Constructing a greenhouse gas emissions inventory using energy balances: the case of South Africa for 1998

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Abstract

This paper discusses the procedures and results of constructing a greenhouse gas (GHG) emissions inventory for South Africa, using the official national energy balance for 1998. In doing so, the paper offers a snapshot of the South African energy supply and demand profile and encompassing greenhouse gas emissions profiles, disaggregated into 40 economic sectors, for the reference year. For convenience, energy supply and use are reported in both native units and terra joule (TJ), while emissions are expressed in carbon dioxide equivalents and reported in giga-gram (Gg). While carbon dioxide makes an overwhelming contribution to global anthropogenic GHG emissions, the inclusion of methane and nitrous oxide offers considerable richness to the analysis of climate change policies. Applying the energy balances, it was possible to compile a comprehensive emissions inventory using a consistent methodology across all sectors of the economy. The inventory allows the economic analyst to model various economic policies either with fuel as an input to production, or the consumption of fuel or the emissions generated during combustion, as a base of the analysis. The dominant role of coal as a source of energy, with a total primary energy supply (TPES) of 3.3 million TJ or 70 per cent of the total TPES, is clearly shown. Emissions from coal combustion (263 783 Gg of carbon dioxide equivalents or 74.7 per cent of total emissions) are henceforth the largest contributor to total emissions, estimated to be 352 932 Gg carbon dioxide equivalents.

Keywords: energy balances, greenhouse gas emissions, greenhouse gas inventory, emission factors, economic sectors, IPCC, South Africa

1. Introduction

Developing countries, also known as non-Annex I parties according to the Kyoto Protocol, have 'common but differentiated' responsibilities as outlined in Article 4 (a-j) of the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC, 1999). This means that neither are they obligated to reduce greenhouse gas (GHG) emissions, nor will they be required to do so during the first commitment period (2008-2012) of the Kyoto Protocol. At the same time, increasing pressure is placed on developing countries to share the burden of GHG reduction. This might result in non-Annex I countries having emission reduction commitments during the second commitment period after 2012. Part of the reluctance of developing countries to participate in global climate change initiatives stems from a lack of empirical research to inform policy. The lack of solid empirical work can partially be explained by the lack of official greenhouse gas emissions inventories that are both on time and reliable.

The question that now arises is whether it is possible to use the national energy balance, published annually by national authorities in charge of energy statistics, as a source of information to calculate an emissions inventory that could be linked to economic sectors to be used in economic analysis and modelling. This is the question addressed in this study, focusing on South Africa. To address this issue, the next section provides background information regarding existing GHG emissions data and motivates for the compilation of a comprehensive and consistent methodology that could be used timeously and repeatedly at low cost, but with a high degree of accuracy, to compile an unofficial greenhouse gas emissions inventory. Thereafter, the methodology followed to calculate the new emissions inventory is discussed, followed by the study results and a discussion thereof. A conclusion completes the paper.

2. Background

Despite the importance of data on greenhouse gas (GHG) emissions, no official GHG emissions inventory beyond 1994 exists in South Africa. The summary of the emissions inventory is provided in Table 1. From this it is clear that carbon dioxide (CO_2) is by far the largest greenhouse gas being emitted, though the global warming potential of the other two gasses, methane (CH_4) and nitrous oxide (N_2O), is significantly higher. It is also clear that the energy sector is the main emitter of GHG emissions. This is mainly the result of the combustion of fossil fuels; especially coal. Notwithstanding the fact that the information is rather dated, the other concern regarding this inventory is that it does not indicate neatly the source of fuel, the fuel type, the sector combusting the fuel or the purpose for fuel combustion. This is the type of analysis, or data mapping, required doing economic analysis when considering the economic impact of various policies aimed at mitigating the country's GHG emissions. This analysis could include the use of economy-wide modelling techniques such as Computable General Equilibrium (CGE) Models, Social Accounting Matrix (SAM) Impact Models and Input-Output Models.

As far as the current South African literature on emission data is concerned, there are a number of sector specific studies that offer sector specific emissions data. These include studies focusing on the transport sector (Gaffen *et al*., 2000 and Freeman *et al*., 2000), the electricity sector (Spalding-Fecher *et al*., 2000), the liquid fuel sector (Lloyd *et al*., 2000) and the mining sector (Clement and Foster, 2000). Other studies focusing on the manufacturing sector include those by Visser *et al*. (2000), Trikam (2002), Blignaut and King (2002) and Blignaut and Zunckel (2004).

Table 1: Official GHG emissions inventory
Source: RSA (2000)

	CO_2		CH_4		N_2O	
	1990	*1994*	*1990*	*1994*	*1990*	*1994*
Energy	**256 764**	**287 851**	**349**	**376**	**5**	**6**
energy industries	156 373	167 817	1	0	3	3
industry	47 026	53 186	6	6	1	1
transport	30 779	42 717	9	11	1	2
commercial	11 844	780	1	0	0	0
residential	7 542	7 397	9	1	0	0
agriculture	3 200	15954	0	31	0	1
fugitive emissions			324	327		
Industrial processes	**31 190**	**30 010**	**3**	**1**	**5**	**6**
mineral products	5 478	5 331				
chemical industry	3 936	3 856	3	1	5	6
metal production	21 776	20 823				
Agriculture			**1014**	**937**	**62**	**51**
enteric fermation			917	844		
manure management			83	78	1	0
agricultural soils					60	50
savanna burning			13	13	1	1
agricultural residues burning			2	2	0	0
Land use change and forestry	**-16 982**	**-18 616**				
changes in biomass	-13 641	-10 886				
soil removals	-3 341	-7 730				
Waste			**666**	**743**	**2**	**3**
solid waste on land			647	722		
waste water handling			19	21	2	3
International bunkers	**7 195**	**10 220**				

All of these have in common the fact that they needed an emissions inventory for the respective economic sectors, and had to rely on various different methodologies and sources of data to compile an inventory for their specific sectors of interest. This has the advantage that, at that time, invaluable information was made available regarding the specific sector. The disadvantage, however, is that, since these studies are based on different methodologies, base years and sources, they are not comparable. Also, trying to get a comprehensive picture of the emissions profile of the country based on such a variety of studies covering a variety of sectors is very cumbersome and difficult, and could ultimately lead to costly mistakes. Howells and Solomon (2000) used such a sector-specific method in developing a greenhouse gas emissions inventory with 1994 as the reference year. They have gone into great length to analyse the energy sector and calculate sector specific emissions based on a common methodology. The problem, however, is that the sector demarcation does not correspond strictly with that of the standard industrial classification used by economic analysts. Furthermore, the most recent comprehensive economy-wide inventory is for 1998, and, lastly, the need exists to get a methodology to estimate a greenhouse gas emissions inventory much more regularly and with a degree of coherent simplicity that makes it possible for a large number of people to estimate a greenhouse gas inventory.

The current state of affairs regarding greenhouse gas emissions inventories leaves the economy-wide economic analyst in a precarious position: either use the dated but comprehensive national GHG inventory and adapt that to conform to the international industrial sector classification used in compiling an input-output or social accounting matrix, or use the more recent but fragmented sectoral studies to construct a new inventory. Neither solution is optimal, hence the need for a comprehensive and internationally consistent GHG emissions inventory. Foster (1998) attempted this. Although he made considerable use of primary data sources, his approach, however, did not allow the mapping of emission by fuel and sector in a way that is inherently consistent across sectors and fuels. This is what is attempted here through this study. It was also the express purpose to develop a methodology that could be repeated regularly, and by various people. This methodology will subsequently be discussed.

3. Methodology

3.1 General

In the light of the difficulties mentioned above, a GHG emissions inventory has been compiled using the national energy balance as published by the Department of Minerals and Energy (DME, 2000). These balances are compiled on an annual basis and provide data on the production, consumption, exports, imports and stock changes of black coal, brown coal, briquettes, coke, crude oil, a variety of petroleum products, natural gas, and electricity production. The published tables reconcile national supply figures for each fuel, calculated from indigenous production, exports and imports, with the detailed sector-by-sector energy consumption figures. Reconciliation is achieved in both native units (i.e. tons, MWh and kl) and standardised energy units (i.e. tons of oil equivalent, and TJ).

This information has been used to calculate the CO_2, CH_4 and N_2O emissions per sector, per fuel group for 1998 using various emission factors (see discussion below). 1998 was selected as a reference year since this corresponds to the latest available official South African Social Accounting Matrix (SAM), but the same methodology could easily be applied to any energy balance. This methodology allowed the mapping of emissions by fuel and sector in a way that is inherently consistent across sectors and fuels and amenable to the structure of the South African SAM (see Table 2 for the sectoral cross tabulation). This implies that economic policy analysis through integrated environmental-economic modelling is possible. Not only the emissions by fuel and sector, but also the energy consumption by fuel and sector in either a standardised unit (e.g. TJ) or native units could be mapped.

The fossil fuels combusting and contributing to GHG emissions included in the inventory comprise coal, oil and natural gas. Most of the emissions embodied in oil are attributed to the consumption of petroleum products, because oil is largely transformed into these products. Only the emissions by oil refineries during the transformation process are attributed to oil. Similarly, to avoid double counting, only the generation of electricity, and not the consumption thereof, contributes to emissions. Currently, the inventory does not account for non-combustion GHG emissions. Non-combustion emissions of GHG comprise fugitive emissions from oil and natural gas systems, and emissions from industrial processes such as aluminium production and cement manufacturing. Neither does the inventory include emissions from burning savannas and agricultural residues.

In the inventory, emissions of each GHG are expressed in carbon dioxide equivalents, based on the global warming potentials that measure the relative radiative forcing of different GHG over a specific period. These global warming potentials over a century time horizon are 1, 21 and 310 for carbon dioxide, methane and nitrous oxide respectively, as recommended by the International Panel on Climate Change (IPCC, 1996).

Table 2: Sectoral cross tabulation: SAM and national energy balance
Source: Own analysis

Energy balance sector	*Treatment in the SAM*
Iron and steel	Iron and steel
Chemical and petrochemical fuel type by each sector	Split into chemical and petroleum products according to the use of each
Non-ferrous metals	Nonferrous metals
Non-metallic minerals	Non-metallic minerals
Transport equipment	Transport equipment
Machinery	Machinery
Mining and quarrying	Split into gold, coal, crude oil and gas and other mining according to the use of each fuel type by each sub-sector
Food and tobacco	Food
Paper pulp and print	Paper, pulp and wood
Wood and wood products	Paper, pulp and wood
Construction	Construction
Textile and leather	Textile
Non-specified (industry)	Other manufactures
Transport sector	Transport services
Agriculture	Split into irrigated and dry field, irrigated and dry horticulture, livestock, forestry and other agriculture according to the use of each fuel type by each sub-sector
Commerce andpublic services	Split into the various service sectors according to the use of each fuel type by each sub-sector
Residential	Allocated to households
Non-specified (Other)	Other service activities

3.2 Carbon dioxide emissions

Coal-based CO_2-emissions

The carbon contained in fossil fuel oxidises and transforms into mainly CO_2 during combustion. Currently there is no technology for the successful mitigation of CO_2 emissions. The emission of CO_2 depends on the quantity and type of the fuel used and follows the laws of material balance and thermodynamics. The amount of CO_2 emitted can be calculated using two different approaches, namely the reference and the sectoral approaches. Using the reference approach, the input data are production, import, export, international bunkers and stock change for primary and secondary fuel. The more detailed sectoral approach implies the calculation of emissions using fuel consumption in different energy sub-sectors. The difference between the reference and the sectoral approaches should be relatively small. This study applies the sectoral approach for calculating the carbon dioxide emissions from the combustion of fossil fuels (see IEA 2001 for details), with some modification.

Emissions of CO_2 from coal combustion were calculated by multiplying the quantity of coal consumed in each sector by an effective emission factor for coal in that sector. To compute CO_2 emission factors for coal combustion, the coal consumption and resulting CO_2 emissions for 2000 reported in Blignaut and King (2002) were used and it was assumed that these factors were the relevant ones for 1998. The implied emission factors are shown in Table 3. These emission factors, especially that of electricity generation, is lower than the listed IPCC default factor of 94.6 t CO_2/TJ, but is based on published data for both emissions and coal consumption. A possible explanation for the difference might lie in the fact that the conversion of coal consumption to TJ is based on Pinheiro *et al.*'s (1997) gross calorific value of coal used for electricity, which is given as 20,37 MJ/kg.

Non-coal-based CO_2-emissions

Carbon dioxide emissions from non-coal fossil fuel sources have been calculated in a similar way to that of coal, namely by multiplying the fuel consumption in each sector by the respective emission factor. The basis for the estimate is the fuel used in different energy sectors, grouped into the fossil fuels categories according to its aggregate condition, namely crude oil, petrol, diesel, other petroleum,

Table 3: Coal emission factors
Source: Own calculations based on Blignaut and King (2002) as reported in Blignaut and Zunckel (2004)

Sector	*Emission factor t CO_2/TJ*
Agriculture	76.43
Mining and quarrying	76.13
Iron and steel	77.15
Non-metallic	76.22
Chemical and petrochemical industries	53.61
Auto-producer electricity plant	76.50
Public electricity plant	85.74
Non specified transport	76.50
Commerce and public services, residential, non-specified other	76.99

gas and renewables. Data about quantities of the fuel used are taken from the energy balance in TJ (DME, 2000).

The carbon content factors used for calculations are distinguished by fuel source and obtained from IPCC guidelines on emission factors. The factors applied to the different fuel categories are shown in Table 4.

Table 4: Carbon emission factors used for other energy sources
Source: IPCC 1995

Liquid fossil	20.0t C/TJ Crude oil 18.9t C/TJ Petrol 20.2t C/TJ Diesel 19.5t C/TJ Jet kerosene 19.6t C/TJ Other kerosene 20.0t C/TJ Shale oil 21.1t C/TJ Residual fuel oil 17.2t C/TJ LPG 16.8t C/TJ Ethane 20t C/TJ Naphta 22.0t C/TJ Bitumen 20.0t C/TJ Lubricants 27.5t C/TJ Petroleum coke 20.0t C/TJ Refinery feedstocks 18.2t C/TJ Refinery gas 20.0t C/TJ Other oil
Gaseous fossil	15.3t C/TJ Natural gas (dry)
Biomass	29.9t C/TJ Solid biomass 20.0t C/TJ Liquid biomass 30.6t C/TJ Gas biomass

General
In short, the carbon dioxide emission factors are calculated by multiplying the carbon emission factors (adjusted for oxidation) of a particular fuel by 3.6667 kg CO_2 per kilogram of carbon, and multiplying that product by the energy amount of that fuel consumed, and the steps followed are depicted by the following equation:

$$CO_2 = \sum \left[ACTIVITY \times EF \times \frac{44}{12} \right]$$

where
CO_2 = carbon dioxide emissions from fossil fuel combustion (in Gg)
ACTIVITY = fuel consumption converted to TJ
EF = emission factor, equal to carbon coefficient multiplied by oxidation factor, expressed as t/TJ
44/12 = molecular weight ratio of CO_2 to carbon.

Because not all carbon is oxidized, a relevant oxidation factor is applied. The oxidation[1] factors used are shown in Table 5.

Table 5: Oxidation factors for CO_2
Source: IPCC (1995, Vol 3)

Fuel	*Utilisation category*	*Oxidation factor*
Coal	Electricity generation	99%[a]
	Manufacturing industry	98%[b]
	Commercial, residential and other	95%[a]
Oil	All	99%[a]
Gas	All	99.5%[a]

Notes
a. default value
b. default value for `best practice'. Depending on maintenance procedures and efficiency, IPCC proposes a range of 90-98% for stoker fired industrial boilers.

3.3 Non-carbon dioxide emissions

As discussed above, the sources of methane and nitrous oxide emissions covered include combustion sources only, and computed using the following approach:

$$GAS = ACTIVITY * EF$$

where
Activity = fuel consumption converted to TJ
EF =emission factor, expressed as kg/TJ

Methane
There are a number of ways suggested in the literature to account for the emission of methane. There are emission factors from the IPCC IGES database, IPCC default emission factors or even using the average from a cluster of countries. This study used

the IPCC default guidelines (see Table 6) to be consistent with the methodology used for carbon. While it generally desirable to use country-specific emission factors, data limitations have dictated the use of this methodology.

Table 6: Emission factors for CH_4 (kg/TJ)
Source: IPCC (1996)

Sector	*Emission factor kg CH4/TJ*
Energy industries	
Liquid fuels	3
Solid fuels	1
Gaseous fuels	1
Waste	30
Manufacturing industries	
Liquid fuels	2
Solid fuels	10
Gaseous fuels	5
Waste	30
Other sectors	
Liquid fuels	10
Solid fuels	300
Gaseous fuels	5
Biomass and waste	300

Nitrous oxide
For nitrous oxide from the transport sector, the IPCC default emission factor values have been used. The IPCC gives a constant emission factor of 0.6 kg/TJ for both petrol and diesel, but a footnote to the gasoline emission factor states that when there are a significant number of cars with three-way catalysts in the country, road transport emission factors should be increased accordingly. To take into account expected increases in emissions over time as the use of catalysts increases, one has to consider changes in technologies. It has been assumed that, while in 1990 all cars in South Africa were non-catalyst-controlled (with an emission factor of 1.4 kg/TJ), in 1998 all cars were equipped with three-way catalysts (with an emission factor of 7.3 kg/TJ). The emission factor for electricity is computed from actual emission figures reported in Eskom (2000) and works out to 2.86 kg N_2O/TJ. The emission parameters used are summarised in Table 7.

Table 7: Emission parameters for N_2O emissions
Sources: IPCC (1996) and Eskom (2000)

Fuel	*Emission factor*
LPG	0.1kg N_2O/TJ
Natural gas	0.1kg N_2O/TJ
Electricity	2.86 kg N_2O/TJ
Diesel	0.6kg N2O/TJ
Petrol	7.3 kg N_2O/TJ

4. Results of the energy and greenhouse gas emission inventory for South Africa (1998)

Total primary energy supply (TPES) comprises indigenous production plus imports, less exports, less international marine bunkers, and less stock changes. Table 8 illustrates the main sources of energy in South Africa in 1998 in TJ. The dominant role of coal in the economy is evident from the Table, contributing more than 70 per cent of the country's energy needs. Approximately 25 per cent of the country's energy needs are met by crude oil, while natural gas, nuclear, renewable energy and biomass combined contribute a total of less than 10 per cent. Also indicated in the table is that petroleum and crude oil are mainly imported, while the other fuels originate mainly from domestic sources.

After adjusting for statistical differences and energy used, or being made available during the energy transformation processes (i.e. the conversion of coal to electricity through coal-fired power stations and crude oil to petroleum products through oil refineries), the energy available for final consumption is derived (see Table 8). Figure 1 indicates the share of final demand by the fuel used in South Africa during 1998. Electricity accounted for approximately 24 per cent of total final demand energy, while petroleum met 33 per cent of final demand energy needs. Coal accounted for 31 per cent of final demand, and renewables and gas for 11 per cent.

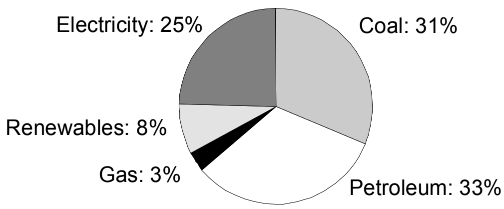

Figure 1: Share of final demand for energy by fuel type in 1998 by percentage
Source: Table 8

Table 9 shows the final demand for energy in TJ and in native units, where applicable, for 40 sectors. Taken as an aggregate, one sees that the industrial sector is the largest consumer of total energy, accounting for 44.2 per cent of all energy consumed in South Africa. Services account for 26.2 per cent of all energy consumed, while agriculture demands 5 per cent, mining 8 per cent and the residential sector demands 16 per cent. Taken individually, the trade sector is the largest consumer of

Table 8: South Africa's total primary energy supply (TJ)
Source: DME (2000) and own calculations

	Coal	*Crude Oil*	*Petroleum*	*Gas*	*Nuclear*	*Hydro*	*Renewables*	*Electricity*	*Total*
Indigenous production	5 278 319	293 876	-	53 983	148 375	5 742	237 400	-	6 017 694
Imports	36 147	897 696	40 948	-	-	-	-	8 550	983 342
Exports	-1 716 393	-28 925	-147 573	-	-	-	-	-16 315	-1 909 207
Intl. marine bunkers	-	-	-122 341	-	-	-	-	-	-122 341
Stock changes	-329 875	-	-	-	-	-	-	-	-329 875
Total primary energy supply (TPES)	3 268 198	1 162 648	-228 966	53 983	148 375	5 742	237 400	-7 765	4 639 614
TPES %	70.4	25.1	-4.9	1.2	3.2	0.1	5.1	-0.1	100
Energy transformation[1]	-2 783 868	-1 162 648	998 318	-22 791	-148 375	-5 742	-47 000	622 322	-2 549 784
Statistical difference[2]	241 939	0	-24 761	43 651	0	0	0	-43 406	217 423
Total final consumption	726 269	0	744 591	74 843	0	0	190 400	571 151	2 307 253

Notes:

1. A portion of the TPES is transformed into other forms of energy, e.g. coal and crude oil to electricity and petroleum products respectively. Energy used during this transformation process is therefore not part of the final consumption component. Henceforth, the fact that petroleum and electricity are indicated as the recipient sectors by a positive value and the source sectors (coal, crude oil, nuclear, hydro, gas and renewables) by a negative sign. During the transformation process, there is a net energy loss of 2.55 million TJ as indicated in the last column.
2. The difference between the TPES plus energy transformation and the total final consumption.

energy, consuming 20.6 per cent of all energy, followed by the residential sector with 16.3 per cent. Iron and steel, petroleum products and other metal products largely account for industrial consumption.

From the same table it is evident that the residential sector, gold mining, iron and steel, other metal products and non-ferrous metals consume the lion's share of electricity. In contrast, agriculture is a relatively small consumer of electricity. The petrochemical industry, iron and steel and other metal products dominate the demand for coal. The rest of the sectors are small consumers spread across the economy. The trade sector demands 61 per cent of petroleum products. Agriculture is also a fairly important consumer of petroleum products. Gas is mainly consumed by the iron and steel industry (almost 79 per cent). The final demand for renewables is exclusively accounted for by the residential sector.

Table 10 shows emissions in carbon dioxide equivalents for 1998 by sector and source of fuel. Of the total amount of CO_2 equivalent emissions of 352 932 Gg, coal dominates the emissions as a source, contributing 263 783 Gg of CO_2-equivalent or 74.7 per cent of the total emissions, followed by petroleum products with 53 744 Gg or 15.2 per cent, then renewables with 6.6 per cent and crude oil and gas with 3.4 per cent. Emissions that occur during energy transformation and the final consumption of the various fuel sources are taken into consideration. To avoid double counting, electricity is not viewed as a fuel source in this respect since emissions during the final consumption of electricity are considered to be zero. Electricity is viewed as a sector that consumes fuel.

Electricity generation (65.9 per cent) and petroleum refineries (20.4 per cent) dominate emissions from the combustion of coal, as indicated in Table 10 as well. These two sectors therefore contribute to more than 86 per cent of total emissions from the combustion of coal. Emissions from the combustion of petroleum are dominated by the trade sector (60.1 per cent), more specifically the retail sales of petroleum. Emissions from crude oil and gas are mainly concentrated in the petroleum refineries (60.1 per cent) and iron and steel industries (27.2 per cent). The former mainly converts crude oil to petroleum and the latter uses gas. It should be noted that emissions are allocated to the sector at the point of combustion. Therefore, the emissions allocated to the petroleum refineries are emissions that occur during the refinery process. The embedded carbon in the fuel is only emitted during the combustion of the fuel, mainly through motor vehicles. Private petroleum sales are allocated to the retail trade sector. This distinction is essential to ensure that there is no double counting. Emissions from renewable sources are only concentrated in the electricity and residential sectors. With regard to the former, it reflects the use of renewable materials for the generation of electricity for own consumption by industries such as in the paper and pulp and automotive industries. In total, electricity generation, petroleum refineries and the retail trade sectors contribute to 77.1 per cent of emissions.

Table 9: Final demand for energy by sector and fuel in TJ, native unit and share percentage
Source: Own calculations based on DME (2000)

	Coal			Petroleum		
	TJ	*T*	*%*	*TJ*	*kl*	*%*
Irrigated field	1 124	41 621	0.2	11 239	307 137	1.5
Dry field	3 772	139 719	0.5	37 742	1 031 404	4.9
Irrigated horticulture	1	20	0	14 425	394 191	1.9
Dry horticulture	1	21	0	3 885	106 161	0.5
Livestock	1	19	0	17 760	485 326	2.3
Forestry	0	13	0	0	0	0
Other agriculture	59	2 173	0	9 099	248 646	1.2
Coal	284	10 526	0	12 929	354 158	1.7
Gold	6 233	230 856	0.9	9 257	253 574	1.2
Crude, pet. & gas	0	2	0	3 766	103 174	0.5
Other mining	34 466	1 276 516	4.7	14 897	408 066	1.9
Food	0	0	0	0	0	0
Textiles	0	0	0	0	0	0
Footwear	0	0	0	399	10 783	0.1
Other chemical & rubber	8 585	317 966	1.2	0	0	0
Petroleum refineries	253 359	9 383 664	34.8	0	0	0
Othr non-metal. minerals	33 990	1 258 880	4.7	0	0	0
Iron & steel	181 673	6 767 902	25.1	0	0	0
Non-ferrous metals	0	0	0	0	0	0
Other metal products	89 253	3 303 538	12.3	16 289	439 999	2.1
Other machinery	0	0	0	0	0	0
Electrical machinery	0	0	0	14 856	401 284	1.9
Radio	0	0	0	2 016	54 466	0.3
Transport equipment	0	0	0	0	0	0
Wood, pulp & paper	0	0	0	0	0	0
Other manufacturing	37 179	1 376 112	5.1	10 045	271 324	1.3
Electricity	0	0	0	0	0	0
Water	10 525	389 798	1.4	21	573	0
Construction	10	387	0	21 647	590 896	2.8
Trade	486	18 013	0.1	449 352	12 791 600	61.1
Hotels	876	32 442	0.1	24	648	0
Transport services	1 396	51 707	0.2	52 632	1 494 073	7.1
Communication	0	0	0	246	6 638	0
Financial institutions	0	0	0	108	2 901	0
Real estate	0	0	0	176	4 749	0
Business activities	0	0	0	121	3 273	0
General government	7 493	277 537	1	14 355	408 067	1.9
Health sector	4 612	170 807	0.6	215	5 794	0
Other service activities	409	15 142	0.1	56	1 512	0
Residential	50 483	1 869 744	6.9	27 033	766 197	3.7
Total	726 269	26 935 123	100	744 591	20 946 615	100

Gas		Renewables		Electricity			Total	
TJ	*%*	*TJ*	*%*	*TJ*	*MWh*	*%*	*TJ*	*%*
0	0	0	0	1 973	547 974	0.3	14 336	0.6
0	0	0	0	6 625	1 840 164	1.2	48 139	2.1
0	0	0	0	3 574	992 796	0.6	17 999	0.8
0	0	0	0	963	267 375	0.2	4 848	0.2
0	0	0	0	4 451	1 236 380	0.8	22 211	1
0	0	0	0	771	214 045	0.1	771	0
0	0	0	0	3 049	846 807	0.5	12 206	0.5
56	0.1	0	0	11 029	3 063 574	1.9	24 298	1.1
123	0.2	0	0	69 117	19 199 242	12.1	84 731	3.7
193	0.3	0	0	25	7 057	0	3 985	0.2
126	0.2	0	0	25 550	7 097 101	4.5	75 039	3.3
1,154	1.5	0	0	2 081	578 116	0.4	3 235	0.1
18	0	0	0	1 342	372 749	0.2	1 360	0.1
0	0	0	0	1 735	482 002	0.3	2 134	0.1
313	0.4	0	0	5 077	1 410 337	0.9	13 976	0.6
2,738	3.7	0	0	4 390	1 219 413	0.8	260 487	11.3
6,314	8.4	0	0	4 159	1 155 161	0.7	44 462	1.9
58 980	78.8	0	0	67 914	18 865 014	11.9	308 567	13.4
957	1.3	0	0	53 170	14 769 314	9.3	54 127	2.3
0	0	0	0	79 970	22 213 943	14	185 512	8
604	0.8	0	0	133	36 875	0	737	0
0	0	0	0	18 884	5 245 503	3.3	33 740	1.5
0	0	0	0	4 790	1 330 642	0.8	6 807	0.3
106	0.1	0	0	55	15 147	0	160	0
541	0.7	0	0	5 986	1 662 673	1	6 526	0.3
2 501	3.3	0	0	11 831	3 286 262	2.1	61 555	2.7
0	0	0	0	0	0	0	0	0
0	0	0	0	3 387	940 745	0.6	13 932	0.6
0	0	0	0	350	97 290	0.1	22 008	1
10	0	0	0	25 775	7 159 615	4.5	475 623	20.6
0	0	0	0	5 271	1 464 032	0.9	6 170	0.3
77	0.1	0	0	12 476	3 465 541	2.2	66 581	2.9
0	0	0	0	5 786	1 607 124	1	6 032	0.3
0	0	0	0	4 760	1 322 227	0.8	4 868	0.2
11	0	0	0	3 881	1 078 060	0.7	4 069	0.2
0	0	0	0	466	129 568	0.1	588	0
19	0	0	0	3 595	998 640	0.6	25 463	1.1
0	0	0	0	2 407	668 637	0.4	7 234	0.3
0	0	0	0	5 770	1 602 712	1	6 235	0.3
0	0	190 400	100	108 587	30 163 089	19	376 504	16.3
74 843	100	190 400	100	571 151	158 652 942	100	2 307 253	100

Table 10: Emissions by sector and source: Gg CO2-equivalent and %
Source: Own calculations

	Coal		*Petroleum*		*Crude oil and gas*		*Renewables*		*Total*	
	Gg	%	Gg	%	Gg	%	Gg	%	Gg	%
Irrigated field	86	0.0	818	1.5	0	0.0	0	0.0	904	0.3
Dry field	290	0.1	2 746	5.1	0	0.0	0	0.0	3 036	0.9
Irrigated horticulture	0	0.0	1 049	2.0	0	0.0	0	0.0	1 050	0.3
Dry horticulture	0	0.0	283	0.5	0	0.0	0	0.0	283	0.1
Livestock	0	0.0	1 292	2.4	0	0.0	0	0.0	1 292	0.4
Forestry	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Other agriculture	5	0.0	662	1.2	0	0.0	0	0.0	666	0.2
Coal	22	0.0	940	1.7	3	0.0	0	0.0	965	0.3
Gold	477	0.2	673	1.3	7	0.1	0	0.0	1 157	0.3
Crude, pet. & gas	0	0.0	274	0.5	11	0.1	0	0.0	285	0.1
Other mining	2 636	1.0	1 083	2.0	7	0.1	0	0.0	3 726	1.1
Food	0	0.0	0	0.0	64	0.5	0	0.0	64	0.0
Textiles	0	0.0	0	0.0	1	0.0	0	0.0	1	0.0
Footwear	0	0.0	29	0.1	0	0.0	0	0.0	29	0.0
Other chemical & rubber	463	0.2	0	0.0	834	6.9	0	0.0	1 297	0.4
Petroleum refineries	53 704	20.4	0	0.0	7 286	60.1	0	0.0	60 990	17.3
Other non-metal. minerals	2 603	1.0	0	0.0	353	2.9	0	0.0	2 955	0.8
Iron & steel	14 080	5.3	0	0.0	3 295	27.2	0	0.0	17 376	4.9
Non-ferrous metals	0	0.0	0	0.0	53	0.4	0	0.0	53	0.0
Other metal products	6 859	2.6	1 192	2.2	0	0.0	0	0.0	8 052	2.3
Other machinery	0	0.0	0	0.0	34	0.3	0	0.0	34	0.0
Electrical machinery	0	0.0	1 087	2.0	0	0.0	0	0.0	1 087	0.3
Radio	0	0.0	148	0.3	0	0.0	0	0.0	148	0.0
Transport equipment	0	0.0	0	0.0	6	0.0	0	0.0	6	0.0
Wood, pulp & paper	0	0.0	0	0.0	30	0.2	0	0.0	30	0.0
Other manufacturing	2 857	1.1	735	1.4	140	1.2	0	0.0	3 732	1.1
Electricity	173 802	65.9	0	0.0	0	0.0	4 608	19.8	178 409	50.6
Water	814	0.3	2	0.0	0	0.0	0	0.0	816	0.2
Construction	1	0.0	1 575	2.9	0	0.0	0	0.0	1 576	0.4
Trade	37	0.0	32 291	60.1	1	0.0	0	0.0	32 329	9.2
Hotels	68	0.0	2	0.0	0	0.0	0	0.0	69	0.0
Transport services	108	0.0	3 785	7.0	4	0.0	0	0.0	3 898	1.1
Communication	0	0.0	18	0.0	0	0.0	0	0.0	18	0.0
Financial institutions	0	0.0	8	0.0	0	0.0	0	0.0	8	0.0
Real estate	0	0.0	13	0.0	1	0.0	0	0.0	14	0.0
Business activities	0	0.0	9	0.0	0	0.0	0	0.0	9	0.0
General government	580	0.2	1 032	1.9	1	0.0	0	0.0	1 613	0.5
Health sector	357	0.1	16	0.0	0	0.0	0	0.0	372	0.1
Other service activities	32	0.0	4	0.0	0	0.0	0	0.0	36	0.0
Residential	3 904	1.5	1 979	3.7	0	0.0	18 666	80.2	24 549	7.0
Total	263 783	100.0	53 744	100.0	12 132	100.0	23 274	100.0	352 932	100.0

Table 11: Selected key ratios concerning greenhouse gas emissions and welfare levels: a country comparison with world averages

Source: Winkler et al. (2001)

Key characteristic	*South Africa*	*Argentina*	*China*	*India*	*Nigeria*	*Brazil*	*World average*	
							Value	*Units*
Share of world (%)								
Total CO_2 emissions per year (1995)	1.37%	0.58%	14.30%	4.07%	0.41%	1.12%	6,098	Million tons carbon
CO_2 emissions cumulative (1915-1995)	1.14%	0.50%	6.70%	1.95%	0.23%	0.69%	227 440	Million tons carbon
Population	0.73%	0.61%	21.49%	16.11%	1.97%	2.74%	5 684.78	Millions
Total GDP for 1995	0.57%	0.78%	9.58%	3.43%	0.39%	2.26%	37 877 689	Millions 1995 Int$ – PPP
Relative to world average (100%)								
GDP per capita	79%	127%	45%	21%	20%	83%	6,663	1995 $ per year
Emissions intensity ($C0_2$ per GDP)	240%	75%	149%	119%	105%	49%	0.16	kg of C / $ of GDP
Emissions per capita	189%	95%	67%	25%	21%	41%	1.07	tons of C per person

Two questions now need to be asked. Firstly, are these numbers important? Secondly, what is the extent of this importance? The answer to the former should be yes when compared to other countries. According to Winkler *et al.* (2001), South Africa's emissions intensity is about 240 per cent above world average, and the highest of the developing countries considered (see Table 11). In 1995, the country's emissions intensity was 2.82 kg CO_2 per purchase power parity adjusted to 1990$ of GDP produced, compared to a world average of 0.87 and a non-OECD average of 1.99. In terms of emissions per capita, South Africa is 189 per cent above the world average of 1.07 tons of carbon per person. This compares extremely unfavourably with that of Argentina (95 per cent of world average), and China's 67 per cent, India's 25 per cent, Nigeria's 21 per cent and Brazil's 41 per cent. Though these are populous countries, they do represent countries of a comparable state of development. These high energy intensities suggest that South Africa has limited scope to increase its emissions at a rate faster that the country's GDP. It also suggests that policies that are custom-made to improve GDP, reduce carbon emissions but also alleviate poverty are much needed.

5. Concluding remarks

A greenhouse gas emissions inventory has been constructed, based on the energy balance of South Africa and various emission factors. The sectoral dimensions of the inventory reconcile to those of the 1998 social accounting matrix of South Africa. This enables the economic analyst to model various policies using a variety of applied modelling techniques.

Based on the information contained in the inventory, greenhouse gas emissions from combustion sources amounted to 352 932 Gg in 1998, with the electricity generation sector contributing 178 409 Gg or almost 51 per cent, followed by the petroleum refineries which contributed 60 990 Gg or 17.3 per cent of the total. It has also been indicated that these values are significant in a global context relative to other developing countries. This necessitates the use of economic modelling techniques in the search for the optimum policy scenario in an effort to reduce the country's carbon footprint.

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Disclaimer

Views expressed in this paper are those of the authors, and do not necessarily reflect those of any institution they may be involved with.

References

Blignaut, J.N and King, N.A. 2002. The externality cost of coal combustion in South Africa. Bridging the Economics/ Environment divide conference proceedings. ISBN 1-86854-437-0. Pretoria: Forum for Economic and Environment.

Blignaut, J.N. and Zunckel, M. 2004. The cost of a decline in air quality. In: Blignaut, J.N. and De Wit, M. (eds.) Sustainable Options. Cape Town: UCT Press.

Clement, K. and Foster, S. 2000. *An investigation into mining as an energy and water using sector and its environmental impacts.* Report by DBSA for GTZ-funded project WWF Macro Economic Reforms and Sustainable Development in Southern Africa.

Department of Minerals and Energy (DME). 2000. *Energy balance for South Africa: 1998*. Pretoria: DME.

Eskom, 2000. Annual Report 2000. Internet: http://www.eskom.co.za/annreport01/ Accessed May 2004.

Foster, S. 1998. A South African national economic and environmental policy frame-work, *Development Southern Africa*, 15(2).

Freeman, P.N.W., Naude, C.M., Pretorius, J., Coovadia, T., Matjila, S.M. 2000. *The Transport Sector –Energy Use and Environmental Impacts*. Report by DBSA for GTZ-funded project WWF Macro Economic Reforms and Sustainable Development in Southern Africa.

Gaffen, M., Naude, C., Lombaard, P., Maasdorp, G., Taylor, A. and Pretorius, J. 2000. *A Quantitative analysis of full cost associated with motor vehicle use in South Africa.* Report for Department of Transport, funded by USAID as well as Moving South Africa: An action Strategy.

Howells, M.I. and Solomon, M. 2000. South African Greenhouse Gas energy emissions inventory for the year 1994. *Journal of Energy in South Africa,* 11(4): 272-278.

IPCC (Intergovernmental Panel on Climate Change). 1996. *IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual, Volume 3,* United Nations Environment Program, the Organisation for the Co-operation and Development, the International Energy Agency and the Intergovernmental Panel on Climate Change, Cambridge University Press, United Kingdom.

Lloyd, P., Rukato, H. and Swanepoel, R. 2000. *Liquid fuels production*. Report by DBSA for GTZ- funded project WWF Macro Economic Reforms and Sustainable Development in Southern Africa.

Pinheiro, H.J., Boshoff, H.P. And Pretorius, C.C. 1997. *Analysis of coal product samples of producing South African collieries.* Pretoria: CSIR.

RSA (Republic of South Africa) 2000. South Africa: Initial National Communication under the United Nations Framework Convention on Climate Change, Pretoria, Department of Environmental Affairs and Tourism.

Spalding-Fecher, R., Matibe, D., Okese, Y., Eberhart, R. and Davis, M. 2000. *Electricity production and the environment.* Report by DBSA for GTZ- funded project WWF Macro Economic Reforms and Sustainable Development in Southern Africa.

Trollip, H. 1996. *Overview of the South African energy sector*. Pretoria, Dept of Minerals & Energy, Chief Directorate: Energy.

UNFCCC (United Nations Framework Convention on Climate Change). 1999. Conference of the Parties, Fourth Session, Buenos Aires, 2-13 November 1998, Item 4(a)(i) of the provisional agenda, FCCC/ CP/1998/11/Add.2 (www.unfccc.de/resource/docs/ cop4/11a02.pdf).

Trikam, A. 2002. Greenhouse gas mitigation options in the industrial sector. *South African Journal of Economic and Management Sciences*, 5(2):473-498.

Visser, M., Spalding-Fecher, R. and Leiman, A. 2000. *Manufacturing and economic growth*. Report by DBSA for GTZ- funded project WWF Macro Economic Reforms and Sustainable Development in Southern Africa.

Winkler, H., Tyani, L., and Spalding-Fecher R. 2001. What could future carbon emission allocation schemes and targets mean for South Africa? Energy and Development Research Centre (EDRC), University of Cape Town, South Africa.

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