Information on climate change in South Africa: greenhouse gas emissions and mitigation options

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1. South African emissions

1.1 Current and historical emission trends

There have been three official analyses of South Africa's greenhouse gas (GHG) emissions to date; the published 1990 and 1994 GHG inventories and the 2000 GHG inventory which is currently under review (DEAT 2009). These official inventories, however, only reflect the country's emissions in specific years and do not give the full picture of the past emissions. In an attempt to understand the country's past emissions, we have reconstructed the country's emissions profile from 1950, based on published historical energy and industrial process statistics. The findings of both the official inventories and our own reconstructions are presented below.

1.1.1 Official 1990, 1994 and 2000 (under review) inventories

The total national emissions for 1990, 1994 and 2000 are 347, 380 and 435 million tons of CO_2-equivalent respectively. Figures 1 and 2 below show the emissions for the three inventory years disaggregated by gas and by sector.

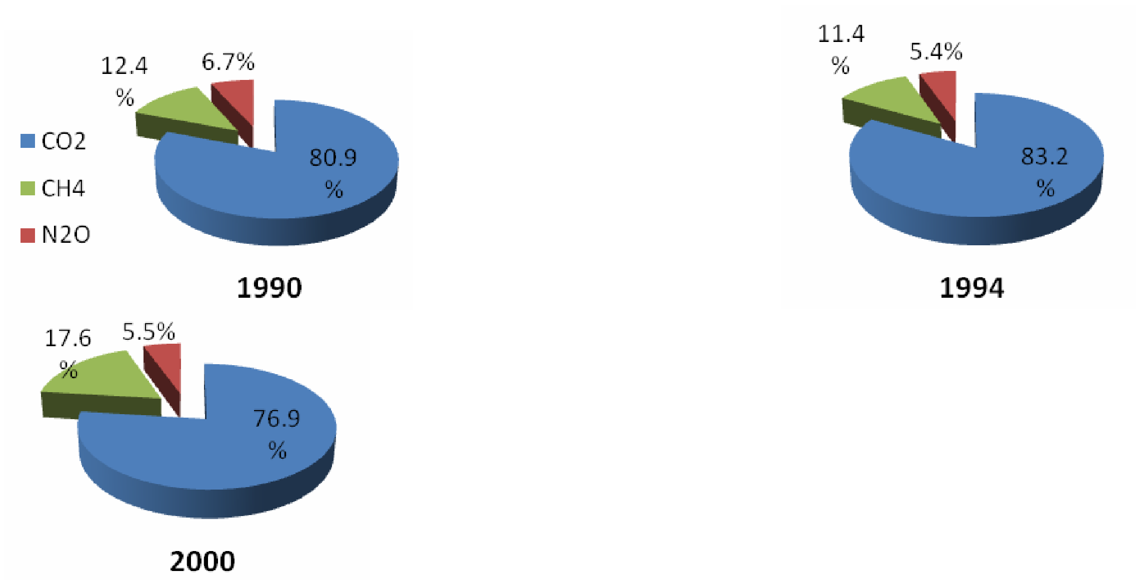

Figure 1: Composition of the official 1990, 1994 and 2000 GHG inventories (DEAT 2004; DEAT 2009)

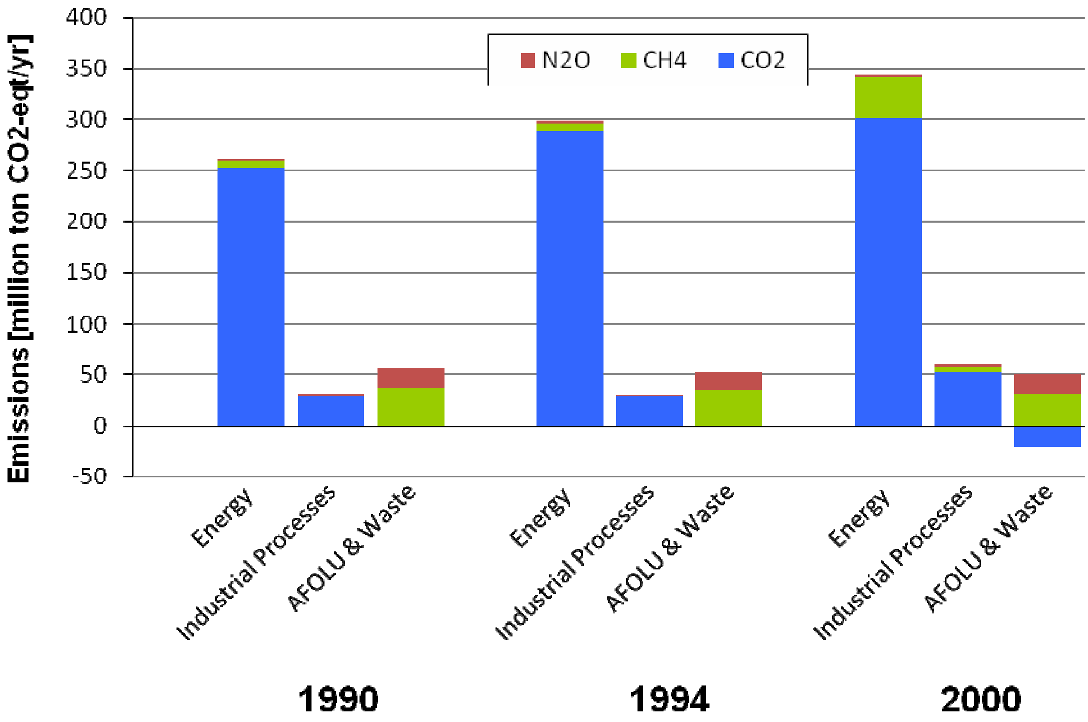

Figure 2: Official 1990, 1994 and 2000 GHG inventories disaggregated by sector and gas (DEAT 2004; DEAT 2009)

1.1.2 Our own reconstructions

Here the IPCC tier one method of estimating GHG emissions was used. Historical energy statistics and industrial process activity data gathered from government resources, NGO databases and industry databases were multiplied by the relevant emission factors to determine emissions of the three main GHGs – CO_2, CH_4 and N_2O.

1.1.2.1 Energy emissions

Using national energy balance data from the International Energy Agency (IEA 2005), the IPCC reference approach was used to estimate fossil energy emissions. The following assumptions were made based on the 1996 IPCC guidelines:

- Emissions of fuels stored in marine bunkers do not contribute to the national inventory.
- Coal and oven coke used in the iron and steel industry were not included in the energy inventory because they are accounted for in the Industrial Processes section.
- Some of the carbon contained in products used for non-energy purposes remains stored and the extent of storage is determined by the following storage factors:

Product/fuel	*Fraction of carbon stored*
Lubricants	0.5
Bitumen	1.0
Coal oils & tars (6% of Coking coal)	0.75
Naphtha as feedstock	0.75
Coal as feedstock in Petrochem industry	0.75
Natural gas as feedstock in Petrochem	0.33

- The fraction of oxidized carbon was assumed to be 0.98 for all primary fuels.

Figures 3 and 4 below present our reconstructions of the reference approach absolute and per capita historical fossil energy CO_2 emissions respectively, and compares them with historical profiles reconstructed by other institutions. One set of data is from the Climate Analysis Indicator Tool (CAIT), developed by the World Resources Institute (WRI 2005), while the other set is obtained from the United States' Energy Information Administration database (IEA 2005).

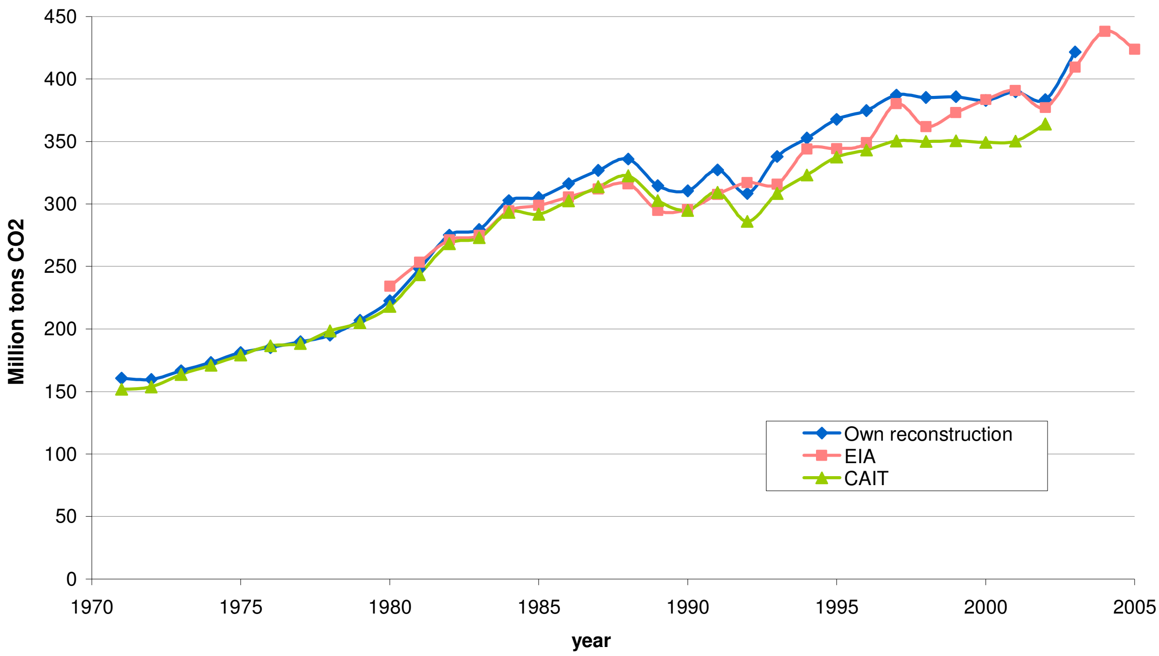

Figure 3: Fossil energy CO_2 emissions: Own reconstruction vs CAIT vs IEA

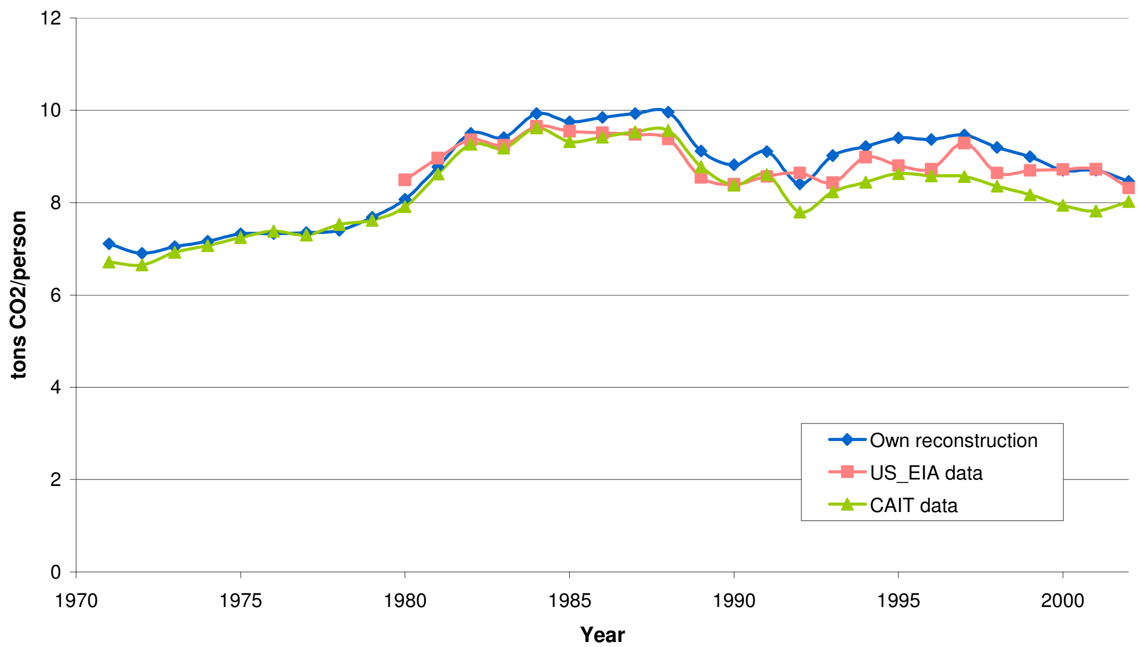

Figure 4: Per capita energy CO_2 emissions: Own reconstruction vs CAIT vs IEA

The reference approach energy CO_2 emissions of the three official inventories were compared to their respective sectoral approach CO_2 emissions, and the resulting average ratio was used to convert the energy CO_2 emissions of the of our own reference approach to sectoral approach emissions. This ratio of reference approach emissions to sectoral approach emissions was found to be 0.793.

1.1.2.2 Industrial processes

The reconstruction of historical GHG emissions from industrial processes was based on the baseline estimates (2003/2004) by Taviv et al. (2008). The main assumption made in this analysis is that the emission factors for all sources have remained constant over the years.

The nine major categories of industrial emissions analysed in this study are as follows:

- **Cement production**: This is a combination of CO_2 emissions from the calcination of limestone and dolomite, fuel firing and fuel consumption. Data on the production and sales of cementitious binders (1993-2007) was obtained from the Cement & Concrete Institute of South Africa (CNCI 2008), while production statistics for the period of 1980-1992 were obtained from a thesis by Persad (1994). A power trendline was used to extrapolate to from 1980 back to 1975.
- **Non-aggregate limestone and dolomite use**: This encompasses all CO_2 emissions from non-aggregate uses of carbonates, excluding cement production. Generally, these emissions are a result of the calcination of carbonate compounds or acid-induced release of CO_2 in a variety of industries. The most significant non-aggregate uses of carbonates are lime production, glass manufacturing, iron and steel production, ceramics, non-metallurgical magnesia production and other uses of soda ash (IPCC 2007). Statistics for non-aggregate use of carbonates (1975-2007) was obtained from the DME's South Africa's Mineral Industry report series (DME 2007).
- **Ammonia production**: The production of ammonia requires both nitrogen, which is usually obtained from air, and hydrogen, which is either obtained from natural gas or some other hydrocarbons. In the past, the country's major producer of ammonia, Sasol, used coal as a source of hydrogen, but has recently switched to natural gas. In the natural gas catalytic steam reforming process, the primary release of CO_2 occurs during the regeneration of the CO_2 scrubbing solution with lesser emissions resulting from condensate stripping (IPCC 2007). It was assumed here that the production of ammonia in the country is proportional to SASOL's synfuels production; hence the 2003 production data obtained from Taviv et al (2008) was extrapolated accordingly.
- **Nitric acid production**: This category reports the nitrous oxide (N_2O) generated unintentionally by the high temperature catalytic oxidation of ammonia during the production of nitric acid from the four operating plants in the country. The production of nitric acid in the country was therefore assumed to be proportional to that of ammonia, and the 2003 production data obtained from Taviv et al (2008) was extrapolated accordingly.
- **Iron and steel production**: This presents the CO_2 and CH_4 emissions from the production of iron, steel and metallurgical coke. Production statistics from 1990 to 2007 were obtained from the South African Iron and Steel Industries (SAISI 2008), while production data for the period 1975-1989 was obtained from the DME's South Africa's Mineral Industry report series (DME 2007).
- **Ferro-alloys and silicon**: The following ferro-alloys are included, together with silicon, in this category: FeCr, FeMn, FeSi and FeSiMn. In the production of ferroalloys and silicon, raw ore and slag-forming materials are usually mixed with coal and coke, and then heated to high temperatures releasing CO_2 or CO and small amounts of CH_4 and N_2O. Ferroalloy and silicon production statistics were obtained from the DME's South Africa's Mineral Industry report series (DME 2007).
- **Aluminium production**: This section estimates the CO2 emissions from the consumption of carbon anodes in the reaction to convert aluminium oxide to aluminium metal, and the perfluorocarbons (PFCs) emissions of CF4 and C2F6 during anode effects (IPCC 2007). Historical production data was obtained from the DME's South Africa's Mineral Industry report series (DME 2007).

- **Coal mining**: This section estimates the CO2 and CH4 emissions released during the mining of coal. Production statistics were obtained from the DME's South Africa's Mineral Industry report series (DME 2007).
- **Synfuels methane point source emissions**: This reports the methane emissions from SASOL's gasification processes at both Sasolburg and Secunda. Activity data of the production of synfuels was obtained from national energy balances reported by the International Energy Agency (IEA 2005).

Figures 5, 6 and 7 below show the emission trends of the most significant Industrial processes in the country, while Figure 8 shows the contributions of each of the above industries to IPPU emissions.

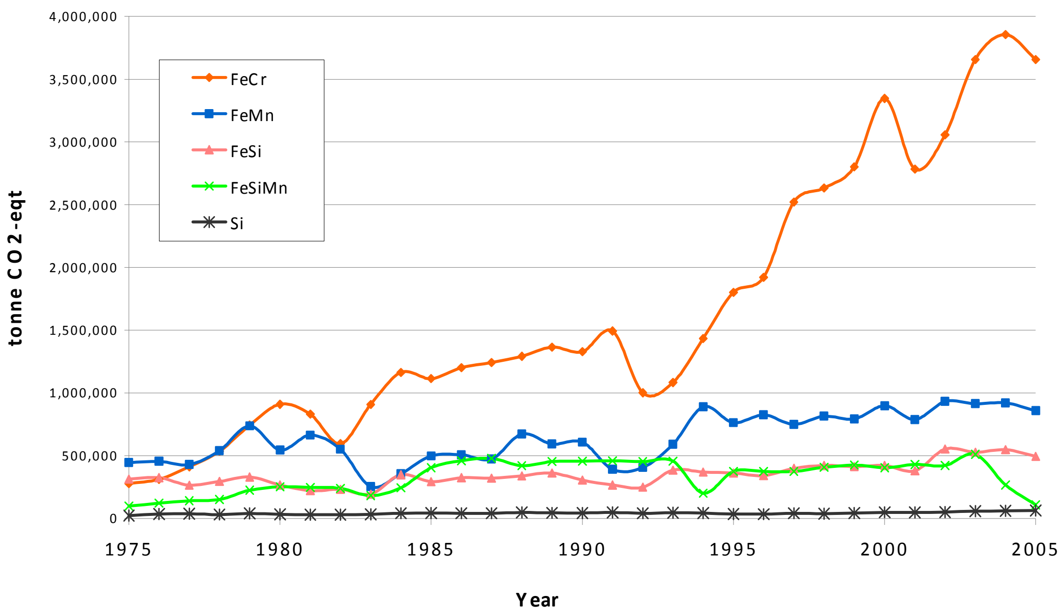

Figure 5: GHG emissions from ferro-alloy production

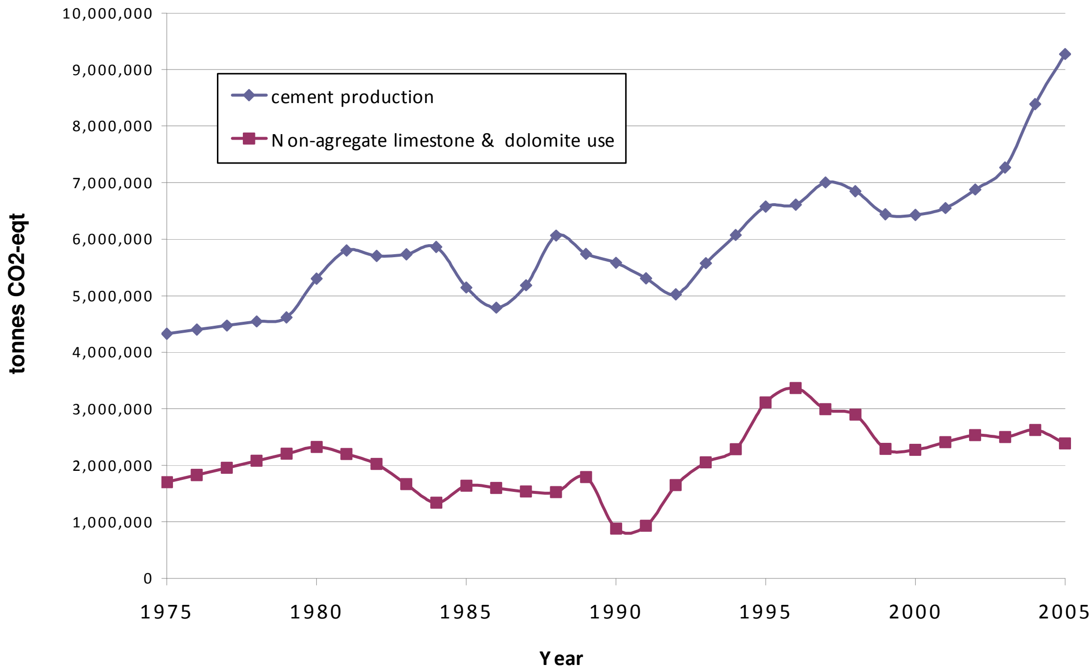

Figure 6: $CO_{2\text{-eq}}$ emissions from non-aggregate use of carbonates

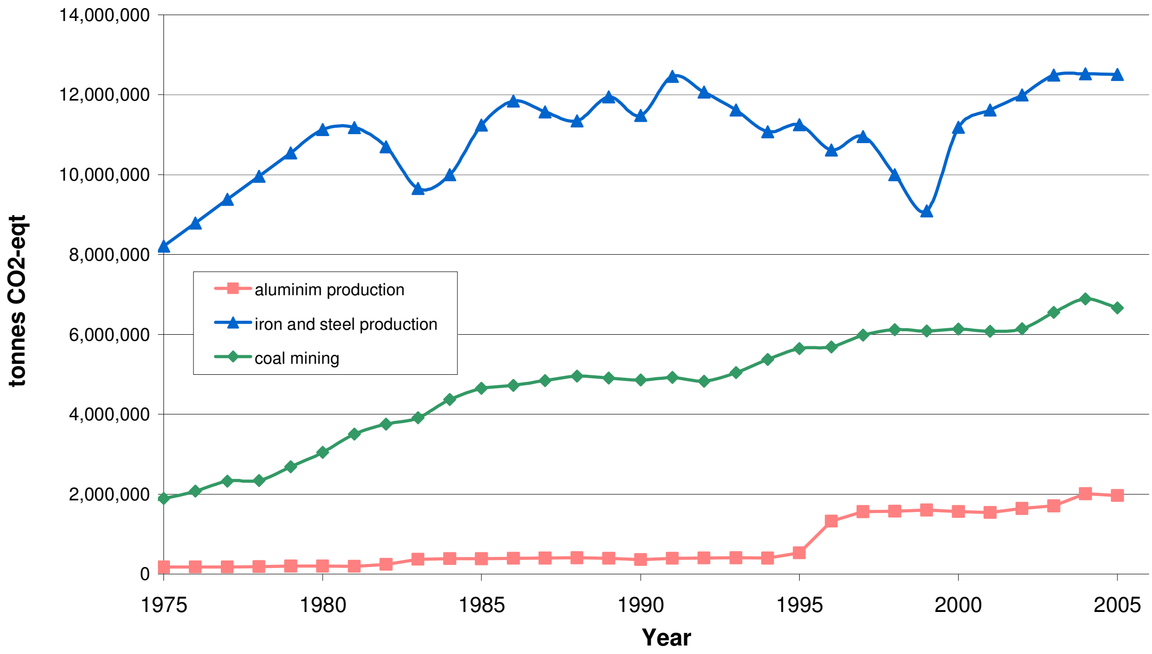

Figure 7: GHG emissions from the production of aluminium, iron and steel and coal mining

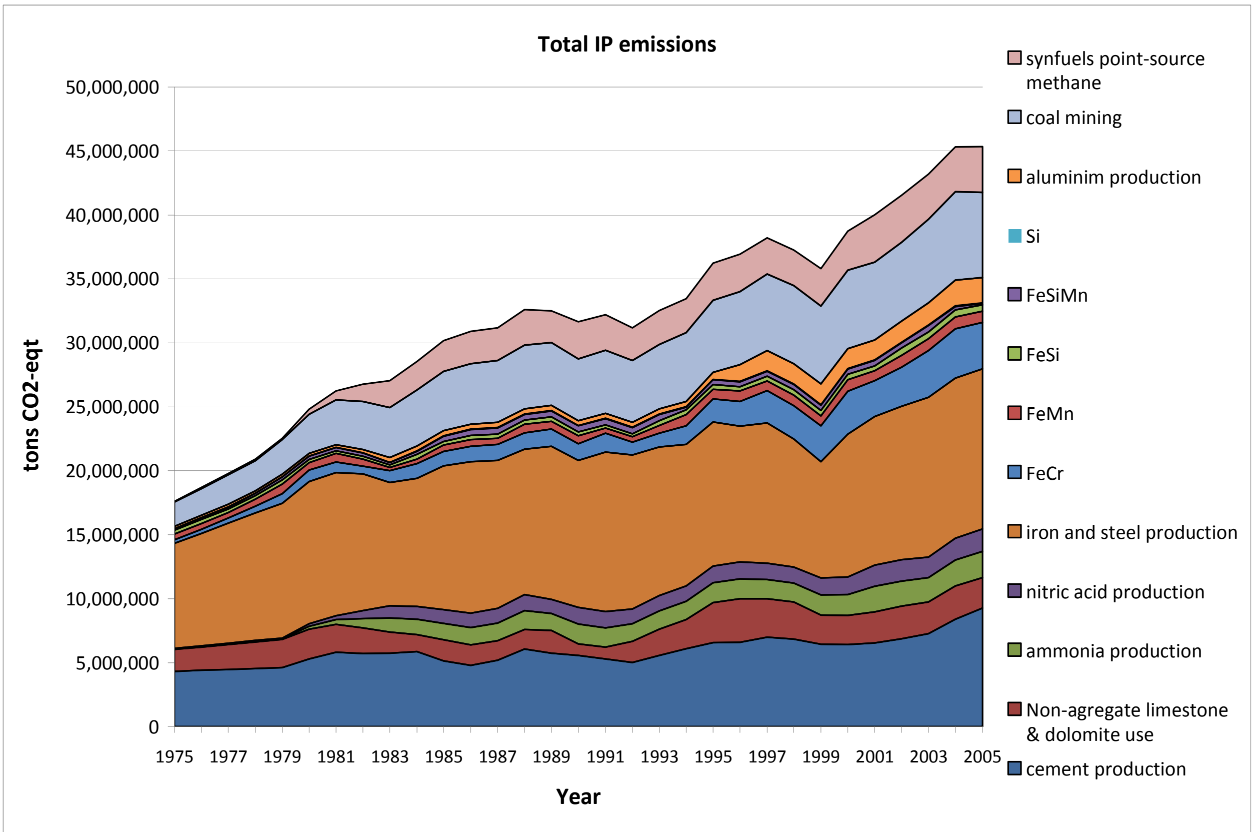

Figure 8: South Africa's GHG emissions from industrial processes

1.1.2.3 Agriculture, land use change, forestry and waste

The emission trends from agriculture, land use change and forestry and waste were constructed based on the baseline emissions reported in the 1994 national GHG inventory (Taviv, Mwakasonda et al. 2008). It was then assumed that these emissions have been growing proportionally to the country's economy; hence the 1994 emissions were extrapolated in both directions (1993-1975 and 1995-2002) using the country's GDP (in constant 2000 dollars) for those years. Historical GDP values for South Africa were obtained from the World Resource Institute's Climate Analysis Indicator Tool (CAIT 2005). Figure 9 presents the extrapolated emission trend for agriculture, land use change and forestry and waste.

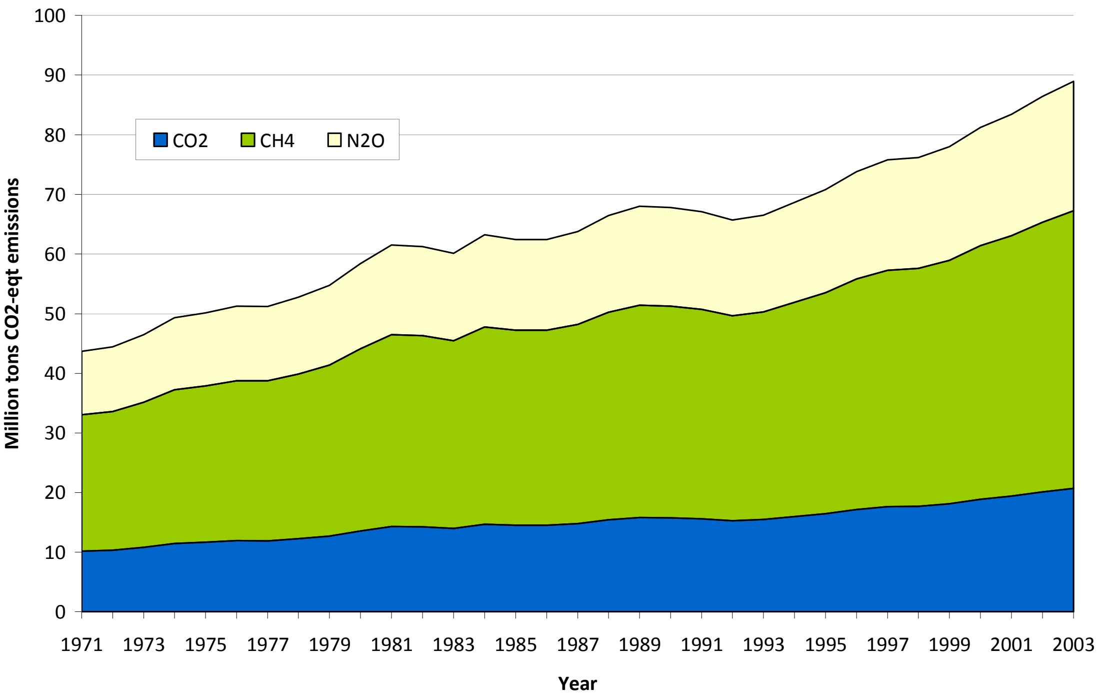

Figure 9: Historical emissions from agriculture, land-use change and forestry, and waste

1.1.2.4 Total emissions

Figure 10 presents our reconstruction of the total sectoral emission trend for South Africa from 1975 to 2003. The figure shows the relative contributions of the different GHGs from the various sectors.

In Figure 11, the country's 1990, 1994 and 2000 emissions of the three major GHGs from our own reconstruction are compared to those from the World Resource Institute's CAIT and the official values reported in the national GHG inventories.

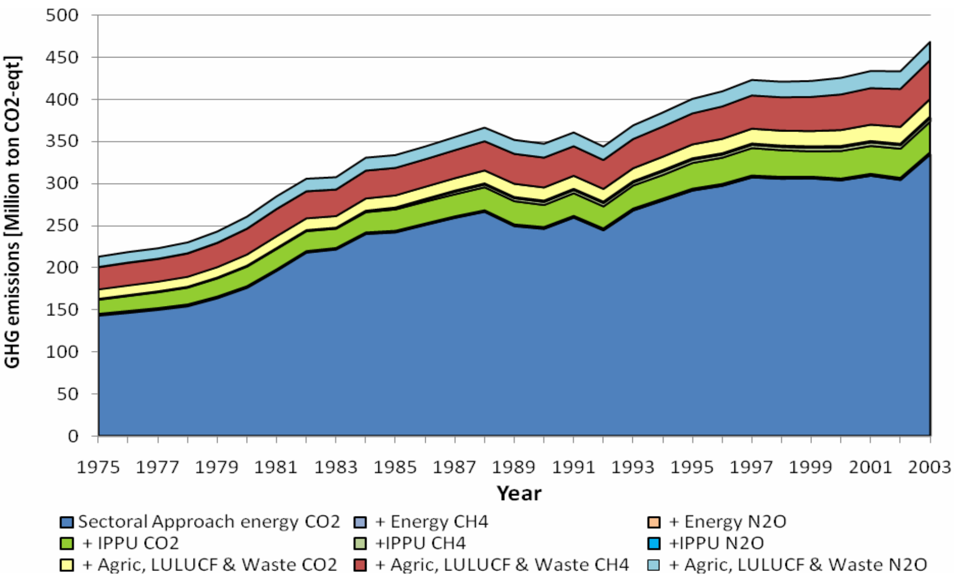

Figure 10: Own reconstruction of total historical emissions for South Africa

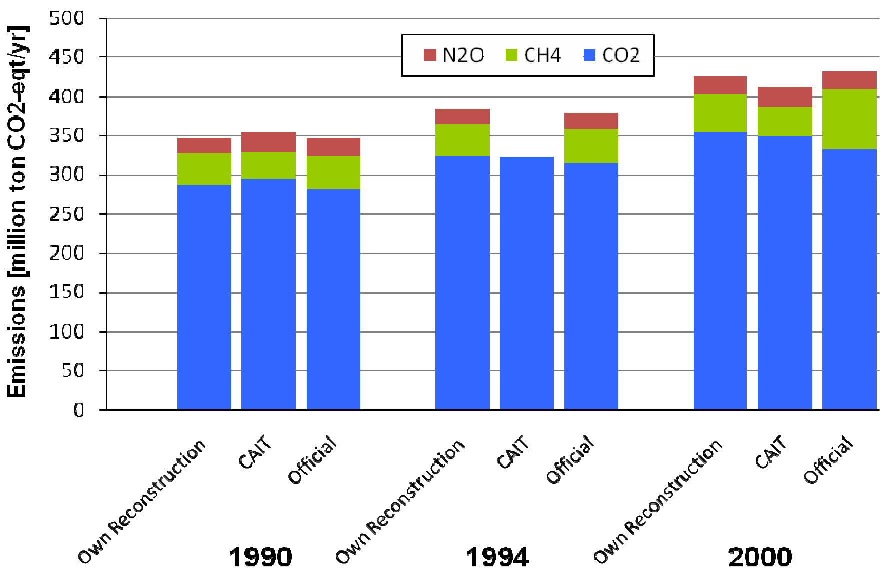

Figure 11: South Africa's 1990, 1994 and 2000 emissions of the three major GHG gases – own reconstruction vs CAIT vs official

1.2 Projections of future emissions

The projections of South Africa's emissions were carried out in the Long Term Mitigation Scenarios (LTMS) process. In the LTMS this baseline projection of the emissions is called the Growth Without Constraints (GWC). GWC represents a scenario where there is no damage to the economy resulting from climate change, no significant oil supply constraints, where choices to supply energy to the economy are made purely on least-cost grounds, without internalizing external costs. GWC assumes that not even existing policy is implemented (Scenario Building Team 2007).

Figure 12 below shows the projected GWC emission trend together with our reconstructed historical emissions and the three official GHG inventory trend.

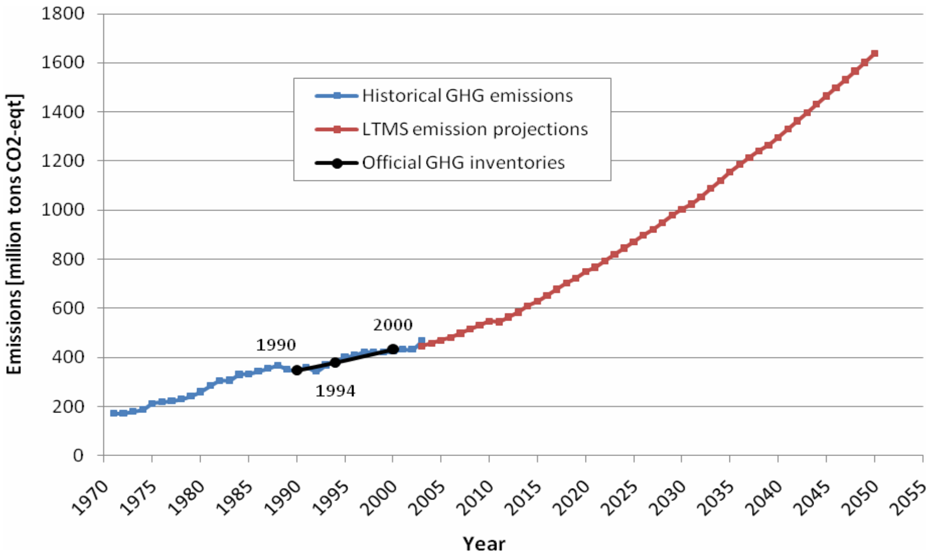

Figure 12: South Africa's historical and projected GHG emissions

2. Emission rankings – international comparisons

Figures 13 to 18 compare South Africa's annual, cumulative, per capita and per GDPppp emissions with various countries and regions around the world, while Table 1 shows where South Africa is ranked in terms of GHG emissions based on various indicators. All the emission information used in this section was obtained from CAIT.

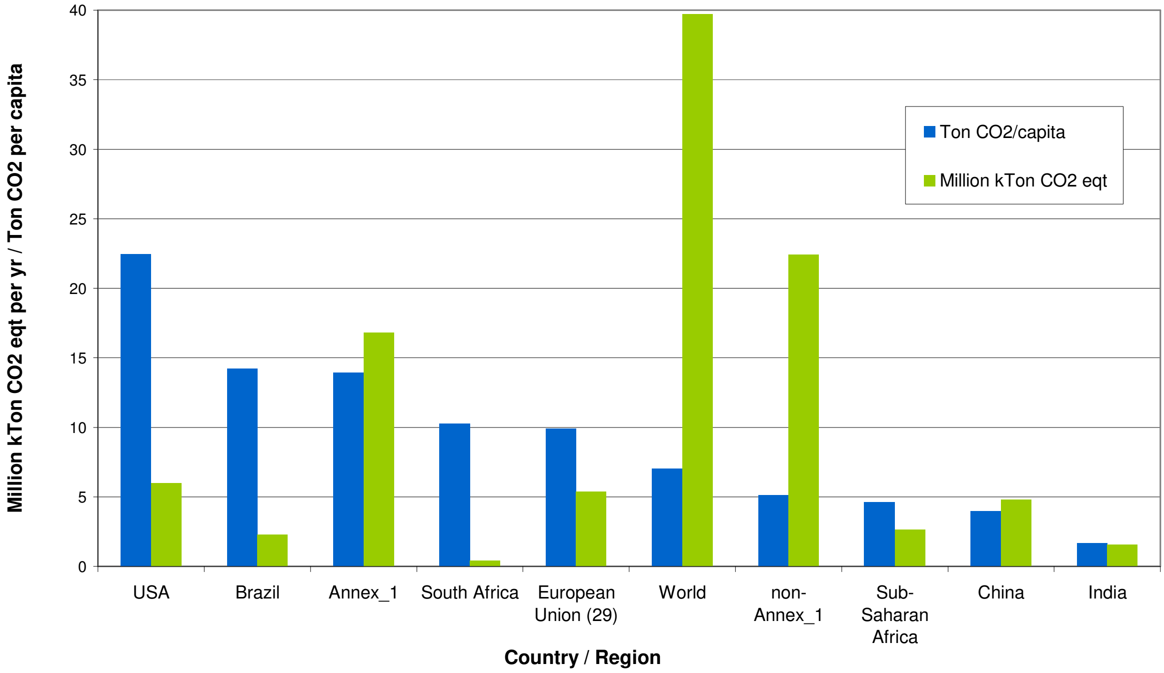

Figure 13: Comparison of South Africa's 1995 annual and per capita emissions with other countries and regions

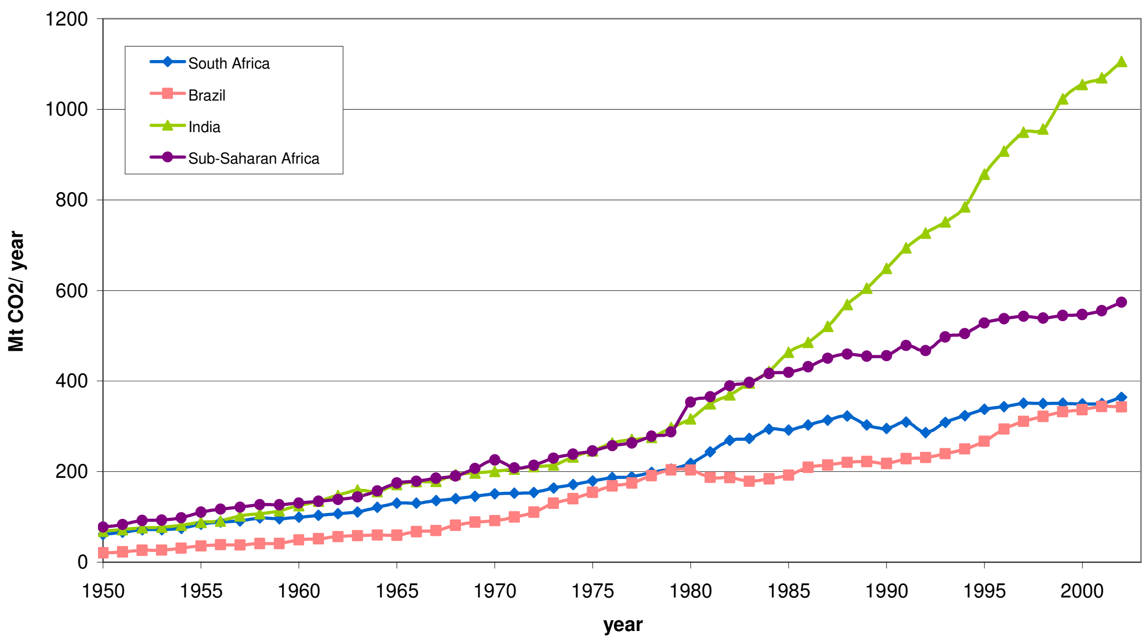

Figure 14: Comparison of historical annual emissions from energy and cement production, 1950-2002

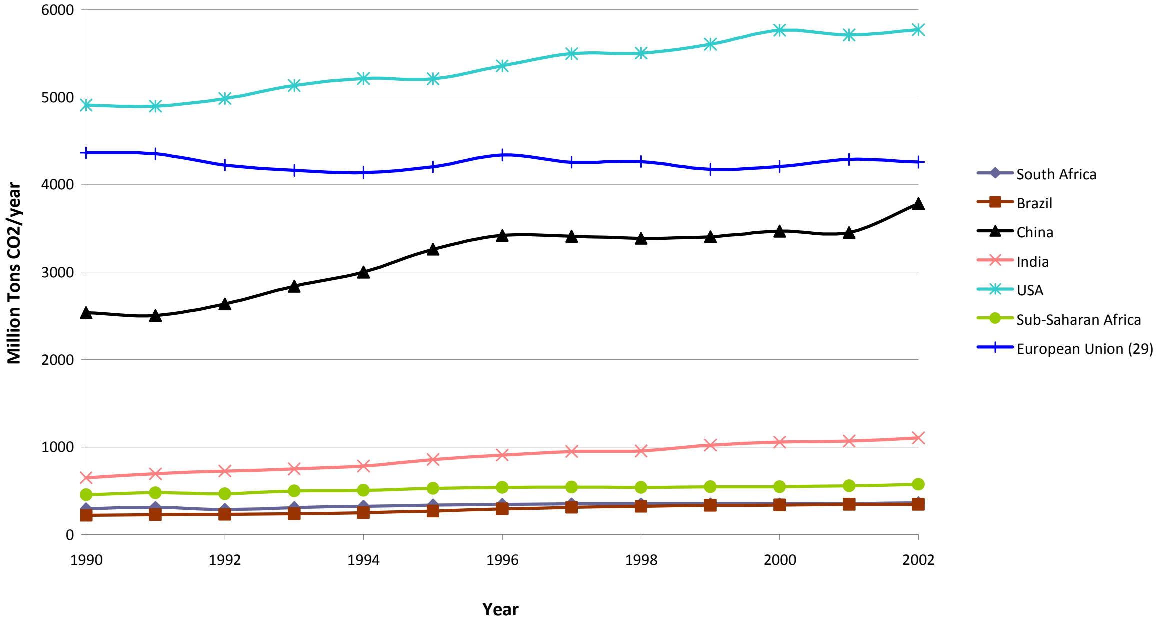

Figure 15: Comparison of annual CO_2 emissions from energy and cement production, 1990-2002

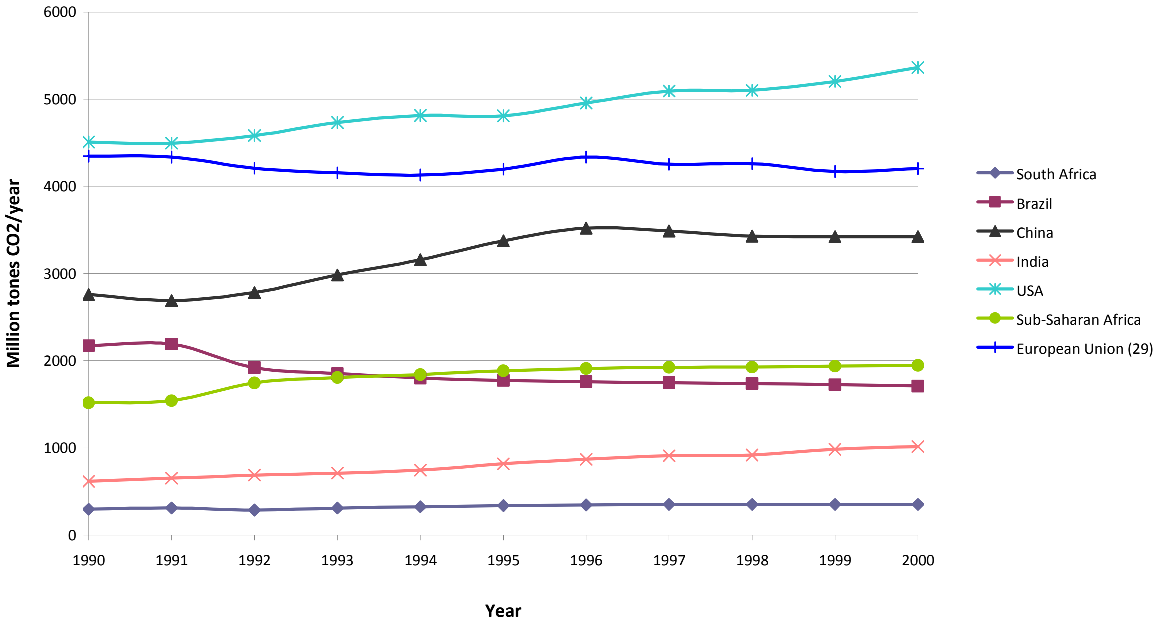

Figure 16: Comparison of annual CO_2 emissions from energy, cement production and LULUCF, 1990-2000

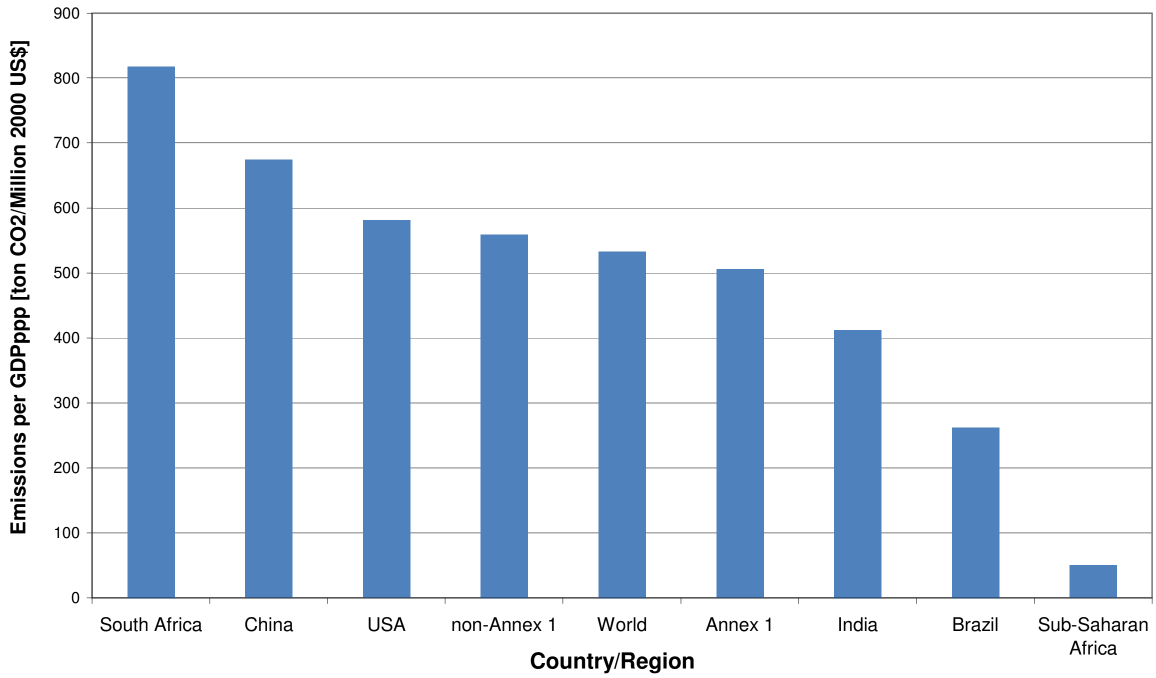

Figure 17: Comparison of 2002 CO_2 emissions per GDPppp (2000 US$) from energy and cement production

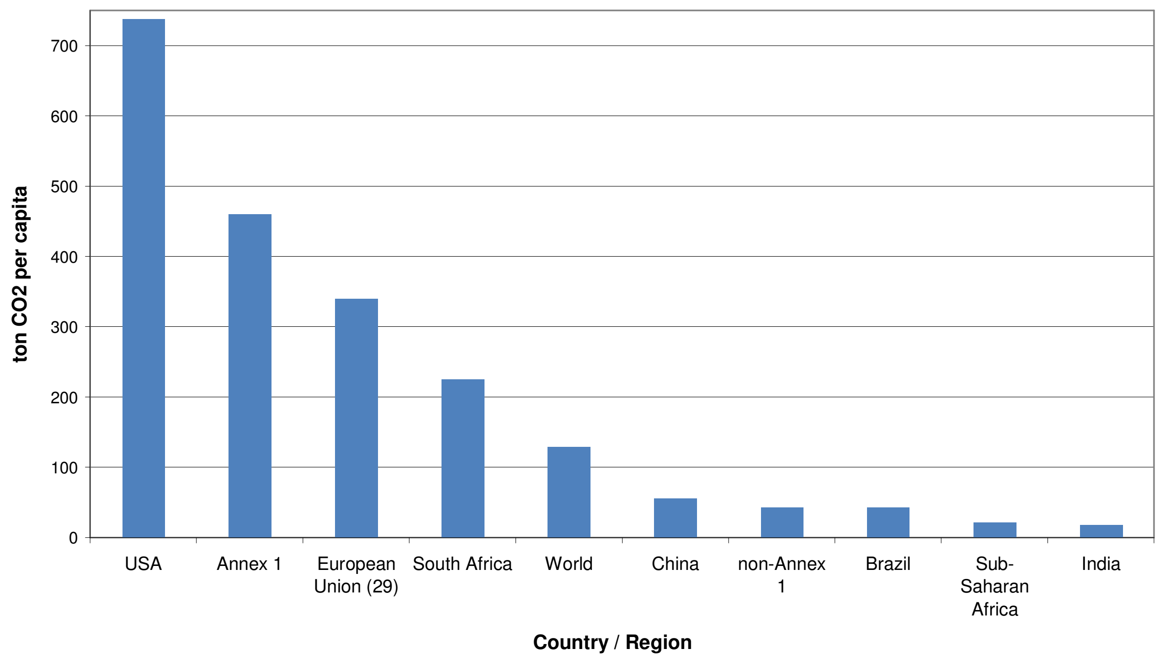

Figure 18: Comparison of cumulative CO_2 emissions per capita from energy and cement production, 1950-2000

Table 1: South Africa's GHG emissions world ranking by indicator

	Rank by emissions	*Rank by emissions per capita*
Cumulative emissions 1950-2000, only energy CO_2	14	46
Cumulative emissions 1950-2000, CO_2 energy and LULUCF	21	63
Annual emissions 2000, CO_2 only, no LULUCF, i.e. energy CO_2	14	39
Annual emissions 2000, CO_2 only, with LULUCF	18	54
Annual emissions 2000, six gases, no LULUCF	19	47
Annual emissions 2000, six gases, with LULUCF	21	63
Annual emissions 2000, three gases, no LULUCF	19	47
Annual emissions 2000, three gases, with LULUCF	21	65

3. Emission factors

3.1 IPCC standard emission factors

Table 2: IPCC default carbon contents (IPCC 2007)

Fuel type English description	Default carbon content [1] (kg/GJ)	Lower	Upper
Crude Oil	20.0	19.4	20.6
Orimulsion	21.0	18.9	23.3
Natural Gas Liquids	17.5	15.9	19.2
Motor Gasoline	18.9	18.4	19.9
Aviation Gasoline	19.1	18.4	19.9
Jet Gasoline	19.1	18.4	19.9
Jet Kerosene	19.5	19	20.3
Other Kerosene	19.6	19.3	20.1
Shale Oil	20.0	18.5	21.6
Gas/Diesel Oil	20.2	19.8	20.4
Residual Fuel Oil	21.1	20.6	21.5
Liquefied Petroleum Gases	17.2	16.8	17.9
Ethane	16.8	15.4	18.7
Naphtha	20.0	18.9	20.8
Bitumen	22.0	19.9	24.5
Lubricants	20.0	19.6	20.5
Petroleum Coke	26.6	22.6	31.3
Refinery Feedstocks	20.0	18.8	20.9
Refinery Gas [2]	15.7	13.3	19.0
Paraffin Waxes	20.0	19.7	20.3
White Spirit & SBP	20.0	19.7	20.3
Other Petroleum Products	20.0	19.7	20.3
Anthracite	26.8	25.8	27.5
Coking Coal	25.8	23.8	27.6
Other Bituminous Coal	25.8	24.4	27.2
Sub-Bituminous Coal	26.2	25.3	27.3
Lignite	27.6	24.8	31.3
Oil Shale and Tar Sands	29.1	24.6	34
Brown Coal Briquettes	26.6	23.8	29.6
Patent Fuel	26.6	23.8	29.6
Coke Oven Coke and Lignite Coke	29.2	26.1	32.4
Gas Coke	29.2	26.1	32.4
Coal Tar [3]	22.0	18.6	26.0
Gas Works Gas [4]	12.1	10.3	15.0
Coke Oven Gas [5]	12.1	10.3	15.0
Blast Furnace Gas [6]	70.8	59.7	84.0
Oxygen Steel Furnace Gas [7]	49.6	39.5	55.0
Natural Gas	15.3	14.8	15.9

Fuel type English description	Default carbon content [1] (kg/GJ)	Lower	Upper
Municipal Wastes (non-biomass fraction)[8]	25.0	20.0	33.0
Industrial Wastes	39.0	30.0	50.0
Waste Oils [9]	20.0	19.7	20.3
Peat	28.9	28.4	29.5
Wood/Wood Waste [10]	30.5	25.9	36.0
Sulphite lyes (black liquor) [11]	26.0	22.0	30.0
Other Primary Solid Biomass [12]	27.3	23.1	32.0
Charcoal [13]	30.5	25.9	36.0
Biogasoline [14]	19.3	16.3	23.0
Biodiesels [15]	19.3	16.3	23.0
Other Liquid Biofuels [16]	21.7	18.3	26.0
Landfill Gas [17]	14.9	12.6	18.0
Sludge Gas [18]	14.9	12.6	18.0
Other Biogas [19]	14.9	12.6	18.0
Municipal Wastes (biomass fraction) [20]	27.3	23.1	32.0

Notes:

[1] The lower and upper limits of the 95 percent confidence intervals, assuming lognormal distributions, fitted to a dataset, based on national inventory reports, IEA data and available national data. A more detailed description is given in section 1.5

[2] Japanese data; uncertainty range: expert judgement;

[3] EFDB; uncertainty range: expert judgement

[4] Coke Oven Gas; uncertainty range: expert judgement

[5] Japan & UK small number data; uncertainty range: expert judgement

[6] 7. Japan & UK small number data; uncertainty range: expert judgement

[8] Solid Biomass; uncertainty range: expert judgement

[9] Lubricants ; uncertainty range: expert judgement

[10] EFDB; uncertainty range: expert judgement

[11] Japanese data; uncertainty range: expert judgement

[12] Solid Biomass; uncertainty range: expert judgement

[13] EFDB; uncertainty range: expert judgement

[14] Ethanol theoretical number; uncertainty range: expert judgement

[15] Ethanol theoretical number; uncertainty range: expert judgement

[16] Liquid Biomass; uncertainty range: expert judgement

[17-19] Methane theoretical number; uncertainty range: expert judgement

[20] Solid Biomass; uncertainty range: expert judgement

4. Carbon accounting

4.1 Life cycle emission estimates for South Africa's electricity and liquid fuels

4.1.1 Electricity generation

Table 3 presents the carbon dioxide emission factor specific to South Africa's Eskom electricity generation, transmission and distribution. The emission factor is based on a study of three of the country's base-load coal-fired power stations (Kendal, Lethabo and Arnot) by a team of engineers and scientists between 2002 and 2005. The study experimentally determined emission factors for underground coal mining, power plant CO2 and NO. It was assumed that the emissions from the three power stations analysed are representative of the emissions in all coal-fired power stations in South Africa. Fractions of electricity generated from the different energy sources were estimated from average electricity generated by different Eskom technologies between 2002 and 2004.

Table 3: Emission factor for Eskom-generated electricity in kg CO_2-eqt per kWh

	Value	*Units per kWh electricity*	*Reference*
% electricity generated from coal	92.0		Eskom (2007)
% electricity generated from gas (kerosene)	0.0000836		Eskom (2007)
% electricity without carbon emissions	8.0		Eskom (2007)
Total emissions from coal-fired plants	0.993	kg CO_2-eqt	
CO_2 emissions from coal power plants	0.978	kg CO_2	Zhou, Yamba et al. (unknown)
N_2O-eqt emissions from coal mining NO_x	0.000038	kg N_2O-eqt	Zhou, Yamba et al. (unknown)
CH_4 emissions from coal mining	0.000178	kg CH_4	Zhou, Yamba et al. (unknown)
CO_2 emissions from kerosene plants	0.955	kg CO_2	Eskom (2007)
Overall power plant emissions	*0.914*	*Kg CO_2-eqt*	
Transmission losses	8.33	%	Eskom (2007)
Distribution losses	1.74	%	Eskom (2007)
Eskom average Emission Factor	1.015	kg CO_2-eqt/kWh	

4.1.2 Liquid fuels

In this section, life-cycle GHG emissions for the liquid fuels sector have been detailed. These emissions have been divided into three categories, based on the primary energy source: crude oil, coal and natural gas.

4.1.2.1 Liquid fuels from crude oil

Assumptions

- Key life cycle steps that have been included in determining GHGs emissions emitted from crude oil-based liquid fuels are:

- crude oil production[1] (including drilling and pre-processing);
- pipeline transport from the oil rig to onshore facilities;
- tanker transport to South African ports;
- liquid fuels production at South African crude oil refineries (Calref, Enref, Natref and Sapref);
- complete combustion of liquid fuels by end-users.

- Liquid fuels transport and distribution emissions have not been explicitly determined. However, these emissions are expected to be embodied in emissions from complete combustion of the fuels.
- Fugitive emissions from pipeline transport of crude oil to inland refineries have not been included.

Liquid fuels production

Table 4 shows carbon dioxide emission equivalents for the production of liquid fuels in South African refineries, using a base year of 1997.

Table 4: GHGs emissions from crude oil-based liquid fuels production in South African refineries (kton CO_2-equiv; base year: 1997; adapted from Frischknecht & Jungbluth (2007))

	Calref	*Enref*	*Natref*	*Sapref*
LPG	40.6	42.3	6.8	120.2
Petrol	958.9	975.3	1021.5	1656.1
Kerosene	338.5	261.3	570.5	515.1
Diesel	866.7	762.0	934.5	1538.9
Heavy fuel oil	579.2	679.3	104.9	1284.1
Refinery gas	0.0	9.1	0.0	23.1
Totals	**2784.0**	**2729.3**	**2638.2**	**5137.5**

Relative contributions of each fuel product to GHG emissions by refinery facility are shown in Figure 19.

[1] It has been assumed that South African crude oil refineries use Middle Eastern (Iranian) crude as their primary feedstock.

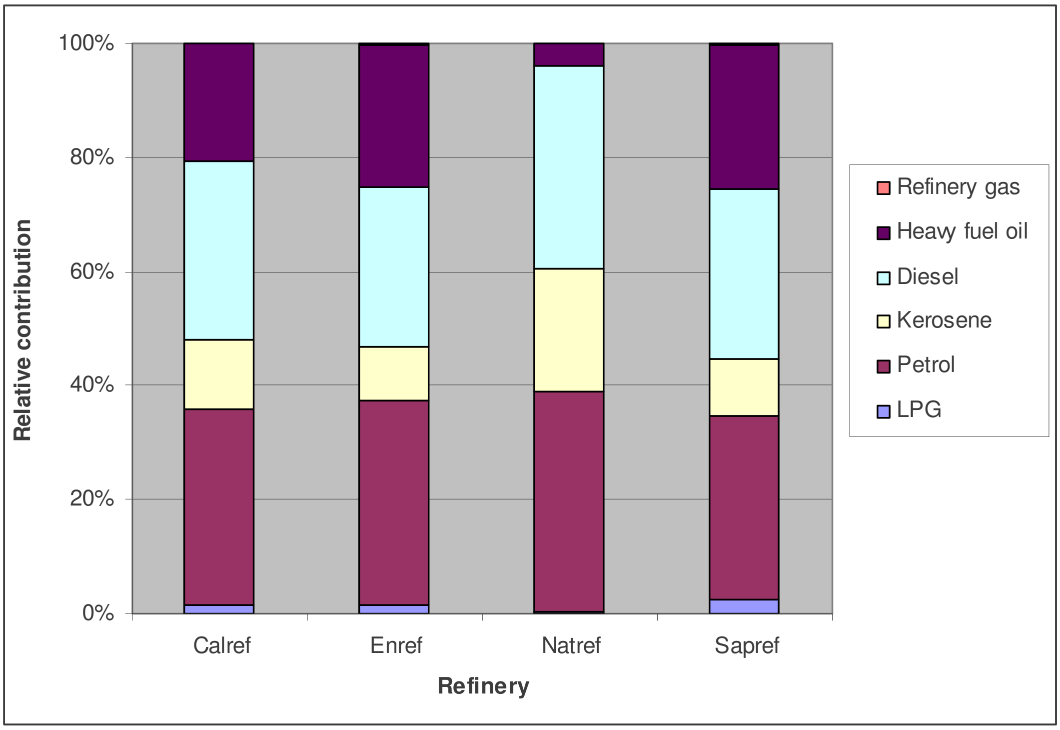

Figure 19: Relative contributions of liquid fuel products to GHGs emissions for South African refineries

End-use combustion

Table 5 below shows carbon dioxide emission equivalents for the consumption of liquid fuels in South African refineries, using a base year of 1997.

Table 5: GHGs emissions from crude oil-based liquid fuels combustion by source (kton CO_2-eq; Base year: 1997)

	Calref	*Enref*	*Natref*	*Sapref*
LPG	0.13	0.16	0.46	0.03
Petrol	0.00	0.03	0.08	0.00
Kerosene	3.50	3.56	6.05	3.73
Diesel	1.55	1.20	2.36	2.61
Heavy fuel oil	4.04	3.55	7.17	4.35
Refinery gas	2.85	3.35	6.33	0.52
Totals	**12.1**	**11.8**	**22.4**	**11.2**

The overall relative contribution of South African crude oil refineries to total GHG emissions from liquid fuels is shown in Figure 20.

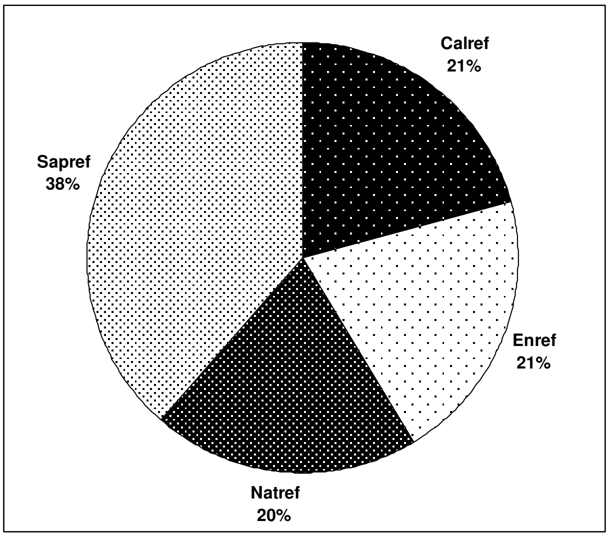

Figure 20: Relative contribution of South African refineries to total country greenhouse gas emissions from crude oil-based liquid fuels production and combustion

4.1.2.2 Liquid fuels from coal

Liquid fuel products in South Africa can be derived from coal using the Fischer-Tropsch process. Sasol is the only significant producing company that utilises this technology in the country. GHGs emissions arising from this production process have thus been included here.

Assumptions

- The Secunda complex is the only production facility using coal as the primary feedstock for the process (the Sasolburg complex, Sasol One, has been using Mozambiquan pipeline natural gas since 2004)
- Fischer-Tropsch products in the Secunda complex are derived from high-temperature Fischer-Tropsch conversion, which favours the formation of light hydrocarbons such as petrol and fuel alcohols (Sasolburg uses a low-temperature Fischer-Tropsch conversion, which has high yields for long-chain hydrocarbons such as waxes and paraffins).
- Fischer-Tropsch products are co-generated with electricity as a process by-product
- Daily GHG emissions were determined from a carbon balance over the process. This carbon balance is shown in Table 6 below.

Table 6: Carbon balance for the production of liquid fuels from coal (Base year: 2003; Adapted from Steynberg & Nel (2004))

Inputs (tons/day)	
Coal	34 782.3
Total	34 782.3
Outputs (tons/day)	
Fischer-Tropsch products	10 967.5
CO_2 removal	18 615.9
Slag	180.8
Sulphur plant flue gas	649.3
Power plant flue gas	4 368.8
Total	**34 782.3**

Table 7 below shows carbon dioxide emission equivalents for the production and complete combustion of liquid fuels from South African coal, using a base year of 2003.

Table 7: Annual carbon dioxide emissions from coal-based production and consumption of Fischer-tropsch fuels in South Africa (Base year: 2003)

	Mtons/annum
Fischer-Tropsch products	13.3
CO_2 removal	22.5
Slag	0.22
Sulphur plant flue gas	0.79
Power plant flue gas	5.28
Total	**42.06**

5. Mitigation options

Mitigation actions in the LTMS were considered in three categories – energy supply, energy use and non-energy emissions. Each of these includes sub-sectors; Energy modelling considered energy supply (notably electricity generation and liquid fuels), as well as energy use in major economic sectors – industry, transport, commercial, residential and agricultural sectors, while industrial process emissions focused on synfuels production, coal mining, iron and steel, ferro-alloys, aluminium and cement production. Non-energy emissions in agriculture, waste and land use, land use change and forestry (LULUCF) were also modelled (Winkler 2007).

Table 8 below presents a description of the mitigation actions that were modelled in the LTMS process, together with their respective mitigation capacities, mitigation costs and investment requirements, arranged in order of mitigation capacity from the largest GHG emission reduction to the smallest. While the mitigation cost depicts the cost of mitigating one tonne of CO_2-equivalent emissions, the investment cost requirement highlights the undiscounted incremental cost of investment from the baseline scenario.

Table 8: Summary of modelled mitigation actions, GHG emission reduction potentials and costs (Winkler 2007)[2]

Mitigation action	*Model description and parameters*	*GHG emission reduction, Mt CO_2-eq, 2003-2050*	*Mitigation cost (R/t CO_2-eq)[3]*	*Rank costs – lowest cost is no.1*
Escalating CO_2 tax	An escalating CO_2 tax is imposed on all energy-related CO_2 emissions, including process emissions from Sasol plants.	12 287	42	20
Nuclear and renewable electricity, extended	Combines the extended renewables and nuclear scenarios below. At 50% each, this is a zero-carbon electricity case	8 297	52	23
Electric vehicles with nuclear, renewables	Electric vehicles are allowed to take up 10% of passenger kilometre demand between 2008 and 2015 increasing to 60% of demand in 2030 and remains at 60% to 2050	6 255	102	28
Nuclear and renewables	Combines the individual nuclear and renewables cases. i.e. no electricity from fossil fuels by 2050	5 559	64	24
Industrial efficiency	Improved boiler efficiency, HVAC, refrigeration, water heating, lighting & air compressors, motors, compressed air management, building shell design optimising process control, energy management systems & introducing variable-speed drives	4 572	-34	8
Renewables with learning, extended	Same as renewables extended (50%), but assuming that the unit costs of renewable energy technologies decline, as global installed capacity increases	3 990	3	13
Subsidy for renewables	-106 R/GJ, on electricity from power tower, trough, PV, wind, hydro, bagasse, LFG	3 887	125	30
Nuclear, extended	The bound on investment in new capacity for both PBMR and PWR were increased to 2050	3 467	20	17
Renewable electricity, extended	In an extended mitigation action, the bound on commissioning of new Parabolic Trough and Solar Power tower plant is increased to 2.5GW/year by 2050	3 285	92	27

2 Negative value of investment cost implies an investment saving compared to the baseline.

3 Average of incremental costs of mitigation action vs. Base case, at 10% discount rate.

Mitigation action	*Model description and parameters*	*GHG emission reduction, Mt CO_2-eq, 2003-2050*	*Mitigation cost (R/t CO_2-eq)*[3]	*Rank costs – lowest cost is no.1*
Renewables with learning	Same as renewables (27%), but assuming that the unit costs of renewable energy technologies decline, as global installed capacity increases	2 757	-143	7
Renewable energy for electricity generation	15% of electricity dispatched from domestic renewable resources by 2020, and 27% by 2030, from local hydro, wind, solar thermal, landfill gas, PV, bagasse / pulp & paper.	2 010	52	22
Nuclear electricity	27% of electricity dispatched by 2030 is from nuclear, either PBMRs or conventional nuclear PWRs – model optimised for cost etc.	1 660	18	16
Synfuels CCS 23 Mt	Carbon capture and storage on coal-to-liquid plant, with maximum storage of 23 Mt CO_2 per year, equivalent to concentrated emissions of existing plant	851	105	29
Improved vehicle efficiency	Improve energy efficiency of private cars and light commercial vehicles by 0.9%-1.2% per year (0.5% in base case).	758	-269	3
Biofuel subsidy	A subsidy of R1.06 per litre on biofuels applied as an incentive for biofuel take-up	573	697	35
Passenger modal shift	Passengers shift from private car to public transport and from domestic air to intercity rail/bus.–moving from 51.8% of passenger kms in 2003 to 75% by 2050	469	-1 131	2
Land use: fire control and savannah thickening	50% reduction in fire episodes in savannah from 2004	455	-15	10
Electric vehicles in GWC grid	Electric up to 60% of the private passenger car market, operating in an unchanged grid, i.e. largely coal-fired	450	607	34
CCS 20 Mt	A cap on CCS use is increased annually starting with 1 Mt in 2015, and reaching a peak of 20 Mt in 2024.	449	72	26
Waste management	Waste Minimisation and composting	432	14	15
Residential efficiency	Penetration of SWHs, passive solar design, efficient lighting, appliance labelling & STDs, geyser insulation, LPG for cooking, ‘Basa Njengo Magogo’ coal fire-lighting method	430	-198	6
Commercial efficiency	In new buildings: SWH, efficient water heating, efficient HVAC, efficient lighting, variable speed drives, efficient motors, efficient refrigeration, building energy management systems, and efficient building shell design. In existing buildings, retrofit equipment and energy management systems	381	-203	5
Hybrids	20% of private cars are hybrids by 2030 (ramped up from 0% in 2001 to 7% in 2015).	381	1 987	36
Agriculture: enteric fermentation	Cattle herd reduced by 30% between 2006 and 2011; 45% of free-range herd transferred to feedlots from 2006; high-protein, high digestibility feed supplementation	313	50	21
SWH subsidy	The cost of SWHs in the residential sector was reduced. The cost after subsidy in 2001 is R534.7 mil /PJ/a, which reduces further to R336.77 mil /PJ/a in 2050	307	-208	4
CCS 2 Mt	A cap is placed on the amount of CO_2 which can be stored annually by CCS to 2Mt.	306	67	25
Land use: afforestation	Rate of commercial afforestation will increase between 2008 to 2030 so that an additional 760 000 ha of commercial forests are planted by 2030	202	39	19
Cleaner coal for electricity generation	27% of electricity dispatched by supercritical coal and /or IGCC coal technologies by 2030; first plant could be commissioned by 2015.	167	-4.8	11

Mitigation action	Model description and parameters	GHG emission reduction, Mt CO_2-eq, 2003-2050	Mitigation cost (R/t CO_2-eq)[3]	Rank costs – lowest cost is no.1
Biofuels	Biofuels blends increased to 8% ethanol with petrol and 2% biodiesel with diesel in 2013. Thereafter the percentage of ethanol in petrol is taken up to an assumed maximum of 20% and biodiesel to a maximum of 5% in 2030.	154	524	33
Synfuels methane capture	Capture CH_4 emissions from existing CTL plants from 2010	146	8	14
Agriculture: reduced tillage	Reduced tillage is adopted from 2007 on either 30% or 80% (more costly) of cropland	100	24	18
Synfuels CCS 2 Mt	Carbon capture and storage on coal-to-liquid plant, with maximum storage of 23 Mt CO_2 per year, equivalent to the largest planned storage at the time.	78	476	32
Coal mine methane reduction (50%)	Capture 25% or 50% (at higher cost) of methane emissions from coal mines, starting in 2020, and reaching goal by 2030	61	346	31
Agriculture: manure management	Percentage of feedlot manure from beef, poultry and pigs which is scraped and dried (does not undergo anaerobic decompositions) raised to 80% by 2010	47	-19	9
Aluminium: PFC capture4	Capture of PFCs from existing aluminium plant, starting in 2011, and reaching 100% by 2020	29	0.2	12
Limit on less efficient vehicles	SUVs limited to 2% of private passenger kms by 2030	18	-4 404	1

5.1 Description of mitigation scenarios

Apart from the GWC, one other envelope scenario called the '*Required by Science*' scenario (RBS) was outlined. This scenario is different from all other scenarios in that it is driven by a climate target. RBS asks what would happen if South Africa reduced its emissions by 30% to 40% from 2003 levels by 2050.

5.1.1 Three modelled strategic options

To bring South Africa's emissions closer to what is required by science three strategic options were modelled in the LTMS. Each option was arrived at by strategically combining various mitigation actions such that the final package of actions is large enough to reveal a distinct emission reduction pathway (Scenario Building Team 2007). These options are described below while their properties are summarised in Table 9.

Table 9: Mitigation costs and emission reduction potentials of combined strategic actions

Mitigation action	Mitigation cost (R/t CO_2-eq)	GHG emission reduction (Mt CO_2-eq, 2003-2050)	Mitigation costs as share of GDP
	Average of incremental costs of mitigation action vs. base case, at 10% discount rate	Positive numbers are reductions of emissions by sources or removals of emissions by sinks	%, negative numbers mean negative costs
Start Now	-R13	11 079	-0.5%
Scale Up	R39	13 761	0.8%
Use the Market	R10	17 434	0.1%

[4] Investment for aluminium is only required once in 2006.

5.1.1.1 Start now

The first option, called *Start now*, is composed of all those mitigation actions in Table 8 that are not labelled as extended, excluding the CO_2 tax and subsidies which are modelled as part of the 'Use the Market' scenario below. All mitigation actions that have upfront costs, but where the savings over time more than outweigh the initial costs – also known as net-negative cost mitigation actions – are part of this strategic option.

Table 9 shows that this option saves money over time, even if implemented up to 2050. The biggest mitigation actions of *Start now* – in terms of emission reductions – are industrial efficiency, more renewables and nuclear sources for electricity generation, passenger modal shift and improved vehicle efficiency. Effectively the *Start now* scenario reduces the gap between GWC and RBS by 43% in 2050 (Scenario Building Team 2007).

5.1.1.2 Scale up

The second strategic option is called the *Scale Up* scenario, and it is an extension of the *Start now* package. Basically all the extendable mitigation actions in *Start now* are replaced in *Scale up* by their extended counterparts as shown in Table 8.

In terms of mitigation, the biggest actions in this scenario are energy efficiency, extended renewables, extended nuclear, synfuels with CCS and electric vehicles. Emissions follow the *Start now* profile fairly closely at first, and continue to rise; but in the last decade they level out (plateau). Under *Scale up*, the emissions gap is closed by two-thirds (64%) in 2050 (Scenario Building Team 2007).

5.1.1.3 Use the market

The last modelled strategic option is termed the *Use the market* scenario. This option focuses on the use of economic instruments, and it includes an escalating CO_2 tax on the whole energy sector, which generates revenue that could be used to provide incentives for renewable electricity, solar water heating and biofuels (Scenario Building Team 2007).

The tax causes electricity supply to move away from coal to nuclear and renewables. No new coal plants are built in this scenario and existing coal power supply declines rapidly from 2025, so that by 2040 only 4GW of coal capacity is left. A total of 14 new conventional nuclear plants are built, adding 25GW of new capacity by 2050. The renewables plants come in smaller units, but add a total of 118GW by 2050. No new coal-to-liquid plant is built, but five additional oil refineries are built (Scenario Building Team 2007).

5.1.2 Reaching for the goal: Strategic options beyond the modelled

FigureFigure 21 shows emission pathways of all the modelled scenarios, and illustrates how far each strategic option closes the gap between GWC and RBS.

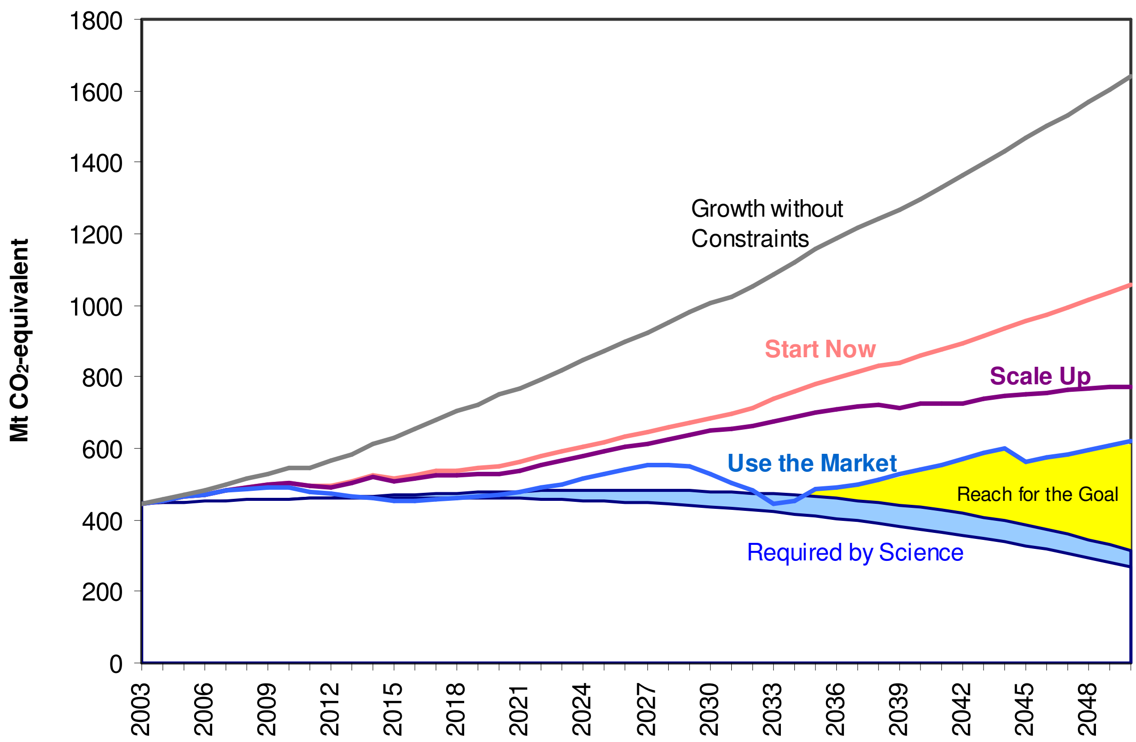

Figure 21: Emission pathways o f GWC, RBS and combined strategic options

While *Scale up* closes the gap between RBS and GWC by about two-thirds (64%) in 2050 and *Use the market* does the job well until around 2035, a 'triangle' of emissions remains between 2035 and 2050. This implies that a new set of options would have to be ready for implementation by this time. It is expected that new technologies will emerge – but what will they look like? Awareness of climate change may induce significant changes in people's patterns of consumption and behaviour – to what extent? The fourth strategic option, *Reaching for the goal*, lays the platform for getting these answers.

While it is acknowledged that the components of the *Reaching for the goal* strategic option cannot be modelled as was done with the other options, it can be imagined what some of its salient characteristics might have to be, by 2050. In the LTMS four actions, all requiring further study, were suggested (Scenario Building Team 2007): 1) New Technology – investigating technologies for the future; 2) Resource identification – searching for lower carbon resources; 3) People-orientated measure – incentivised behaviour; and 4) Transition to a low-carbon economy – redefining SA's competitive advantage

6. Useful links

6.1 National

- Department of Environmental Affairs and Tourism: http://www.environment.gov.za
- Department of Minerals and Energy: http://www.dme.gov.za
- CSIR: http://www.csir.co.za
- Sasol: http://www.sasol.com
- Eskom: www.eskom.co.za
- South African Biofuels Association: http://www.saba.za.org
- National biofuels chair: http://academic.sun.ac.za/biofuels/
- African Sustainable Fuels Centre: http://www.asfc.org.za/
- Sustainable Energy Africa: http://www.sustainable.org.za/focus-areas/sustainable-energy-africa.html
- AGAMA Energy: http://www.agama.co.za/
- African Alternative Energy: http://www.aae.co.za/
- The Green Building: http://sustainable.org.za/greenbuilding/
- Environmental Monitoring Group: http://www.emg.org.za/default.htm
- Biodiesel Centre: http://www.biodieselcentre.co.za/
- Sustainable Energy Society Southern Africa: http://www.sessa.org.za/
- Project 90 X 2030: http://www.project90x2030.org.za/
- Food and trees for Africa: http://www.trees.co.za/
- Genergy: http://www.genergy.co.za/

6.2 International

- International Panel on Climate Change: http://www.ipcc.ch/
- United Nations Framework Convention on Climate Change: http://unfccc.int/2860.php
- International Energy Agency: http://www.iea.org/
- US Energy Information Administration: http://unfccc.int/2860.php
- World Resource Institute's Earth Trends: http://www.earthtrends.wri.org/
- Renewable Energy and Energy Efficiency Partnership: http://www.reeep.org/

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