sub>4</sub> emitted by dams is rotting vegetation soils flooded by reservoirs and the organic matter (plants plankton algae etc.) that flows into reservoirs and is produced in reservoirs. The gases are released at reservoir surfaces at turbines and spillways and downstream. Post-flood emission can occur through diffuse emission bubbling or degassing emissions but the Tier 1 approach only covers diffuse emission.

As emissions from flooded lands have not been previously estimated for South Africa the IPCC Guidelines recommend starting with Tier 1 methodology. This methodology is based on equation 3A.1 below.

$$CH_4 \text{ emissions}_{WW \text{ flood}} = P * E(CH_4)_{diff} * A_{flood \text{ total surface}} * 10^{-6} \quad \text{(Equation 3A.1)}$$

where:

CH<sub>4</sub> emissions<sub>WW flood</sub> = total CH<sub>4</sub> emissions from Flooded Land Gg CH<sub>4</sub> yr<sup>-1</sup>

P = ice-free period days yr<sup>-1</sup> (for South Africa this would usually be 365)

E(CH<sub>4</sub>)<sub>diff</sub> = averaged daily diffusive emissions kg CH<sub>4</sub> ha<sup>-1</sup> day<sup>-1</sup>

A<sub>flood total surface</sub> = total flooded surface area including flooded land lakes and rivers ha

The emission factors E(CH<sub>4</sub>)<sub>diff</sub> for different climate zones are provided in Table 3.A2 (IPCC 2006 Vol.3) and the median average for the warm temperate dry climate zone was selected (see IPCC Guidelines 2006 Vol.4 Ch.3 p.3.39 on definition of climate zones). This climatic zone matches those of the majority of provinces in South Africa. The emission factor for the warm temperate dry climate zone is the lowest of all and therefore provides a conservative estimation.

It is assumed that the area of Flooded Land is the same as the area of waterbodies. This is an overestimation as Waterbodies include rivers lakes and lagoons. However it was decided that for this first estimate this approximation would be sufficient (this is further discussed under 5.2.8.4 “Uncertainties”).

The area of Flooded Land was found to be 566 191 ha. This was calculated using the NLC2000 data supplemented by the DWAF and CDSM datasets as well as information provided by Mallory (pers. comm. 2008) and captured from SPOT data (see Taviv et al. 2008 for details). As no worksheet was available for this calculation it was created in the same format as existing spreadsheets.

The resulting emission of 9.09 Gg CH<sub>4</sub> is about 0.04% of the total CO<sub>2</sub>-equiv emissions estimated for the year 2000. This is a very small contribution to the total emissions.

**TABLE 5-7: CALCULATION OF EMISSIONS FROM FLOODED LANDS**

Sector		Agriculture forestry and other land use				
Category		Flooded land remaining flooded land: CH <sub>4</sub> emissions				
Category code		3B4c				
Sheet		1 of 1				
<b>Equation</b>		<b>Equation 3.A1</b>				
<b>Land-use category</b>		<b>Subcategories for reporting year</b>	<b>Area of flooded land* (ha)</b>	<b>Ice free period  (days year<sup>-1</sup>)</b>	<b>Average daily diffusive emission (Kg ha<sup>-1</sup> day<sup>-1</sup>)</b>	<b>Annual CH<sub>4</sub> emission from flooded land (Gg CH<sub>4</sub> yr<sup>-1</sup>)</b>
Initial land use <sup>1</sup>	Land use during reporting year			(default = 365)	0.044 or Table 3A.2	CH <sub>4</sub> Emission WW <sub>flood</sub> = $\sum_i A_i$ *P*E(CH <sub>4</sub> ) <sub>diff</sub> *10 <sup>-6</sup>
			A <sub>i</sub>	P	E(CH <sub>4</sub> )	
WL <sub>Flooded</sub>	WL <sub>Flooded</sub>	(a)	566 191	365	0.044	9.09
		(b)				

#### 5.4.7.7 Uncertainties

The main sources of uncertainty are inaccuracies in the estimates of the area of flooded land and emission factors.

The uncertainty in estimates of flooded area is described in Taviv et al. (2008). According to IPCC 2006 (Vol.4 Appendix 3) estimates of flooded area can have an uncertainty of up to 10% for countries with large dams and hydroelectric reservoirs and an uncertainty of more than 50% for countries where national databases are not available.

The uncertainty in emission factors is described in the IPCC Guidelines (2006 Vol. 4 Appendix 3 p Ap.3.6). In South Africa the climate zones for six provinces are classified as warm temperate dry and for the other three provinces as tropical dry. The emission factors for these zones are 0.044 and 0.295 kg ha<sup>-1</sup>day<sup>-1</sup> respectively. The simplifying assumption of classifying the whole country as a warm temperate dry zone was made for this 2000 inventory.

The bubbling and degassing component of emissions was ignored which is supported by a study on tropical dams (Abril et al 2005).

In addition to permanently flooded land there are emissions from periodically flooded land. This emission source is not included in the IPCC Guidelines and therefore is not covered in this 2000 inventory. However a study in South Africa (Otter & Scholes 2000) found that Southern Africa Floodplains produce more CH<sub>4</sub> than the region's Savannas consume. This study was based on CH<sub>4</sub> fluxes measured over a two-year period at four sites. It was found that emission rates were

highest when the water level was between 0.1m below the soil surface to 0.4m above the soil surface with emissions declining to zero as the water becomes deeper than 0.4m. This finding suggests that the methodology and the factors for the calculation of emissions from a flooded area need further research for South Africa. It was therefore decided to exclude this emission source from the total emissions reported until more conclusive information becomes available.

#### ***5.4.7.8 Planned improvements***

This source was reported for the first time so improvements to the methodology and emissions factors by the international researchers need to be followed up.

Accuracy would be improved if dams located in different climatic zones (warm temperate dry and tropical dry) were identified accurately and appropriate emission factors applied as the emission factors for these two climatic zones differ widely (0.044 and 0.295 kg ha<sup>-1</sup>day<sup>-1</sup> respectively).

To achieve international acceptance and inclusion in the IPCC Guidelines local research on both periodically and permanently flooded land should also be promoted.

### **5.4.8 Settlements**

#### ***5.4.8.1 Source-category description***

Roughly 2% of the earth's terrestrial surface is covered by urban areas which are home to about 3 billion people – a number that is projected to double within five years (IPCC 2006 Guidelines Vol.4 Ch.8 p 8.5). In South Africa urban areas covered 2.5% of South Africa's land by the late 1980s (State of Environment 1999 <http://www.ngo.grida.no/soesa/nsoer/issues/land/state.htm>). More than half of the population lives in rural areas.

#### ***5.4.8.2 Definition***

The definition of the Settlements class according to Standards South Africa is: A generic urban class essentially comprising all formal built-up areas in which people reside on a permanent or near-permanent basis identifiable by the high density of residential and associated infrastructure. Includes both towns villages and where applicable the central nucleus of more open rural clusters (SSA 2004).

#### ***5.4.8.3 Data sources***

According to Fairbanks (2000) the combined surface area of settlements in South Africa was 2 127 000 ha in 1983. The spatial layers of settlements extracted from NLC 2000 for the whole country give the surface area as 1 832 725 ha. The value used for this 2000 inventory is very similar to the value of 1.85 million ha used in the State of Environment report (<http://soer.deat.gov.za/themes.aspx?m=45>).

#### ***5.4.8.4 Methodological issues***

The methodology for emissions calculation for settlements is described in the IPCC 2006 Guidelines Vol.4 Ch.8. Inventories based on the IPCC 1996 Guidelines did not include settlement areas.

The carbon pools for settlements include above ground and below ground biomass dead organic matter (DOM) and soil carbon.

The category 'Settlements remaining Settlements' refers to urban areas that were settlements the last time data was collected and are still settlements. As the 2000 inventory is the first inventory to consider Settlements it is proposed that the 2000 data be used as the base data for future calculations.

#### **5.4.8.5 Uncertainty**

Fairbanks (2000) stated that the method which was used to determine the area for the previous estimations was unknown implying that the quality of information is not known. The overall accuracy of the NLC 2000 is about 66% (ARC & CSIR 2005).

#### **5.4.8.6 Planned improvements**

To increase transparency and eliminate errors it is good practice to report the total settlement area regardless of whether stocks are changing (IPCC Vol.4 Ch. 8 p 8.26).

It is recommended that for the next inventory both ‘Settlements remaining Settlements’ and ‘Land converted to Settlements’ be reported.

Information on the emission factors for Settlements is currently very limited. A study on urban forest has been conducted in Canberra Australia (Brack 2002). This and further studies could assist the application of Tier 2 methodology in South Africa.

The Tier 1 methodology assumes no change in carbon stocks meaning that the growth and loss of carbon are in balance. South Africa as most of the developing countries experiences the process of urbanisation and therefore this assumption is not correct. However it was decided that for this inventory Tier 1 methodology is appropriate for South Africa as the Settlements category is not a key category and areas under settlements are relatively small compared to the total land area (less than 2%).

### **5.4.9 Other lands**

#### **5.4.9.1 Source-category description**

The Other Lands sub-class includes bare soil rock ice and all land areas that do not fall into any of the other classes (IPCC 2006 vol.4 Ch.9 p. 9.4). The classification applied for this 2000 inventory is more specific and includes the SSA (2004) groups “bare rock and soil” as well as “mines and quarries”.

Savanna is defined as rolling grassland scattered with shrubs and isolated trees normally found between tropical rainforest and desert biome. Savanna “is the largest biome in South Africa occupying over one third of the area of South Africa” (Mucina & Rutherford 2006). The FAO (2008) definition is accepted in this inventory.

The Arid Shrubland class is made up of deserts Nama and Succulent Karoo. The Mucina and Rutherford (2006) definition was accepted for this sub-class.

The Fynbos and Shrublands sub-class includes fynbos and shrublands derived from “Shrubland and low Fynbos” and “Thicket Bushland Bush Clumps High Fynbos” – NLC 2000 classes that do not fall into any of the other biomes. Fynbos is a member of the Global Mediterranean biome which has large number of species and a wide local and regional endemism. It is classified as a global hot spot.

#### **5.4.9.2 Methodological issues**

The Tier 1 methodology assumes no change in carbon stocks so growth and loss are in balance. This methodology is appropriate for South Africa as all sub-classes of Other Lands class are not key categories.

The 1994 inventory included Wooded Savanna as Woodlands and included its biomass accumulation as carbon sink. According to Shackleton (1998) the deadwood production in savannas of South Africa is about 1.7% of standing biomass and is less than the rate of production of living biomass leading to accumulation of biomass. A more recent study attempted

to quantify savanna densification complemented by fire control leading to a consequent increase in biomass (Taviv et al. 2007). Another recent study based on carbon flux measurements using an eddy covariance technique (Archibald et al. 2008) found that the long-term net ecosystem exchange is close to zero. No comprehensive model is yet available to explain the coexistence and productivity of tree and grass components across diverse savannas (Sankaran et al. 2004). In the 2000 inventory it was assumed that the Savanna class biomass is in balance unless there had been biomass burning. More clarity is required to incorporate the results of the recent research in the next inventory.

## **5.5 Aggregate sources and non-CO<sub>2</sub> emissions on land**

This class includes eight categories:

- Biomass burning (IPCC section 3C1)
- Liming (IPCC section 3C2)
- Urea application (IPCC section 3C3)
- Direct N<sub>2</sub>O emission from managed soils (IPCC section 3C4)
- Indirect N<sub>2</sub>O emission from managed soils (IPCC section 3C5)
- Indirect N<sub>2</sub>O emission from manure management (IPCC section 3C6)
- Rice cultivation (IPCC section 3C7)
- Harvested products (IPCC section 3D1)

Only the first of these (biomass burning) has been quantified using IPCC 2006 Guidelines. Carbon emission from liming (3C2) is included in croplands and indirect N<sub>2</sub>O emissions (3C4 and 3C6) are included under agricultural sector calculations (see section 5.1 above). Rice cultivation is not applicable in South African agriculture.

Harvested products are accounted for in the calculation for the Forestry Lands class. The applied Tier 1 methodology assumes that all harvested products lose all their carbon in the same year but in reality most store carbon over a longer time. In the 1994 inventory (Van der Merwe & Scholes 1998) it was estimated that carbon sequestration in long-lived products could be as high as 3.67 Tg CO<sub>2</sub>/a. The IPCC 2006 Guidelines include a new carbon pool called “harvested wood products”. The changes in carbon stock for harvested wood products are calculated in the same way as calculations for solid waste using a first order decay model available from IPCC. Since this is not a key category it was decided not to use this model in this inventory as it requires new data and expertise. It is suggested that it be applied in the next inventory.

### **5.5.1 Biomass burning**

#### ***5.5.1.1 Source-category description***

Fire plays an important role in many South African biomes. In Grasslands Savanna and Fynbos fires are necessary in order to maintain ecological health. Biomass burning also plays a significant role in biogeochemical processes. Most biomass burning happens either anthropogenically (by people) or as a result of veld fires (wildfires).

Approaches to fire management in the fire-prone ecosystems of South Africa have undergone several changes based on numerous local studies. One recent study (Van Wilgen et al. 2004) found that “the area which burned in any given year was independent of the management approach and was strongly related to rainfall (and therefore grass fuels) in the preceding two

years. On the other hand management did affect the spatial heterogeneity of fires as well as their seasonal distribution.”

Fire control is one of the factors which lead to the enhancement of savanna thickening more commonly known as “bush encroachment” or savanna extension. Bush encroachment is a widespread phenomenon occurring in savanna and grassland regions of the world. According to Hudak and Wessman (2000) a 30% increase in woody cover was observed worldwide between 1955 and 1996 and this would have increased the carbon sink. The mitigation potential and the cost of this intervention were quantified (Taviv et. al. 2007).

#### 5.5.1.2 Methodological issues

The Tier 2 methodology and Equation 2.27 from IPCC 2006 Guidelines were applied. The IPCC (2006) requires calculating five types of burning:

1. Grassland burning (which includes burning perennial woody shrubland and savanna)
2. Burning agricultural residues
3. Burning of litter understorey and harvest residues in Forest Land
4. Burning following forest clearing and conversion to agriculture
5. Other types of burning (including wildfires)

Type 4 was not included in the 2000 inventory as it was considered to be insignificant in South Africa.

The IPCC 1996 Guidelines required non-CO<sub>2</sub> emissions from agricultural crop residue and Savanna burning to be reported under Agriculture. The IPCC 2006 Guidelines adopt a more consistent approach stating that all fires on managed lands should be reported. Fire is treated as a disturbance that affects not only the biomass (in particular the above ground biomass) but also dead organic matter such as litter and dead wood (IPCC 2006 Vol. 4 Ch. 2).

CO<sub>2</sub> net emissions should be reported when CO<sub>2</sub> emissions and removals from the biomass pool are not equivalent in the inventory year. For Grassland biomass burning and the burning of agriculture residues the assumption of equivalence (synchrony principle) is generally reasonable.

Although the IPCC 1996 Guidelines only required calculation of emissions from Savanna South Africa reported in its 1994 inventory on emissions from all main biomes. This was further extended and improved for this 2000 inventory. Tier 2 methodology and equation 2.27 from the IPCC 2006 Guidelines were used to calculate emissions:

$$L_{fire} = A \cdot M_B \cdot Cf \cdot G_{ef} \cdot 10^{-3}$$

where

$L_{fire}$  = mass of greenhouse gas emissions from fire in tonnes of each GHG e.g. CH<sub>4</sub> N<sub>2</sub>O etc

A = area burnt ha

$M_B$  = mass of fuel available for combustion tonnes ha<sup>-1</sup> – this includes biomass ground litter and dead wood

Cf = combustion factor dimensionless (defaults in IPCC 2006 Table 2.6)

$G_{ef}$  = emission factor g kg<sup>-1</sup> dry matter burnt (default values in IPCC 2006 Table 2.5)

Sugar cane burning was also reported in the previous inventory under burning of agricultural residue. This residue burning is still an acceptable practice in South Africa (Hurly et ally et al 2003) but no published data is available on the areas burnt.

Emissions from fires were reported separately in new tables under IPCC Code 3.C.1 which sets out spreadsheets for the main required land use classes (Forest Grasslands Croplands and Wetlands). The IPCC spreadsheets were combined into one spreadsheet with the summary sheet.

#### ***5.5.1.3 Data sources***

In order to calculate emissions from veld fires in South Africa it is necessary to calculate the total area of different vegetation types burnt. Eight different biome types were used for this analysis based on a reclassification of the 2006 map of biomes for South Africa.

Unlike for the 1990 inventory when the burnt area of each vegetation type had to be estimated from reports on the fire return period (Scholes et al. 1996) it is now possible to use remote-sensing data devices to get estimations of burnt area. These devices cannot identify all burning as they are restricted by the scale of observation (usually 500m to 2km) and sometimes by extended periods of cloud cover (although this is not usually a problem in South Africa). Even so they provide the first regional-scale empirical data on burning on the sub-continent.

#### ***5.5.1.4 Data preparation***

A recently released monthly burnt area product based on a Moderate Resolution Imaging Spectroradiometer (MODIS) (MCD45A1 Roy et al. 2008) was available for 2000-2008. This was downloaded and reprocessed into eight annual (burn-no burn) data surfaces. Invalid data was excluded from the analysis. The data files were re-projected to an Albers equal area projection. The map of biomes was also re-projected and converted to raster format. The data were then combined in a spatial analysis software package to produce summary values of the number of square kilometres of burnt area for each year for each vegetation group (Arid Shrubland Forest Fynbos Grassland Savanna Thicket Waterbodies and Wetlands).

#### ***5.5.1.5 Incorporating plantation fires into the forest category***

The forest category was dealt with differently as most forest fires in South Africa occur in plantation forests.

A 26-year dataset on plantation fires was available and this was used to fill the Forest Burnt Area category. The forest burnt area was then calculated in two steps.

First all pixels within the forest biome (natural forest) that were identified as burned were assumed to be grassland fires: these were therefore subtracted from the forest burnt area total and added to the grassland burnt area total. The same was done for the thicket biome.

Second the area of plantation fires for each year was obtained from the plantation dataset and substituted into the burnt forest area value. Finally the area of forest and grassland was altered – the total area of plantation (also obtained from the plantation database) was added to the forest category and subtracted from the grassland category to reflect the fact that plantations generally occur in the grassland biome. Thus the resulting table shows the ‘forest’ class to include all plantations while the grassland class excludes all areas transformed to plantation.

#### ***5.5.1.6 Calculation of area burnt***

Table 5-8 shows the percentage of each vegetation category that burned each year according to the satellite-derived MODIS burnt area product (collection 5). Plantation values represent plantations and natural forest. It was assumed that natural forest thicket and waterbodies do not burn.

**TABLE 5-8: PERCENTAGE OF EACH VEGETATION CATEGORY THAT BURNED 2000-2007**

Biome	2000	2001	2002	2003	2004	2005	2006	2007
Arid shrubland	0.02	0.01	0.02	0.04	0.03	0.03	0.01	0.03
Plantations	1.24	1.21	2.08	2.04	1.61	2.08	--	--
Fynbos	0.98	0.63	1.21	1.19	0.53	1.08	1.06	0.75
Grassland	8.39	9.42	9.58	8.17	6.53	10.22	8.91	9.12
Savanna	3.64	5.17	4.38	2.08	2.89	4.92	4.26	3.05
Thicket	0	0	0	0	0	0	0	0
Waterbodies	0	0	0	0	0	0	0	0
Wetlands	3.47	3.23	4.09	3.14	3.15	4.65	4	2.82

The mean percentage and the standard deviation were calculated from this data and used in conjunction with the area for each biome to determine burnt area (BA). The results are presented in Table 5-9.

The percentage of area burnt for agricultural residue was assumed to be the same (50%) as the value used in the 1994 inventory (Van der Merwe & Scholes 1998).

**TABLE 5-9: MEAN AREA OF EACH VEGETATION CATEGORY THAT BURNED (BA)**

Biome	Area (km <sup>2</sup> )	Mean BA (%)	Mean BA (km <sup>2</sup> )
Arid shrubland	335 055	0.02 (0.01)	80 (36)
Plantations	13 911	1.71 (0.42)	238 (58)
Fynbos	85 949	0.93 (0.26)	798 (223)
Grassland	346 019	8.79 (1.12)	30424 (3875)
Savanna	428 976	3.80 (1.07)	16296 (4513)
Wetlands	22 365	3.57 (0.62)	794 (140)
<b>Total</b>	<b>1 271 588</b>		<b>48633</b>

(Figures in brackets are standard deviations)

It should be noted that the areas in Table 5-9 differ from the values for AFOLU classes as biome data were used for the calculations.

The area under sugar cane was sourced from Abstracts of Agricultural Statistics ([www.nda.agric.za](http://www.nda.agric.za)) and the representative value was calculated as a five-year average for the period of 1998 to 2002.

The amount of fuel that is possible to burn in any area can be determined from the area burnt and the density of the fuel ( $M_B$ ) present. The fuel density can include biomass dead wood and litter which will vary as a function of the type age and condition of the vegetation.

The values for fuel density were sourced from the 1994 inventory. The only exceptions were Fynbos and Savanna/Grasslands. For fynbos a more accurate value of 12.9 t/ha (instead of the 1994 value of 20 t/ha) was sourced from the IPCC default (IPCC 2006 Table 2.4). This value is

very close to the value of 12.8 t/ha reported in a local study done by Richardson et al. (1994). For Grasslands and Savanna the data were updated from recent local measurements (Hély et al. 2003).

The combustion factor (Cf) is a measure of the proportion of the fuel that is actually combusted. It varies according to type of vegetation season of burning and moisture content. The values for Cf were sourced from the 1994 inventory with the exception of Grasslands and Savanna. For these the combustion factor was calculated by relating field measurements of moisture-content and combustion completeness (Hély et al. 2003) to seasonal patterns of burning (Archibald et al. in press). This resulted in a value of 0.88 which is slightly higher than the IPCC default (0.74) but lower than the estimate in the 1994 inventory (0.95).

Finally there is the emission factor which gives the amount of a particular greenhouse gas emitted per unit of dry matter combusted. This can vary as a function of the carbon content of the biomass and the completeness of combustion. The values for emission factors were sourced from the 1994 inventory.

The emissions from wetlands were assumed to be zero in the 1994 inventory but the MODIS data showed that biomass burning occurs in wetlands. These emissions were added on the assumption that the factors for wetlands are the same as for grasslands.

#### 5.5.1.7 Emissions calculations / results

The emissions from biomass burning are presented in the table below.

**TABLE 5 -10: TOTAL BIOMASS BURNING EMISSIONS (T/A) 2000**

Land type	Code	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	CO <sub>2</sub> eq
Forest	3C1a	471.24	9.12		662.79
Croplands	3C1b		1.79	0.05	52.10
Grasslands	3C1c		39.47	2.47	1593.56
Wetlands	3C1d		0.67	0.04	27.22
<b>Total</b>		<b>471.24</b>	<b>51.06</b>	<b>2.56</b>	<b>2 335.67</b>

It should be noted that the Forest category includes Fynbos and Arid Shrublands while the Grasslands category includes Savanna.

The main differences between this 2000 inventory and the previous inventories are: the inclusion of CO<sub>2</sub> emission for Forestry class the addition of emissions from Wetlands and more accurate data for burnt areas.

The CH<sub>4</sub> CO NO<sub>x</sub> and NMVOC emissions are slightly lower than the values calculated in the 1994 inventory as a result of lower values for burnt areas. However N<sub>2</sub>O emissions are slightly higher as a result of the assumption that all Savanna is grassy.

#### 5.5.1.8 Uncertainties

According to Scholes and Andrease (2000 cited in Mucina & Rutherford 2006) biomass burning also results in seasonal troposphere ozone enhancement. Korontzi et al. (2003 cited in Mucina & Rutherford 2006) state that fire is an important generator of aerosols and trace gases from Savannas. Fires also lead to formation of inert carbon (charcoal or char). However knowledge on

rates of formation of char and subsequent turnover rates is limited and hence cannot be included in this inventory (IPCC 2006 Vol.4 Ch. 2).

#### *5.5.1.8.1 Uncertainty in area burnt*

The Moderate Resolution Imaging Spectroradiometer (MODIS) burnt area product is one of three multi-year burnt area products available currently (Tansey et al. 2008; Roy et al. 2008; Simon et al. 2004). This product produces a finer resolution than other products (500m rather than 1km) and uses a more sophisticated change-detection process to identify a burn scar (Roy et al. 2005). The MODIS product also provides ancillary data on the quality of the burn scar detection and shows where cloud cover or missing data prevented identification of burnt pixels.

A recent accuracy assessment shows that the Moderate Resolution Imaging Spectroradiometer (MODIS) burnt area product identifies about 75% of the burnt area in southern Africa (Roy et al. in press). For each 500m pixel the product gives the approximate day of burning (accurate to within eight days) or a code indicating ‘unburned’ or ‘no burning detected but snow detected/water detected’ or ‘insufficient number of MODIS observations to make a detection decision’ (usually due to cloud or missing data). The ancillary processing path and quality information are also provided.

Due to the different scales of the remotely sensed burnt area data and the biome data and the fact that Forest and Thicket patches are scattered throughout the Savanna and Grassland biomes some corrections had to be made for mis-classified pixels in the Waterbodies Thicket and Forest classes.

In the case of the Forest and Thicket classes it was assumed that these pixels were actually Grassland pixels that burnt and the burnt area values were adjusted accordingly (see discussion on plantation fires below). A very small area ( $\pm 5 \text{ km}^2$ ) of the Waterbodies class was classified as burnt and this area was divided equally between the remaining seven classes.

The area burnt under sugar cane is highly uncertain as no published data is available. Recent research has shown that “green harvesting” has many benefits but the replacement rate of burning by this new and more conservative practice is not known. The estimate of 50% of area burnt which has been used in this 2000 inventory is probably an over-estimation.

#### *5.5.1.8.2 Uncertainty in fuel density*

Fuel density varies as a function of type age and condition of the vegetation. The amount of fuel available for combustion is also affected by the type of fire. For example fuel available for low-intensity ground fires in forests will be largely restricted to litter and dead organic matter on the surface whereas a higher-intensity ‘crown fire’ will consume substantial amounts of tree biomass as well. The values used in the 1994 inventory did not include dead wood and litter and therefore could be under-estimations. The calculations for the year 2000 did not distinguish between types of fire or take into account the season when the fire occurs (early season burns have lower fuel density than mid/late season burns). All these factors increase uncertainty.

The IPCC default for fuel density for fynbos is quite accurate. According to IPCC 2006 Table 2.4 it is  $12.9 \pm 0.1 \text{ t/ha}$ . This default value and standard deviation were verified using a local study by Richardson et al. (1994) who arrived at a very similar value of 12.8 t/ha.

The biggest uncertainty is for Savanna as the fuel density of Savanna can vary from 2.1 to 7 t/ha depending on type and season. The standard deviation could be as high as 70% (IPCC 2006 Table 4).

The local field data on fuel loads was used to define fuel density for this 2000 inventory.

#### *5.5.1.8.3 Uncertainty in combustion fraction and emission factors*

The combustion fraction varies as a function of the size and architecture of the fuel load – a smaller proportion of large coarse fuel such as tree stems will be burnt compared to fine fuels such as grass leaves. The combustion fraction also depends on the moisture content of the fuel and the fire's intensity and rate of spread which is markedly affected by climatic variability and regional differences (IPCC 2006 Table 2.6).

The combustion factor can vary between 0.4 and 0.95. The inaccuracy is higher for lower values (over 50% for the 0.4 value of the Savanna category). In this 2000 inventory only the overall Plantation category has a value as low as 0.4 but in this case it is more accurate as standard deviation for most of the individual plantation categories is 25% or lower. For the rest of the categories only higher values (0.74 to 0.95) were used so the expected standard deviation should be below 25%.

The emission default factors have an accuracy in the range of 30% (IPCC 2006 Table 2.5). The data used in this 2000 inventory is based on an extensive local study (SAFARI) (Hély et al. 2003) and should have an even greater accuracy.

In order to calculate emissions from veld fires in South Africa it is necessary to calculate the total burnt area of different vegetation types in the country. Eight different biome types were defined for this inventory. Remotely-sensed data products were used to get estimations of burnt area using a Moderate Resolution Imaging Spectroradiometer (MODIS) (MCD45A1 Roy et al. 2008). This study covering 2000 to 2008 provided the first regional-scale empirical data for burning on the sub-continent.

The area under sugar cane was sourced from Abstracts of Agricultural Statistics ([www.nda.agric.za](http://www.nda.agric.za)) and the representative value was calculated as a five-year average from 1998 to 2002.

Most of the other parameters were sourced from the 1990 inventory (Van der Merwe & Scholes 1998) and the IPCC defaults. For Grasslands and Savanna the fuel density and combustion factor data were updated from recent local measurements (Hély et al. 2003).

In the 1994 inventory the emissions from wetlands were assumed to be zero. The MODIS data showed that biomass burning occurs in wetlands. For the 2000 inventory these emissions were added using the assumption that the factors for wetlands are the same as for grasslands.

#### *5.5.1.9 Quality control*

South Africa is one of the leaders of research into biomass burning. The 2000 inventory used detailed methods to derive the input needed as well as very comprehensive and locally relevant data. This improved the accuracy of the emission estimate significantly when compared to previous inventories and even when compared to the inventories submitted by other countries.

#### *5.5.1.10 Planned improvements*

The accuracy could be improved if Savanna were split into Woody and Grassy sub-categories.

## 6 WASTE

The IPCC Guidelines (IPCC 2006 Vol. 5. Chapter 1) list the main waste sector emissions sources as:

- Solid waste disposal (section 4.A IPCC 2006 Vol. 5. Chapter 3)
- Biological treatment of solid waste (section 4.B IPCC 2006 Vol. 5. Chapter 4)
- Incineration and open burning of waste (section 4.C IPCC 2006 Vol. 5. Chapter 5)
- Waste water treatment and discharge (section 4.D IPCC 2006 Vol. 5. Chapter 6)

It is estimated that in 2000 the disposal of solid waste contributed to under 2% of total greenhouse gas (GHG) emissions in South Africa mainly through emissions of methane (CH<sub>4</sub>) from urban landfills.

Landfill gases (LFGs) which include methane are produced through the natural process of bacterial decomposition of organic waste under anaerobic conditions. Production of LFGs starts six to nine months after the waste is deposited in a landfill and can continue for several decades.

In this 2000 inventory only those greenhouse gases generated from managed disposal landfills in South Africa are presented. There are two reasons for this. Firstly data on waste dumped in unmanaged and uncategorised disposal sites have not been documented. Secondly most of the unmanaged and uncategorised disposal sites are scattered throughout rural and semi-urban areas across South Africa and are generally shallow (i.e. less than 5m in depth). In such shallow sites a large fraction of the organic waste decomposes aerobically which means methane emissions are insignificant compared those from managed landfill sites.

Besides these gaps in the data information on the quantities of waste generated in South Africa is far from complete. There is no periodically updated inventory on the various waste streams which include domestic wastes industrial wastes and sludge from waste-water treatment plants. However there are alternative forms of data available to estimate quantities of waste: the use of population statistics; previously estimated waste-generation rates dating from the 1990s; population distribution between urban and rural areas; and other data sources. Using these sources it becomes feasible to estimate the annual waste quantities that are generated and disposed of in managed municipal solid waste (MSW) landfills from 1950 to 2000 in South Africa and hence the GHGs emissions from this source.

### 6.1 Managed disposal in landfills: land filling of municipal waste

#### 6.1.1 All categories

##### *6.1.1.1 Source-category description*

Waste streams deposited into managed landfills in South Africa comprise waste from households commercial businesses institutions and industry as well as from the clearing of gardens and parks.

A State of Environment report (<http://soer.deat.gov.za/themes.aspx?m=369>) estimated that waste from households commercial enterprises institutions and the manufacturing sector was approximately 13.5 to 15 million tonnes annually. In addition industrial wastes generally handled and disposed of onsite were estimated to be about 22 million tonnes annually.

In this 2000 inventory report only the organic fraction of the waste in solid waste disposal sites in South Africa was considered for estimations of GHG emissions. Other waste stream components like metals ash plastics rubble and soil were excluded because they generate insignificant quantities of methane from landfills.

Based on the activity data and other variables a total of 385 Gg methane (or 8.09 Mt CO<sub>2</sub> equivalent) was estimated as being generated from landfills for the year 2000. This estimate was based on the assumption that the urban population of the country had good access to well managed solid waste dumping sites.

The methane emissions from landfills using first-decay-order (FOD) methodology are presented in Table 6-1 for the period 1990 to 2000. The estimations are based on the bulk waste because there is no waste composition data for the period under study.

The increasing quantities of methane emissions from landfills is a direct consequence of South Africa's higher rate of waste generation which itself is a consequence of the rapidly increasing population in the urban areas of the country and of better basic services provision to citizens. This trend is likely to continue as the government is attempting to meet universal millennium development goals (MDGs) by 2014. Trends in methane emissions from landfills in South Africa show a considerable increase from 1990 to 2000 – about 71%.

**TABLE 6-1: WASTE METHANE EMISSIONS FROM MANAGED LANDFILLS**

Year	CH <sub>4</sub> emissions (Gg)	CH <sub>4</sub> emissions (Tg)	CH <sub>4</sub> emissions (Tg CO <sub>2</sub> e)
1990	225	0.225	4.73
1991	234	0.234	4.91
1992	245	0.245	5.14
1993	257	0.257	5.39
1994	270	0.270	5.67
1995	285	0.285	5.99
1996	302	0.302	6.34
1997	320	0.320	6.72
1998	340	0.340	7.14
1999	362	0.362	7.60
2000	385	0.385	8.09

Table 6-1 shows total emissions in South Africa to be significantly lower for the year 2000 than the USA's 6 280 Gg (USEPA 2007) and Australia's 703 Gg (DEWR 2007). Per capita South Africa is also significantly lower with 8.5kg methane emissions per capita for 2000 compared to 21.7kg for the USA and 35.5kg for Australia.

Van der Merwe and Scholes (1998) estimated emissions from landfills in 1990 in South Africa using the theoretical gas yield methodology (IPCC 1997). Their results incorporated in the 1990 South African GHG inventory reported the methane emissions from landfills as 359 Gg (7.54 Tg CO<sub>2</sub> equivalent). This is 37% higher than computed values derived from the FOD model (225 Gg for 1990) shown in Table 6-1.

However it is possible to account for this large margin. The theoretical gas yield methodology assumes that all the organic matter deposited into landfills decomposes completely within a year. In reality the half-lives of the organic components of the waste are longer than a single year which means the methodology over-estimates actual emissions. For the emission estimations reported here the FOD model used a default half-life of 14 years under the bulk waste conditions as recommended by the IPCC Guidelines of 2006.

A further discrepancy between the two methodologies is due to the assumption in the theoretical gas yield methodology that the annual waste quantities and compositions were relatively constant over the previous several years. In fact neither the quantities nor the compositions are likely to have been constant in South Africa because of the instability of the urban population in the 1980s. There is no way of verifying that these are all the reasons for the discrepancy since there is no consistent documented data for waste disposal into landfills for the period.

Another reason for the comparatively lower estimates of the FOD methodology is that the FOD model reflects the time lags and slower growth in emissions from landfills. This point is noted by Bogner et al. (2008) who compare the methane emissions from USA landfills based on the results of USEPA (2006) which used the theoretical gas yield methodology with those of Monni et al. (2006) who used the FOD model approach.

The reported range of values for the methane emissions from landfills in South Africa for both 1990 and 2000 using the FOD model (IPCC 2006) are in agreement with previous model predictions of Bogner and Lee (2005) who estimate the total annual methane emissions from landfills in South Africa to range from about 200 Gg to 400 Gg.

It should be noted that the waste sector methane emissions reported by South Africa to the UNFCCC (DEAT 2004) were significantly higher at 688 Gg for 1990 and 743 Gg for 1994. The reasons were due both to the error caused by applying the theoretical gas yield methodology and an over-estimation of the size of the population that has access to waste collection services (see 7.1.1.2.1).

#### ***6.1.1.2 Methodological issues***

For the 2000 GHG inventory it was assumed that all methane generated came from managed municipal solid waste (MSW) landfills. A first order decay (FOD) model was used for estimating the methane emissions from MSW landfills as described by IPCC guidelines (IPCC 2006). The FOD model required historical data for at least three to five half-lives so the data used in the model included the quantities of waste disposed annually into landfills from 1950 to 2000 (see section 7.1.1.2.1).

In addition to the annual waste quantities other parameters are used to estimate methane generated: emission rates half-lives of the bulk waste stream rate constants methane correction factor (MCF) degradable carbon fraction and other factors described in Vol. 5 Ch. 3 of the IPCC Guidelines (IPCC 2006). In cases where no country-specific values were available for South Africa default values were used.

Emission constants are climate-dependent as they depend on the moisture content of the landfill waste and the rate of decomposition. Given the diversity of climate in South Africa separate data for all South Africa's geographical regions had to be used to assess the mean annual precipitation (MAP) the ratio of mean annual precipitation to the potential evapotranspiration (PET) and the mean annual temperature (MAT).

The data presented in Table 6-2 show that South Africa can be categorised as a dry temperate climatic region according to the IPCC classification (IPCC 2006 Vol.5 Ch.3) and therefore the

IPCC default values for various parameters in the model were based on the dry temperate climatic conditions.

**TABLE 6-2: MEAN ANNUAL TEMPERATURES AND RAINFALL FOR DIFFERENT REGIONS IN SOUTH AFRICA**

Province	MAP (mm)	MAT (°C)	PET (mm)	MAP/PET
Limpopo	527	20.0	2218	0.238
Mpumalanga	736	17.1	1946	0.378
North-West	481	18.3	2646	0.182
Northern Cape	202	17.4	2690	0.075
Gauteng	668	16.5	2178	0.307
Free State	532	15.8	2233	0.238
KwaZulu-Natal	845	18.1	1770	0.477
Eastern Cape	552	16.1	1930	0.286
Western Cape	348	16.5	2230	0.156

(Source: Schulze 1997)

To ensure that methane emission estimates satisfy IPCC recommendations carbon stocks must be calculated for at least three to five half-lives. The default bulk waste half-life is 14 years under dry temperate climatic conditions (IPCC 2006 Vol.5 Ch.3). In this 2000 inventory the carbon stock was estimated for period of 50 years so as to cover more than three half-lives. Since the first comprehensive estimates of various quantities and types of waste were reported in 1998 (DWAF 1998) linear interpolating and extrapolating of various parameters to derive the annual waste quantities over the period from 1950 to 2000 were used.

An extensive literature review together with consultation with experts was undertaken on gas extraction from landfills in South Africa. This indicated a low recovery of methane not exceeding 0.1 Gg in any given year (Lombard 2004). Prior to the year 2000 many of the landfill gas recovery projects had been running for very limited periods of time most of them under six months so methane recovery from landfills was assumed to be negligible in this inventory.

Beyond 2000 methane recovery will change the GHG inventory related to waste sources in South Africa as many clean development mechanism (CDM) projects have commenced full-scale operations. Considerable quantities of methane will be recovered as the activity lifespans of most of these projects range from seven to 21 years (DME 2008).

#### **6.1.1.3 Quantities of landfilled waste**

A great challenge in South Africa one which is common to many developing countries is the limited and at times total lack of statistical data on waste quantities and types of waste (whether generated land-filled recycled incinerated) annual waste composition matrixes and specific categorisation of solid waste disposal sites (SWDS) among others. It is known that some waste is deposited in industrial landfills but no data which could be used in estimating methane emissions from such sources could be obtained. There is no reliable data on waste disposed into landfills from industrial sources (DWAF 2001).

Because of all these constraints the quantities of MSW used for computing the methane generated from landfills in South Africa had to be derived from simulations based on various parameters and assumptions which can be summarised as follows:

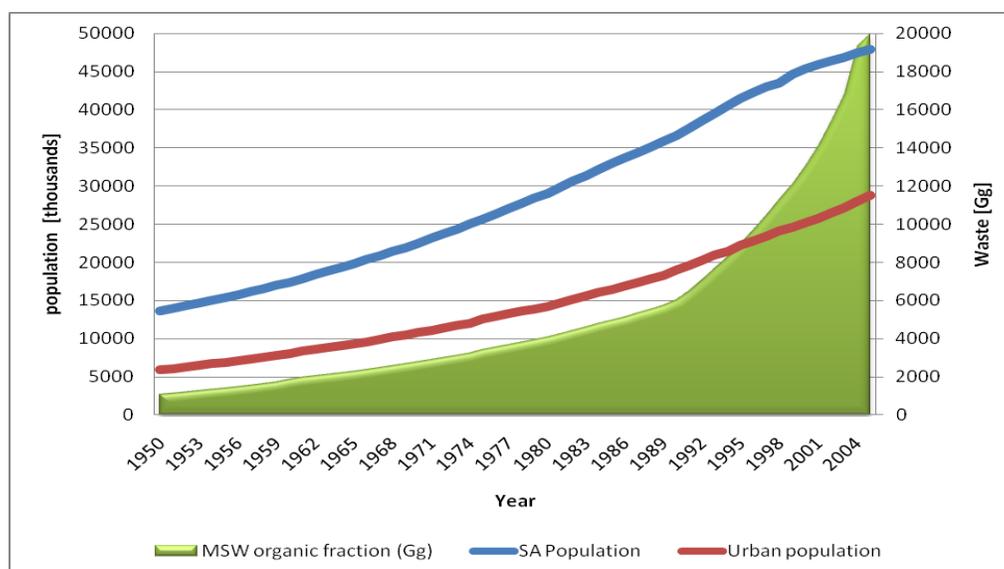
The base waste generation rates for South Africa in 1990 were estimated as 318 kg/cap/a (Van der Merwe & Scholes 1998). After careful examination of the generation rates and the disparities of generation rates per province (DWAF 1998) the estimated 318 kg/cap/yr was presumed to be more representative if it related to the organic fraction of MSW. Using this estimate with 1990 as the base year the MSW quantities generated and disposed of into landfills were computed for the period 1950 to 2000.

For these computations the following assumptions were made. Firstly the waste growth rate from 1990 to 2000 assumed to grow with the GDP growth. Lower waste growth rate assumed for the earlier period (2% for the period 1950 to 1960 and 1% for the period 1961 to 1989). According to Statistics South Africa (Kok and Collins 2006) South Africa's urban population grew from about 43% of total population in 1950 to 56% in 2001 with a higher growth rate after 1990.

The annual South Africa population statistics used for estimating the annual waste generation were sourced from the United Nations Statistics web-link (<http://esa.un.org/unpp>). The UN estimates were found to be more suitable than the Statistics South Africa values as they consistently covered the entire period under investigation. The country-specific data from Statistics SA are insufficient because only since the 1996 census are the data considered truly representative of the country's demographics.

The population data used in this 2000 inventory are significantly lower than the data used in the DEAT (2004) report which stated that the population receiving waste collection services had increased from 34 million in 1990 to 38 million in 1994. The DEAT figures are an over-estimation and were replaced by more realistic figures in this inventory.

Figure 6-1 shows the annual estimations of generated MSW in South Africa disposed into landfills from 1950 to 2005. As noted these figures only account for the organic fraction of the total waste disposed in well-managed SDWS. It is acknowledged that this assumption may introduce a certain level of error in the computed value. The waste quantities reported by DWAF (2001) on the actual reported figures and those estimated by calculations suggest that the error due to this assumption ranges from 15% to 20% in the South African context. This margin of error is within the acceptable limits of 30% for countries that collect waste generation data regularly. Even double this margin of error is acceptable for countries with poor quality data as outlined in the 2006 IPCC guidelines (Vol.5 Ch.3 Table 3.5).



**FIGURE 6-1: ANNUAL ESTIMATES OF SA MSW DISPOSED INTO LANDFILLS FROM 1950 TO 2005**

#### **6.1.1.4 Waste composition**

Data on waste composition in South Africa varies considerably and is also very limited. The data that is accessible comes from a small number of municipalities and covers only certain years.

The first available national average figures for waste composition were for the year 2001. These statistics could not be used here being outside the period under study and also because they provided no indication of waste composition evolution from the 1950s to 1990s. There is no data dating back into the 1950s showing how waste composition has changed annually and how this relates to urban income disparities and population densities.

To ensure consistency in calculations the methane generation rate ( $k$ ) and the waste decay half-lives used in the computations were based on defaults for bulk waste category under dry temperate climatic conditions.

#### **6.1.1.5 Landfill gas use**

South Africa's use of landfill gas has been very limited particularly for the reporting period prior to 2000. Consequently in the estimations presented here no methane recovery was taken into account. This situation is likely to change after 2000 as mentioned earlier.

The spreadsheets used to calculate emissions from waste reported in the South Africa Initial National Communication under the UNFCCC (DEAT 2004) were examined. The recovered quantities of methane from landfills – 4Gg in 1990 and 29 Gg in 1994 – were reported for South Africa's GHG inventories for those years. However no methodology on how these values were obtained was provided. According to Lombard (2004) there was no gas recovery from landfills at any large scale in South Africa in the 1990s. Only two small demonstration plants were known at that time both in Durban – Mount Hill and Bisasar Road Landfills. Lombard (2004) reports that the first large scale landfill gas recovery for energy generation in South Africa was developed by the eThekweni Municipality after the World Summit on Sustainable Development held in Johannesburg in 2002.

Given the above the values in the previous inventories were ignored and no methane recovery was included in the estimation values.

#### **6.1.1.6 Oxidation factor**

For methane estimations for South Africa the oxidation factor (OX) based on the default value for well-managed SWDS was assumed to be zero. Currently no data is accessible neither for well-managed nor unmanaged dump-sites which outlines the extent to which oxidation influences the overall methane emissions. This justifies the use of the default 2006 IPCC Guidelines value of zero for all the computations presented in the 2000 report.

There is no data in South Africa detailing the extent to which annual MSW deposited into landfills is covered with methane-oxidising materials such as soil and compost. Moreover for developing countries where management practices for landfills are not strict the oxidation factor is recommended as zero or very close to zero (IPCC 2000 Chapter 5). This is because only a fraction of the emissions generated diffuse through homogenous oxidation materials. Most emissions escape through cracks or via lateral diffusion without being oxidised.

#### **6.1.1.7 Methane emission estimates from solid waste disposal**

The results of computations using the IPCC methodology and the data described above are presented in Table 6-4. These results are also presented graphically in Figure 6-1.

The results vary significantly from previous inventories (DEAT 2004): 669.3 Gg of CH<sub>4</sub> for 1990 and 721.73 Gg of CH<sub>4</sub> for 1994. The difference can be attributed to an improved methodology and more accurate data. Further verification is provided in section 7.1.15.

**TABLE 6-3: METHANE EMISSIONS FROM SOLID WASTE DISPOSAL**

Year	CH <sub>4</sub> (Gg)	CH <sub>4</sub> (CO <sub>2</sub> eq)(Tg)
1990	225	4.73
1991	234	4.91
1992	245	5.14
1993	257	5.39
1994	257	5.67
1995	270	5.99
1996	285	6.34
1997	302	6.72
1998	340	7.14
1999	362	7.6
2000	385	8.09

#### **6.1.1.8 Uncertainties**

The results on methane emissions from landfill waste sources are subject to a number of uncertainties:

- A primary shortcoming of the data for landfills in South Africa is the lack of adequate characterisation (deep shallow etc) as well as no knowledge of the quantities of waste disposed in them over the medium to longer term (10 or more years).

- Closely related to the above uncertainty is the fact that methane production has to be estimated using bulk waste – as opposed to separate forms of waste such as garden waste wood and paper and textiles – because of the lack of waste composition data.

Thus:

- The extrapolation techniques used for estimating the annual MSW waste generation rates for the period 1950 to 2000 could not be verified as no recorded data were available to validate the computed values.
- For the purpose of these estimates the whole of South Africa is classified as dry temperate climate zone even though some landfills are located in dry tropical climatic conditions. The variance and effect of methane generation rates could not be accounted for as the quantities of the waste disposed of in both climatic zones are unknown.
- While it is stated in the literature that there is a certain degree of landfill gas recovery in South Africa no data on annual quantities were available for the period. The quantities were therefore presumed insignificant and were not included in the estimates.
- The exclusion of methane emissions from industrial landfills may lead to under-estimation in this category. Lack of data on the industrial waste disposed on site in South Africa makes it unfeasible to account for the emissions from this source.

Industrial waste from the pulp and paper industry and the food industry could be very significant. For example if IPCC 2006 defaults are applied to the production values reported by PAMSA (Paper Manufacturers Association of South Africa [www.pamsa.co.za](http://www.pamsa.co.za)) the organic waste produced could be more than 2.6 Mt of COD. If this amount was landfilled it would increase the national waste sector CH<sub>4</sub> emissions by more than 50%. The uncertainty estimates from the IPCC 2006 are provided in Table 6-5. SAPPI already provided their emission estimates as part of CDP 2008 so their experts could be used to approach to check what methodology and emission factors were used ([www.cdproject.net/download.asp?file=67\\_329\\_169\\_CDP%20South%20Africa%20Report%202008.pdf](http://www.cdproject.net/download.asp?file=67_329_169_CDP%20South%20Africa%20Report%202008.pdf)).

**TABLE 6-4: ESTIMATES OF UNCERTAINTY WITH ACTIVITIES AND PARAMETERS FOR THE FOD MODEL**

Activity data and parameters	Uncertainty range
Total municipal solid waste (MSWT)	30% is a typical value for countries which collect waste generation data on regular basis. For countries with poor quality data: more than a factor of two.
Fraction of MSWT sent to SWDS	For countries with poor quality data: more than a factor of two
Waste composition – bulk waste used as no data on waste composition was available for the study period	For countries with poor quality data: more than a factor of two
Carbon decomposed (DOCF)-selected IPCC default value =0.5	± 20%
Methane correction factor (MCF) – selected value=1	-10% +0%
Fraction of CH <sub>4</sub> in generated landfill gas (F)- selected IPCC default value: = 0.5	±5%

Methane recovery (R) –selected value =0	The uncertainty range depends on how the amounts of CH <sub>4</sub> recovered and flared or utilised are estimated: ± 50% if metering is not in place.
Oxidation Factor (OX) ) –selected value =0	OX should be included in the uncertainty analysis if a value other than zero has been used for OX itself

(Based on Table 3.5 IPCC 2006 Vol. 5 Ch.3)

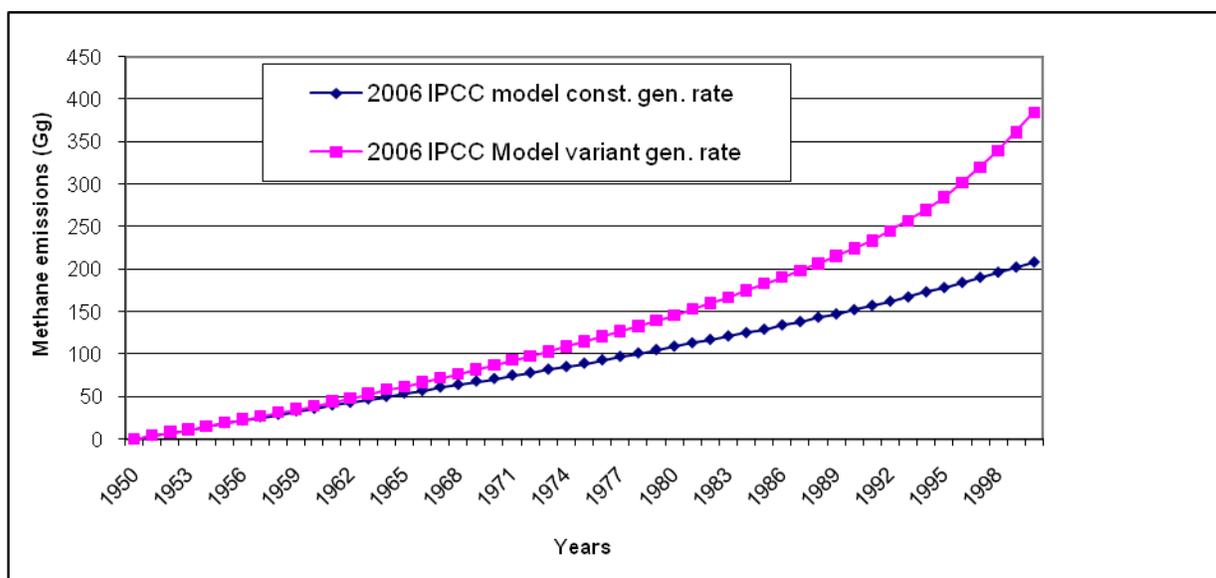
It is clear from Table 6-5 that the main uncertainty is the fraction of solid waste that is deposited at the large managed landfills and the composition of this waste.

#### 6.1.1.9 Source-specific quality assurance control

To verify the accuracy of the methane estimations for the period 1950 to 2000 the methane emissions were recalculated using the IPCC FOD model based on regional default values and including the total urban South African population as the activity data. Again the bulk waste option and dry temperate conditions were selected.

According to IPCC 2006 Guidelines (Vol. 5 Ch.3) the regional default for waste generation rates in Southern Africa is 290 kg/capita/year. Also the model assumes that 69% of the generated wastes ( $0.69 \times 290 \approx 200$  kg/capita/year) were disposed of in managed landfills and the remaining 31% were sent to unmanaged SWDS. Based on these inputs and assuming the oxidation factor to be zero the simulation yielded emission estimates of 152 Gg for 1990 and 208 Gg for 2000.

Figure 6-1 shows how methane emissions estimates using the 2006 IPCC model with a constant generation rate differs from estimates using the model with varying generation rates.



**FIGURE 6-2: ESTIMATED METHANE EMISSIONS FROM SOUTH AFRICA LANDFILLS**

Under the constant waste generation rates scenario using IPCC default values for the Southern Africa region the emissions were under-estimated by 46%. This large margin shows the improved accuracy in calculations reflecting the annual waste generation dynamics resulting from improved real GDP per capita in South Africa since the middle of 1980s (Du Plessis & Smit

2006) and the increase of the urban population in South Africa (Statistics South Africa 2006). Nonetheless the estimated value for year 2000 (208 Gg) is within the range 200 to 400 Gg as reported by Bogner and Lee (2005).

#### **6.1.1.10 Planned improvements**

The values for the waste generation rates need to be verified using the latest data collected for different cities and the values need to be updated.

Additional efforts will have to be made to include methane estimates from industrial landfill sources as well as methane recovered annually from landfills.

#### **6.1.2 Other sources: landfilling of residues from mechanical-biological waste treatment**

No coherent annual data on the quantities of sludge added to landfills from wastewater treatment plants in South Africa could be obtained. The level of inconsistency of the available statistics makes the data unsuitable for the calculation of emissions.

### **6.2 Biological treatment of solid waste**

In the 2000 inventory category 4.B is included in 4.A.

### **6.3 Incineration and open burning of waste**

In the 2000 inventory it is assumed that incineration is relatively small although no consistent and sufficient data could be found for this practice. In South Africa the incineration of residential waste is not recommended while incineration of biomass waste for energy production is covered in the Energy Sector. The GHG emissions from incineration of medical waste appear to be insignificant (IPCC 2006 Vol. 5 Ch.2.2.4). Manure management and burning of agricultural waste is considered under the AFOLU sector.

There is some incineration of industrial sludge but the estimates based on non-published data showed that that large industry would contribute only about 0.01Mt and therefore it was decided to exclude industrial sludge from the 2000 inventory.

For future inventories the open burning of waste should be assessed and if possible quantified.

### **6.4 Wastewater treatment**

Wastewater handling contributes to anthropogenic emissions mainly methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). The generation of CH<sub>4</sub> is due to anaerobic degradation of organic matter in wastewater from domestic commercial and industrial sources. The organic matter can be quantified using Biological Oxygen Demand (BOD) values.

Wastewater can be treated on site (mostly industrial sources) or treated in septic systems and centralised systems (mostly for urban domestic sources) or disposed of untreated (mostly in rural and peri-urban settlements). Most domestic wastewater CH<sub>4</sub> emissions are generated from centralised aerobic systems that are not well managed or from anaerobic systems (anaerobic lagoons and facultative lagoons) or from anaerobic digesters where the captured biogas is not completely combusted.

Unlike in the case of solid waste organic carbon in wastewater sources generates comparatively low quantities of CH<sub>4</sub>. This is because even at very low concentrations oxygen considerably inhibits the functioning of the anaerobic bacteria responsible for the generation of CH<sub>4</sub>.

N<sub>2</sub>O is produced from nitrification and denitrification of sewage nitrogen which results from human protein consumption and discharge.

The Revised 1996 IPCC Guidelines (IPCC 1997) included one equation to estimate emissions from wastewater and another to estimate emissions from sludge removed from wastewater. This distinction was removed in the 2006 IPCC Guidelines (IPCC 2006 Vol.5 p 6.9) so both emissions are now calculated by the same equation.

In South Africa most of the wastewater generated from domestic and commercial sources is treated through Municipal Wastewater Treatment Systems (MWTPs).

For wastewater generated by industrial processes the IPCC 2006 Guidelines list the industry categories which use large quantities of organic carbon that generate wastewater (IPCC 2006 Vol.5 p.6.22). The IPCC 2006 Guidelines require the development of consistent data for estimating emissions from wastewater in a given industrial sector (IPCC 2006 Vol.5 p 6.22). Once an industrial sector is included in an inventory it should be included in all future inventories.

South African data on industrial categories with high organic content are very limited. Some data exist on wastewater in sectors such as vegetables fruits and juices and the wine industry but these are available only for a specific year making it impossible to extrapolate such statistics accurately over any period. Therefore in this 2000 inventory only CH<sub>4</sub> emissions from domestic sources are presented. However wastewater from commercial and industrial sources discharged into sewers is accounted for so the term “domestic wastewater” in this inventory refers to the total wastewater discharged into sewers from all sources.

#### **6.4.1 Domestic wastewater methane emission estimates**

##### ***6.4.1.1 Source-category description***

Domestic and commercial wastewater CH<sub>4</sub> emissions mainly originate from septic systems and centralised treatment systems such as MWTPs. Because of the lack of national statistics on the quantities of BOD generated from domestic and commercial sources in South Africa annually the yearly estimates were determined using the IPCC 2006 default Tier 1 method.

The annual CH<sub>4</sub> estimates mainly depend on total amount of organic matter (expressed as kg BOD/year) from wastewater treated anaerobically. The quantities of BOD treated in South Africa using different treatment systems were based on per capita BOD generation default values in the IPCC 2006 Guidelines. The total quantity (kg BOD/year) was determined using the following parameters:

- National population. The South Africa population for each year was derived from the United Nations population statistics database. The same population values were used as for the solid waste section.
- Population distribution (urban low-income urban high-income and rural). The statistics on the population distribution for South Africa were based on the default values provided in the IPCC 2006 Guidelines (IPCC 2006 Vol. 5 Table 6.5). The same population distribution values were used as for the solid waste section.
- The default country BOD production of 37g/person/day was taken as the average. Note that this value can vary from 35g to 45g/person/day and hence introduces a certain level of uncertainty (IPCC 2006 Vol. 5 Table 6.4).
- Collection factor. A factor of 1.25 was applied to account for industrial BOD discharges released into the sewer systems (IPCC 2006 Vol. 5 Equation 6.3).

For the South African context the emission factors (EFs) for the treatment or disposal systems are shown in Table 6-6 which was computed using the IPCC default values. This shows that the main sources of emissions are latrines and sewers (open and warm).

**TABLE 6-5: EMISSION FACTORS FOR DIFFERENT WASTEWATER TREATMENT AND DISCHARGE SYSTEMS**

Type of treatment or discharge	Maximum methane producing capacity ( $B_0$ ) (kg CH <sub>4</sub> /kg BOD)	Methane correction factor for each treatment system ( $MCF_j$ )	Emission factor ( $EF_j$ ) (kg CH <sub>4</sub> /kg BOD) $EF_j = B_0 \times MCF_j$
Septic system	0.6	0.5	0.30
Latrine – Rural	0.6	0.1	0.06
Latrine - Urban low income	0.6	0.5	0.30
Stagnant sewer(open and warm)	0.6	0.5	0.30
Flowing sewer	0.6	0.0	0.00
Other	0.6	0.1	0.06
None	0.6	0.0	0.00

Table 6-7 presents the distribution and utilisation of different treatment and discharging methods in South Africa. The values used are IPCC values specific to South Africa (IPCC 2006 Vol. 5 Table 6.5).

The values in Table 6-7 were kept constant over the entire period following the recommendation in IPCC 2006 (Vol. 5 p 6.16) on ensuring data consistency. This assumption was verified by the Statistics South Africa report of 2007 (SSA 2007) which indicated that although across the country sanitation service provision had improved and the fraction of the population without basic sanitation services had been reduced the fraction of the population using latrines has not changed much – in 2001 this was 28.5%.

**TABLE 6-6: DISTRIBUTION AND UTILIZATION OF DIFFERENT TREATMENT AND DISCHARGE SYSTEMS IN SOUTH AFRICA**

Income group	Fraction of population income group ( $U_i$ )	Type of treatment or discharge pathway	Degree of utilization ( $T_{ij}$ )
Rural	0.39	Septic tank	0.1
		Latrine - rural	0.28
		Sewer stagnant	0.1
		Other	0.04
		None	0.48

Income group	Fraction of population income group ( $U_i$ )	Type of treatment or discharge pathway	Degree of utilization ( $T_{ij}$ )
Urban high income	0.12	Sewer closed	0.7
		Septic tank	0.15
		Other	0.15
Urban low income	0.49	Latrine - urban low	0.24
		Septic tank	0.17
		Sewer (open & warm)	0.34
		Sewer (flowing)	0.2
		Other	0.05

The characteristic emission factors (EFs) for each treatment or discharge technique were determined according to the IPCC 2006 default values for the maximum methane producing capacity factor ( $B_0 = 0.6 \text{ kg CH}_4/\text{kg BOD}$ ) and the relevant methane correction factors (MCFs) data taken from the IPCC 2006 Guidelines.

In South Africa there are very few systems to capture  $\text{CH}_4$  emissions from treatment systems hence the computed values do not show any form of biogas recovered from either domestic or commercial treatment systems. Based on the EF values and the total population under different income categories the  $\text{CH}_4$  emissions for the period 1990 to 2000 were calculated from domestic sources including wastewater from commercial and industrial sources discharged into sewers. These are presented in Table 6-8.

**TABLE 6-7: METHANE EMISSIONS FROM DOMESTIC AND INDUSTRIAL WASTEWATER TREATMENT**

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Unit
$\text{CH}_4$	26	26.7	27.5	28.3	29	29.8	30.4	31	31	32.4	32.9	Gg
$\text{CH}_4$ ( $\text{CO}_2\text{eq}$ )	0.546	0.561	0.577	0.594	0.608	0.625	0.638	0.652	0.66	0.68	0.691	Tg

#### 6.4.1.2 Uncertainties

The uncertainty for  $\text{CH}_4$  emissions from wastewater sources can be attributed to the uncertainties of the input parameters used. These include the UN population estimates for South Africa the maximum methane producing capacity factor ( $B_0$ ) the methane correction factor (MCF) and activity data such as the degradable organic component (BOD)/person/annum. In addition the fractions of the population using different wastewater treatment systems are unknown.

In this 2000 inventory most of the input data used were the default values provided in the IPCC 2006 Guidelines. These may have introduced a degree of uncertainty ranging from 30% to 50% (IPCC 2006 Vol.5 Table 6.10).

Nevertheless the total value for the 1990 inventory (Table 6-8) of 26 Gg of  $\text{CH}_4$  compares well with the results of the previous inventory (Van der Merwe & Scholes 1998) of 21.9 Gg of  $\text{CH}_4$ .

Although the methodologies and the data used for the two inventories were different the difference in the final emissions is only 16%.

## 6.4.2 Domestic wastewater nitrous oxide emission estimates

### 6.4.2.1 Source-category description

The nitrous oxide (N<sub>2</sub>O) emissions from domestic wastewater were estimated using the default values provided in the IPCC 2006 Guidelines. N<sub>2</sub>O was not computed for industrial wastewater. This was partly because data on wastewater generated in different industrial sectors are not easily available in South Africa and partly because the IPCC 2006 Guidelines do not offer any methodology for estimating the N<sub>2</sub>O from industrial sources.

The methodology adopted took into account the average per capita protein intake in South Africa to estimate the production of nitrogen (N). Because of the lack of raw sewage data from many sewage plants in South Africa the default values provided in the IPCC were used. The IPCC methodology uses the annual per capita protein consumption (kg protein/person-year) and a per capita protein consumption of 76.6 g/day (27.96 kg/year) was used for South Africa for year 2000. A default IPCC emission factor (EF) of 0.005 kg N<sub>2</sub>O-N/kg sewage N was applied to estimate the proportion of the raw sewage converted into N<sub>2</sub>O.

Based on these data the 2000 N<sub>2</sub>O emission estimate was found to be 0.618 Tg CO<sub>2</sub>eq nitrous oxide emissions from the wastewater treatment systems. The N<sub>2</sub>O emissions for the period 1990 to 2000 are summarised in Table 6-9.

**TABLE 6-8: NITROUS OXIDE EMISSIONS FROM DOMESTIC AND INDUSTRIAL WASTEWATER TREATMENT**

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Unit
N <sub>2</sub> O	1.57	1.59	1.64	1.68	1.72	1.76	1.8	1.83	1.85	1.89	1.99	Gg
N <sub>2</sub> O (CO <sub>2</sub> eq)	0.488	0.494	0.507	0.52	0.533	0.546	0.556	0.567	0.572	0.587	0.618	Tg

### 6.4.2.2 Uncertainties

The data on quantity of protein consumed per person per day were highly uncertain and introduced large margins of error.

For the IPCC 2006 Guidelines the default emission factor from the wastewater was 0.005 kg N<sub>2</sub>O-N/kg sewage N. However in the 1994 inventory a value of 0.01 kg N<sub>2</sub>O-N/kg sewage N was used which was the default value of the 1996 IPCC Guidelines (IPCC 1997 p 6.23). This change in the default IPCC values introduced an additional margin of error. The uncertainty estimates from the IPCC 2006 Guidelines are provided in Table 6-10.

**TABLE 6-9: THE UNCERTAINTY ON THE N<sub>2</sub>O EMISSIONS**

<b>Emission factor / activity data</b>	<b>Description/units</b>	<b>Default value</b>	<b>Range</b>
EF <sub>EFFLUENT</sub>	Emission factor (kg N <sub>2</sub> O-N/kg -N)	0.005	0.0005 - 0.25
EF <sub>PLANTS</sub>	Emission factor (g N <sub>2</sub> O/person/year)	3.2	2 – 8
Protein	Annual per capita protein consumption	Country-specific	± 10 %
FNPR	Fraction of nitrogen in protein (kg N/kg protein)	0.16	0.15 - 0.17
Tplant	Degree of utilization of large WWT plants	Country-specific	± 20 %
FNON-CON	Factor to adjust for non-consumed protein	1.1 for countries with no garbage disposal 1.4 for countries with garbage disposal	1.0 – 1.5
FIND-COM	Factor to allow for co-discharge of industrial nitrogen into sewers	1.25	1.0 - 1.5

(Based on Table 6.11 IPCC 2006 Vol. 5 Ch.6)

#### **6.4.2.3 Planned improvements**

As mentioned both the emission factors and activity data used in these computations are default values and contain large margins of error. Therefore it is recommended that to improve future GHG inventories in South Africa the Department of Water Affairs and Forestry (DWAF) should provide updated statistics on the fraction of population using different forms of sanitation. The already well-documented Water Services Information System ([http://www.dwaf.gov.za/dir\\_ws/wsnis](http://www.dwaf.gov.za/dir_ws/wsnis)) could be extended to provide this information in a format that could improve future GHG inventories for South Africa. However since the contribution of wastewater to national emissions is very small the application of Tier 1 is acceptable for this and future inventories.

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## APPENDIX 1: EMISSION SUMMARY TABLE

Greenhouse Gas Source And Sink Categories (CO <sub>2</sub> eq(Gg))	CO <sub>2</sub> <sup>(1)</sup>	CH <sub>4</sub>	N <sub>2</sub> O	HFCs <sup>(2)</sup>	PFCs <sup>(2)</sup>	SF <sub>6</sub> <sup>(2)</sup>	Total
<b>Total (Net Emissions)<sup>(1)</sup></b>	<b>333 363.70</b>	<b>76 114.36</b>	<b>23 764.51</b>	<b>0.00</b>	<b>2 219.05</b>	<b>0.00</b>	<b>435 461.62</b>
<b>1. Energy</b>	<b>301 068.8513</b>	<b>40 914.1433</b>	<b>2 123.2266</b>				<b>344 106.22</b>
A. Fuel combustion (sectoral approach)	301 044.5212	527.8308	2 123.2266				303 695.58
1. Energy industries	212 226.4851	78.23095	1 070.09671				213 374.81
2. Manufacturing industries and construction	38 879.3449	65.61301	145.86900				39 090.83
3. Transport	38 623.8837	258.18776	629.23388				39 511.31
4. Commercial/institutional	1 901.5957	0.43144	9.277687				1 911.30
5. Residential	5 547.2488	122.24885	258.89859				5 928.40
6. Agriculture/forestry/fishing	3 705.5446	3.05605	9.73621				3 718.34
5. Other	160.4185	0.06273	0.1145				160.60
B. Fugitive emissions from fuels	24.33	40 386.31	NA NO				40 410.64
1. Solid fuels	24.33	40 366.25	NA NO				40 390.58
2. Oil and natural gas	0.00	20.07	NO				20.07
<b>2. Industrial processes and product use</b>	<b>52 574.28</b>	<b>4287.37759</b>	<b>2 388.39</b>	<b>NA NO</b>	<b>2 219.05</b>	<b>NA NO</b>	<b>61 469.09</b>
A. Mineral products	6 863.200	NA	NA				6 863.20
B. Chemical industry	23 751.68	4 284.08	2 388.39	NO	NO	NO	30 424.14
C. Metal production	21 959.40	3.30	0.00	NA	2 219.05	NA NO	24 181.75
D. Other production	NO						NO
E. Production of halocarbons and SF <sub>6</sub>				NA NO	NA NO	NA NO	NA NO
F. Consumption of halocarbons and SF <sub>6</sub> <sup>(2)</sup>				NE	NE	NE	NE
G. Other	NA	NA	NA	NA	NA	NA	NA
<b>3. Agriculture forestry and land use</b>	<b>-20 279.43</b>	<b>22 136.94</b>	<b>18 636.00</b>				<b>20 493.51</b>
A. Enteric fermentation		18 969.09					18 969.09
B. Manure management		1 904.70	415.40				2 320.10
C. Forest land	-13 020.52	NA NO					-13 020.52
D. Cropland	-7 730.15						-7 730.15
E. Grassland							
F. Wetlands		190.89					190.89
G. Settlements							
H. Other land							
I. GHG emissions from biomass burning	471.24	1072.26	793.6				2 337.10
J. Liming							
K. Urea application							
L. Direct N <sub>2</sub> O emissions from managed soils							
M. Indirect N <sub>2</sub> O emissions from managed soils			17427				17 427.00
N. Rice cultivation		NA	NA				NA
O. Harvested wood products							
P. Other							0.00
<b>4. Waste</b>	<b>0.00</b>	<b>8 775.90</b>	<b>616.90</b>				<b>9 392.80</b>
A. Solid waste disposal on land		8 085.00					8 085.00
B. Waste-water handling		690.90	616.900				1 307.80
C. Waste incineration							
D. Other							
5. Other (as specified in Summary I.A)	NA	NA	NA	NA	NA	NA	NA
Memo items: <sup>(3)</sup>							
International bunkers	11 645.83	17.11	95.56				11 758.50
Aviation	2 906.25	0.43	25.20				2 931.87
Marine	8 739.59	16.68	70.36				8 826.62
Multilateral operations	NO	NO	NO				NO
CO <sub>2</sub> Emissions from Biomass	4 700.00						4 700.00
<b>Total CO<sub>2</sub> equivalent emissions without land use land-use change and forestry</b>							<b>436 257.30</b>
<b>Total CO<sub>2</sub> equivalent emissions with land use land-use change and forestry</b>							<b>435 461.62</b>
1. For CO <sub>2</sub> from Land Use Land-use Change and Forestry the net emissions/removals are to be reported. For the purposes of reporting the signs for removals are always negative (-) and for emissions positive (+).							
2. Actual emissions should be included in the national totals (2006 IPCC Guidelines)							
3. Countries are asked to report emissions from international aviation and marine bunkers and multilateral operations as well as CO <sub>2</sub> emissions from biomass under Memo Items. These emissions should not be included in the national total emissions from the energy sector. Amounts of biomass used as fuel are included in the national energy consumption but the corresponding CO <sub>2</sub> emissions are not included in the national total as it is assumed that the biomass is produced in a sustainable manner. If the biomass is harvested at an unsustainable rate net CO <sub>2</sub> emissions are accounted for as a loss of biomass stocks in the Land Use Land-use Change and Forestry sector.							

## APPENDIX 2: OVERVIEW OF GREENHOUSE GAS INVENTORY

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO <sub>2</sub>		CH <sub>4</sub>		N <sub>2</sub> O		Documen- tation	Disaggre- gating	Foot- notes
	Est.	Quality	Est.	Quality	Est.	Quality			
1. Energy									
A. Fuel combustion									
Reference approach	ALL	M	M	M	ALL	M	H	1	
Sectoral approach	ALL	M	M	M	ALL	M	H	3	
1. Energy industries	ALL	M	M	M	ALL	M	H	3	
2. Manufacturing industries & construction	ALL	M	M	M	ALL	M	H	3	
3. Transport	ALL	M	M	M	ALL	M	H	3	
4. Commercial/institutional	ALL	M	M	M	ALL	M	H	3	
5. Residential	ALL	M	M	M	ALL	M	H	3	
6. Agriculture/forestry/fishing	ALL	M	M	M	ALL	M	H	3	
5. Other									
B. Fugitive emissions from fuels									
1. Solid fuels			PART	H			H	3	
2. Oil and natural gas			PART	H			H	3	
2. Industrial processes and product use									
A. Mineral products	ALL	M	ALL	M	ALL	M	H	3	
B. Chemical industry	ALL	M	ALL	M	ALL	M	H	3	
C. Metal production	ALL	M	ALL	M	ALL	M	H	3	
D. Other production									
E. Production of halocarbons and SF <sub>6</sub>	NA								
F. Consumption of halocarbons and SF <sub>6</sub> <sup>(2)</sup>	NA								
G. Other									
3. Agriculture forestry and land use									
A. Enteric fermentation									
B. Manure management									
C. Forest land									
D. Cropland									
E. Grassland									
F. Wetlands									
G. Settlements									
H. Other land									
I. GHG emissions from biomass burning									
J. Liming									
K. Urea application									
L. Direct N <sub>2</sub> O emissions from managed soils									
M. Indirect N <sub>2</sub> O emissions from managed soils									
N. Rice cultivation									
O. Harvested wood products									
P. Other									
4. Waste									
A. Solid waste disposal on land									
B. Waste-water handling									
C. Waste incineration									
D. Other									
5. Other (as specified in Summary 1.A)									
Memo items: <sup>(3)</sup>									
International bunkers									
Aviation	ALL	M					L	2	
Marine	ALL	M					M	2	
Multilateral operations									
CO <sub>2</sub> emissions from biomass	ALL	L					L	1	

**NOTATION FOR OVERVIEW TABLES**

Estimate		Quality		Documentation		Disaggregation	
Code	Meaning	Code	Meaning	Code	Meaning	Code	Meaning
PART	Partly estimated	H	High confidence in estimation	H	High (all background information included)	1	Total emissions estimated
ALL	Full estimate of all possible sources	M	Medium confidence in estimation	M	Medium (some background information included)	2	Sectoral split
NE	Not estimated	L	Low confidence in estimation	L	Low (only emissions estimates included)	3	Sub-sectoral split
IE	Included elsewhere						
NO	Not occurring						
NA	Not applicable						