Chapter 1: Introduction and Motivation

1.1. Background

Since the first Earth Summit in 1992, climate change and greenhouse gas (GHG) emissions reduction has occupied a permanent place on the international environmental agenda. The United Nations Framework Convention on Climate Change (UNFCCC) is a multilateral environmental agreement that has been signed and ratified by over 70 countries. South Africa is a signatory to the UNFCCC as well as the Kyoto Protocol, which is an agreement that commits all countries to stabilise their GHG emissions and share the burden. The Protocol came into effect in February 2005 and it commits Annex 1 countries to reduce their GHG emissions to 1990 levels by the year 2012. Under the Protocol South Africa is classified as a non-Annex 1 country and as such does not have any commitments for emission reductions during the first commitment period, 2008-2012 but it is very likely that this will change during the next commitment period.

Greenhouse gases include; carbon dioxide, methane, carbon monoxide, nitrogen oxides, sulphur oxides and hydrocarbons which are mainly produced from the combustion of fossil fuel. South Africa has an energy intensive economy with a high reliance on fossil fuels due to an abundance of coal. The country has an above average energy intensity[1]. Ten other countries have higher commercial primary energy intensities than South Africa (Davidson, 2002). South Africa's gross national product (GDP) is the 26th highest in the world but its primary energy consumption ranks 16th (GCIS, 2001).

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[1] Energy intensity refers to the amount of energy required to generate one unit of economic output. In South Africa the amount of energy used for every unit of GDP generated in the economy is higher than the global average.

South Africa also has one of the cheapest sources of energy, as this is viewed as a comparative advantage for economic development.

The energy sector is the single largest source of GHG emissions in South Africa accounting for about 89% of the country's total emissions (DEAT, 2000a). The national GHG inventory estimates that carbon dioxide is the most significant GHG in South Africa (DEAT, 2000a). It accounts for more than 80% of the three GHGs in the national inventory. In 1990, the energy sector was responsible for 89.7% of total carbon dioxide emissions, in 1994 this increased to 91.1 % and in 2000 it was estimated that the energy sector was responsible for 92.3% of total carbon dioxide emissions (DEAT, 2000a; UNDP, 2002). This is attributed to an increase in electricity consumption brought about by the South African government's plan to provide electricity to all. In 2005, the Minister of Public Enterprises stated that electricity consumption in the past decade has increased at the same rate as economic growth. According to Davidson (2002), this trend is expected to continue as South Africa strives to meet its economic and developmental objectives.

In 1994, the new South African government recognised a need to complement political liberation, global market access and international investments with poverty alleviation so that all South Africans benefit. In an attempt to alleviate poverty, economic growth and reduction in high levels of unemployment were identified as government's main priorities. The White Paper on the Reconstruction and Development Programme (RDP) and the Growth Employment and Redistribution (GEAR) strategy provide the macro-economic framework for alleviating poverty and improving welfare (GNU, 1994; GEAR, 1996).

The RDP highlight’s the urgency for achieving rapid economic growth that contributes to development, particularly the eradication of poverty (GNU, 1994). GEAR as one of the principal strategies for the realisation of the policy objectives contained in the RDP White Paper states that macro-economic stability should be promoted by; reducing the budget deficit and the rate of inflation, growing the economy through increased exports and investments and achieving redistribution by creating jobs from economic growth and labour market reforms (GNU, 1994; GEAR, 1996).

1.2. Problem Statement

South Africa is faced with the dilemma of simultaneously alleviating poverty, reducing unemployment, growing the economy and responding to international pressure to reduce GHG emissions. Policy makers need to promote options that benefit the environment without being harmful to economic growth and national developmental priorities. Environmental fiscal reform presents one such option. The impacts of this are still unclear for South Africa and this study explores this issue in detail.

1.3. Objectives of the study

The objective of this study is to undertake empirical research that will assess current energy supply and use patterns in South Africa. A number of national databases will be used to develop a single integrated framework, which is an energy emissions input-output model. The model will calculate energy emissions for each sector, thereby evaluating energy and energy GHG emissions in the overall economy. This will be used to evaluate the efficacy of alternative policy options. Energy consumption, energy emissions will be analysed in comparison to reduced economic output as measured by GDP, household consumption and employment.

Previous studies on energy emissions reduction policies undertaken by, Zhang (2001); Labandeira and Labeaga (2001); Cruz (2000); Gay and Proops (1993) and Proops *et al.* (1993) focus only one the analysis of primary energy. This study will develop a framework that will be used to assess the impact of these energy emission reduction policies on both primary and secondary energy sources. Primary and secondary energy data will be used to develop a set of energy accounts. The augmented energy IO model developed in this study will use these energy accounts. The specific objectives of this study are to:

1. Develop an augmented monetary energy input-output (IO) table for South Africa using the supply and use tables for 2000 and energy accounts developed by the study.
2. Develop a physical energy IO table for 2000 using National Energy Balance data for South Africa.
3. Develop a physical energy emissions IO table for 2000 according to an energy emissions inventory developed by the study for South Africa using energy balance data and emission conversion factors.
4. Integrate the augmented monetary energy IO table, physical energy IO table and physical energy emissions IO table into an energy emissions IO model for 2000 with both monetary and physical data.
5. Develop an integrated analytical model and use it to analyse the impact of different energy emissions reduction policies on GDP, employment, household consumption, energy consumption and energy emissions reduction.

1.4. Approach and methods

The aim of this study is to develop an integrated framework for the analysis of energy emission reduction policies on both primary and secondary sources of energy. The approach adopted by the study is input-output (IO) analysis as this technique can be used to integrate physical energy and energy emissions data together with economic data into a single model that includes both monetary and physical transactions. IO models focus on the inter-industry production structure, have fixed prices, present linear production structures and allow for the analysis of macro economic variables such as GDP and employment. In its most basic form IO models consist of a system of linear equations, where each equation describes the distribution of each industry's product through the economy. This study modifies a traditional IO model to include energy and emissions data by adhering to conditions of inter-industry production, pollution generation and pollution abatement.

South Africa's supply and use tables for 2000 as published by Statistics South Africa will be used to develop an IO table (Statistics South Africa, 2003). Energy industry data from a number of sources will be used to develop energy accounts for the following primary energy source; coal, oil, gas, biomass, nuclear and renewable energy and electricity and petroleum products as secondary energy types. These energy accounts will be used to augment this IO table into a monetary energy IO table (DME, 2002; Eskom 2000; GCIA, 2001, NER, 2000; NNR, 2002). The National Energy Balance as South Africa's official energy database published by the Department of Minerals and Energy annually will be used to develop a set of physical energy accounts (DME, 2002b). Pollution co-efficients from the National Greenhouse Gas Inventory, the

Intergovernmental Panel on Climate Change (IPCC) and local studies will be used to develop an energy emissions inventory for 2000 (DEAT, 2000a; IPCC, 1996; Blignaut and King, 2002).

Policy options for energy emissions reduction will be developed from energy studies undertaken for South Africa (Blignaut and King, 2002; Hassan and Blignaut, 2004; IEA, 1999). This includes the cost of carbon dioxide emissions emitted from fossil fuels and some work on energy subsidies. Energy related carbon dioxide emissions are generated from the consumption of coal, crude oil, electricity and petroleum products. This study will analyse the impact of carbon dioxide taxes and energy subsidy reform. Given that poverty alleviation, economic growth and employment have been identified as national macro-economic priorities, policy analysis will focus on these variables as well as energy consumption and energy emissions reduction.

1.5. Structure of the study

This study is organised into seven chapters. Chapter one presents an introduction and motivation to the study. In Chapter two energy, energy emissions and the economy in South Africa are discussed. Chapter three presents a review of current literature on energy emissions reduction policy analysis using IO models. The methodology adopted by the study is explained in Chapter four. Chapter five develops and discusses the structure of the energy emissions IO model for South Africa. Emissions reduction policy scenarios are analyzed and discussed in Chapter six. Chapter seven concludes the study with recommendations.

Chapter 2: Energy supply and use, Emissions and the Economy

2.1. Introduction

The combustion of fossil fuels is listed as one of the main sources of greenhouse gas (GHG) emissions and given South Africa's dependence on this energy source, it is perceived that it will not be easy to reduce domestic GHG emissions without negatively impacting on economic growth. In an attempt to reduce poverty in the country, unemployment and economic growth are the main developmental priorities identified by the government. As a result South Africa is presented with the challenge of achieving global environmental objectives at the expense of domestic priorities. This chapter will discuss energy use, emissions reduction, poverty alleviation, economic growth and unemployment in an attempt to assess the trade-offs involved in pursuing multiple goals.

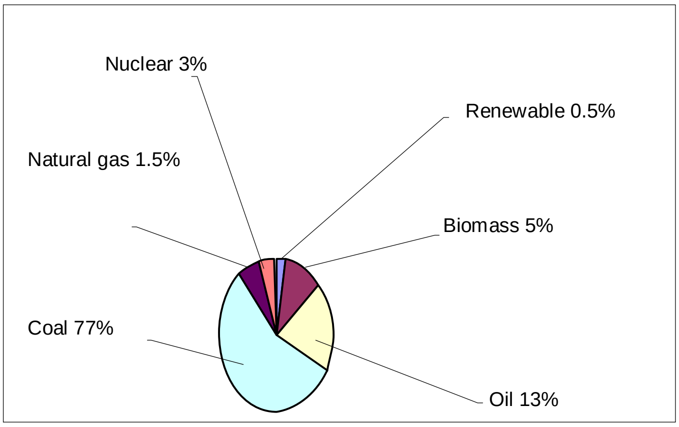
2.2. Energy supply and use in South Africa

Key policies that directly affect primary energy production and consumption in South Africa includes the following documents, the Energy White Paper, the White Paper on the Promotion of Renewable Energy and Clean Energy Development and White Paper on the Renewable Energy Policy (DME, 1998; DME, 2003; DME, 2004). Prior to 1994, South Africa's energy policies were dominated by the need to secure energy supplies in the face of international boycotts, sanctions and the oil embargo. Post 1994 energy policies replaced energy security with the need for social equity and economic efficiency within the context of sustainable development.

Energy production

There are six primary energy types that contribute to the energy mix in South Africa. These include coal, crude oil, natural gas, nuclear, biomass and renewable energy. Figure 2.1 illustrates the share of primary energy in South Africa in 2000. The graph also illustrates the economy's reliance on coal with 77% of the country's energy coming from this source. Approximately 13% of the country's energy needs were met by crude oil, while natural gas, nuclear; renewable energy and biomass combined contributed less than 10%. 80% of South Africa's primary energy needs were met by fossil fuels.

Figure 2.1: Share of primary fuel types in 2000



Source: ERI (2001)

Table 2.1 compares primary energy types in South Africa during the period 1998-2002. Coal consumption increased steadily while the use of crude oil decreased during this period. The use of biomass and natural gas consumption increased slightly while the share of nuclear energy and renewable energy consumed remained fairly constant. The increase in coal consumption appears to have been offset by the decrease in crude oil consumption. This trend is attributed to changes in international crude oil prices.

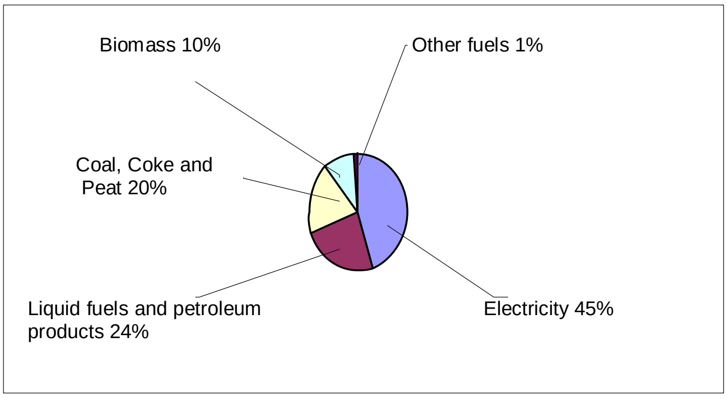
Table 2.1: Share of total primary fuel types during 1998-2002

Primary Energy Fuel	1998	2000	2002
Coal	75%	77%	79%
Crude oil	15%	13%	10%
Biomass	5%	5%	5.5%
Natural gas	1.5%	1.5%	2%
Nuclear	3%	3%	3%
Other renewable energies	0.5%	0.5%	0.5%

Source: DME (1998; 2002b); ERI (2001)

Four basic final demand energy types consumed in South Africa includes; electricity, liquid fuels which includes petroleum products, coal which includes coke and peat; and biomass. Electricity is mainly obtained from coal. Less than 10% of electric power comes from crude oil, nuclear and other energy sources. A large proportion of the total liquid fuels and petroleum products consumed in South Africa are derived from coal. Coal is used for coke and peat production. Fuel wood and agricultural residue are the main source of biomass. Figure 2.2 shows the share of final demand fuel types used in South Africa during 2000. Electricity accounted for approximately 45% of total final demand for energy, while liquid fuels and petroleum met 24% of final demand energy needs. 20% of total final demand energy was obtained from coal, coke and peat and 10% was obtained from biomass.

Figure 2.2: Share of final demand fuel types in 2000



Source: ERI (2001)

Approximately 90% of total final demand energy consumed in South Africa in 2000 was derived from fossil fuels. Table 2.2 indicates that the decrease in electricity consumption was approximately equal to the increase in liquid fuels and petroleum products. Coal, coke and peat use increased during the period 1998-2002 while biomass and other final demand energy types remained fairly constant during this period. These trends indicate that both final demand energy and primary energy in South Africa is largely met by fossil fuels.

Table 2.2: Share of final demand fuel types during 1998-2002

Energy source	**1998**	**2000**	**2002**
Electricity	46%	45%	32%
Liquid fuels and petroleum products	23%	24%	33%
Coal, coke and peat	20%	20%	25%
Biomass	10%	10%	9%
Other fuels	1%	1%	1%

Source: DME (1998; 2002b); ERI (2001)

Energy consumption

The industrial sector is the largest consumer of primary energy accounting for 35% of all primary energy consumed in South Africa as indicated by Figure 2.3. This is followed by the transport sector, which uses approximately 27%. While non-energy[2] activities account for 19% of all energy consumption, residential energy consumption makes up almost 10% of the total. The smallest primary energy consumers are the agricultural sector, which uses 4% and the commercial sector that consumes 3%.

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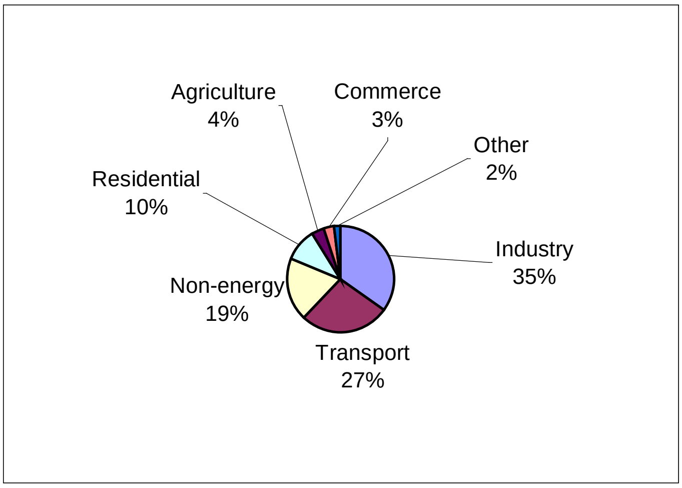
[2] Non-energy activities refer to the use of energy related materials such as coal, oil and wood that could be used to produce energy but are directly used produce products such as chemicals, plastics and paper.

Figure 2.3: Primary energy consumed per sector



Source: ERI (2001)

2.3. Energy emissions in South Africa

As a signatory to the UNFCCC, South Africa is obligated to produce a National Communications Report with GHG inventories. South Africa's most recent National Communications Report was submitted in 2000 and national GHG inventories have been developed for South Africa for 1990 and 1994 (DEAT, 2000a). The National Climate Change Response Strategy for South Africa is the most updated domestic policy document that specifically focuses on the management of GHG emissions reduction in South Africa (DEAT, 2004). GHG emissions are mentioned and discussed in other policy documents such the National Environmental Management Air Quality Act of 2004, the Integrated Waste Management Strategy, the Energy White Paper, the White Paper on the Promotion of Renewable Energy and Clean Energy Development and the White Paper on the Renewable Energy Policy (Government Gazette No. 27318, 2005; DEAT, 2000b; DME, 1998; DME, 2002c; DME 2004).

The country contributes about 1.6% to global GHG emissions, 42% to the total GHG emissions emitted in Africa and it ranks amongst the top ten countries contributing to global warming (Davidson *et al.*, 2002). As one of the most industrialised countries in the region South Africa is the single largest emitter of GHG emissions in Africa primarily because of the overall size of the economy and its dependence on coal. On a global scale the country's contribution to GHG emissions is relatively small but on a per capita basis emission levels are well above the average for other middle-income developing countries. The South African economy is carbon intensive producing US$ 259 per ton of carbon dioxide emitted as compared with US$ 484 for Mexico and US$ 418 for Brazil, which are countries with similar levels of social and economic development (GCIS, 2001).

South Africa currently does not have any GHG emission standards and there is no independent GHG emissions agency for certifying baseline emission levels and monitoring industries and activities. The National Treasury is currently exploring the possibility of introducing environmental fiscal reform and GHG emissions reduction has been identified as one of the areas where this will be applied. Theoretically carbon dioxide taxes and energy subsidy reform appear to be the most desirable economic instrument for carbon dioxide emissions reduction in South Africa. But the lack of political will from government and economic will from industry is recognised as the main barriers restricting immediate implementation within the current framework. It is becoming increasingly evident that South Africa's political and economic decision-makers need to reach consensus on environmental fiscal reform implementation especially with regard to GHG emissions reduction. This was made evident in the national 2005 budget presented by the Minister of Finance (National Treasury, 2005).

2.4. The South African economy

Since 1994 there has been a pressing need to address the economic legacy of apartheid, staggering inequalities, widespread poverty, unequal access to social services and infrastructure and an economy that has been in crisis for nearly twenty years. During the past ten years the White Paper on the Reconstruction and Development Programme (RDP) and the Growth, Employment and Redistribution (GEAR) Strategy have influenced South Africa's path to economic growth (GNU, 1994; GEAR, 1996).

2.4.1. Economic growth

GEAR (1996) estimates that an annual average economic growth rate of 6% is necessary to alleviate high levels of poverty and unemployment. Real growth has been far from the target and extremely variable ranging from 2-3%. Table 2.3 presents the rate of economic growth in South Africa highlighting that economic growth in 1998 fell drastically which was the result of global economic crisis. The rate of inflation during the period 1994-2003 decreased from 8.8% to 5.9%. The budget deficit decreased from 5.1% in 1994 to 1.4% in 2001 then increased to2.1% in 2002 and 3.2% in 2003. The increase in the budget deficit is due to government's effort to curb unemployment and revive the economy.

The target of 400 000 new jobs annually as set by GEAR (1996) has also fallen short in an attempt to reduce unemployment. Unemployment in both the private and informal sectors increased slightly from 1994 to 1995. The dramatic increase in unemployment in 1996 was in response to a decline in world demand for South African exports, which resulted in massive shedding of labour by South African firms. After decreasing slightly in 1997, unemployment increased substantially in 1998 as a result of poor economic performance in the domestic and global economy. In 1999 unemployment fell but it has been slowly increasing during the last five years.

According to the Human Sciences Research Council (HSRC) (2004), estimates of 57% show that the proportion of people living in poverty in South Africa, did not change significantly between 1994 and 2003 but those households below the poverty line have become poorer and the gap between the rich and the poor has widened. This study defines the poverty line as R800 per household per month. The poverty gap has grown from R56 million in 1996 to R81 million in 2001 indicating that poor households have sunk deeper into poverty over this period. In 1996 the total poverty gap was equivalent to 6.7% of GDP, by 2001 it rose to 8.3%. The extent of inequality has increased during the last decade as reflected by the country’s Gini coefficient, which increased from 0.56 in 1995 to 0.57 in 2003 (Heinz, 2003).

Table 2.3: Economic and social indicators for South Africa (1994-2002)

	1994	1995	1996	1997	1998	1999	2000	2001	2002
Economic growth	3.2%	3.1%	4.3%	2.6%	0.8%	2.0%	3.5%	2.8%	2.9%
Inflation rate	8.8%	8.7%	7.3%	8.6%	6.9%	5.2%	5.4%	5.7%	5.8%
Real prime lending rate	6.8%	9.2%	12.2%	11.4%	14.9%	12.8%	9.1%	8.1%	6.0%
Exchange rate (R/$US), year end	R3.54	R3.65	R4.68	R4.87	R5.86	R6.15	R7.57	R12.13	R8.51
Budget deficit/GDP	5.1%	4.5%	4.6%	3.8%	2.3%	2.0%	2.0%	1.4%	2.1%
Rate of accumulation of fixed capital	0.8%	1.3%	1.7%	1.9%	2.0%	1.0%	0.8%	0.9%	0.9%
Growth rate: private sector employment	-0.9%	-0.5%	-2.6%	-2.5%	-4.4%	-1.3%	-2.0%	-1.4%	-1.5%
Growth rate: total formal sector employment	-0.4%	-1.1%	-0.7%	-1.7%	-3.5%	-2.0%	-2.7%	-1.6%	-1.7%
National income per capita (R1995)	R13586	R13656	R13961	R13987	R13759	R13641	R13789	R13862	R13935

Source: Heintz (2003); South African Reserve Bank (2004), DEAT (2002)

2.4.2. Energy prices and the economy

As indicated in the Energy White paper, energy prices play an important role in regulating energy consumption in South Africa (DME, 1998). Annual energy prices are plotted against the consumer price index (CPI) in Figure 2.4 and annual energy consumption was plotted against the CPI in Figure 2.5. The CPI increased dramatically during 1970 to 1980 then increased steadily from 1990 to 1999. In 2000 it dropped and has been stable during the period 2000 to 2002. The trend of the CPI is explained by economic and political changes that have taken place in South Africa. The South African economy faced many challenges from 1970 to the mid-1990s as a result of international sanctions, political unrest, and political and global economic uncertainty. During the mid-1990s to 2000 global conditions affected the South African economy negatively but since then both political and economic conditions have been relatively stable. Some of these includes, the economic crisis in many Asian countries, global and regional political unrest and terrorism, fluctuations in currencies such as the American dollar and the Japanese Yen and a review of global trade practices including the role of subsidies and market access for developing economies and economies in transition.

Energy prices increased steadily during the period 1970-2002 except for the price of octane and paraffin, which increased drastically from 1970 to 1980 then, decreased until 1990 when the price remained fairly constant until 2000 when it increased drastically and remained constant thereafter. This was probably the result of the oil crisis in the early 1970s and an increase in the price of oil in 2000. Energy consumption increased steadily during the period 1970 to 2002. Figures 2.4 and 2.5, respectively, indicate that the CPI is not linked to energy prices or to energy consumption.

Table 2.4: Annual energy prices and consumer price index (1970-2002)

Year		1970	1980	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Consumer Price Index (CPI)	(100c) = R	5.39	14.95	58.62	67.58	76.96	84.47	92.03	100.00	107.36	116.56	124.60	131.08	100.00	105.70	110.40
Wholesale Coal	(c/100 ton)	40.80	86.17	76.45	76.61	60.86	54.66	50.13	55.11	61.55	64.41	95.85	102.27	104.09	126.26	140.71
Wholesale Electricity	(10c/kWh)	102.00	135.10	134.40	125.30	119.00	113.50	112.10	115.30	106.00	102.38	99.26	95.53	96.44	94.93	94.30
Retail Coal	(c/kg)	14.20	23.96	13.23	40.65	44.31	44.66	22.69	23.00	24.38	25.51	37.97	40.51	41.23	50.01	55.74
Retail Firewood	(c/kg)	22.46	34.67	22.86	36.40	42.49	42.98	29.61	30.03	33.65	38.56	44.44	50.50	55.90	57.81	60.00
Retail Paraffin	(c/20l)	278.52	600.11	340.69	386.92	344.19	351.50	354.78	338.50	353.31	367.44	353.20	352.31	494.55	494.55	495.00
Retail 93 Octane-Coast	(c/l)	142.78	343.21	199.60	198.27	193.60	200.08	181.47	176.00	196.54	216.75	219.84	252.26	330.77	356.61	393.08
Retail 93 Octane-Reef	(c/l)	170.60	363.95	214.96	211.59	206.59	213.10	192.33	186.00	205.86	229.19	232.30	265.49	342.24	373.35	413.79

Source: DME (2002b); South African Reserve Bank (2003)

Figure 2.5: Annual energy prices and consumer price index (1970-2002)

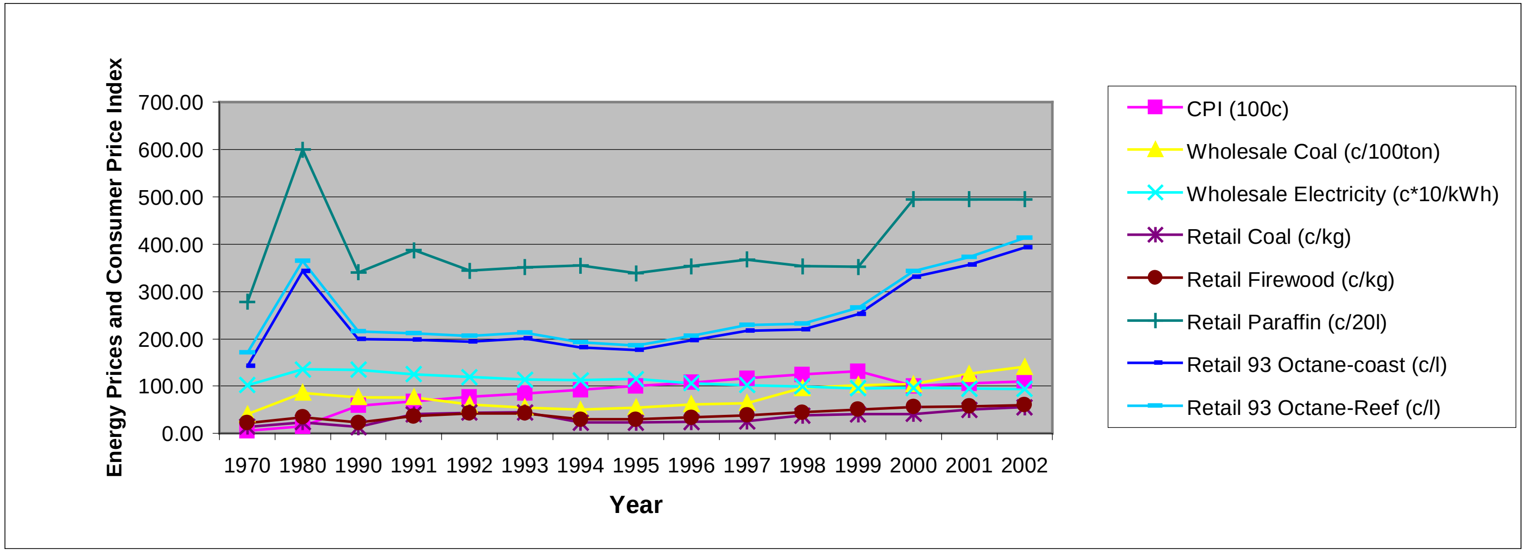
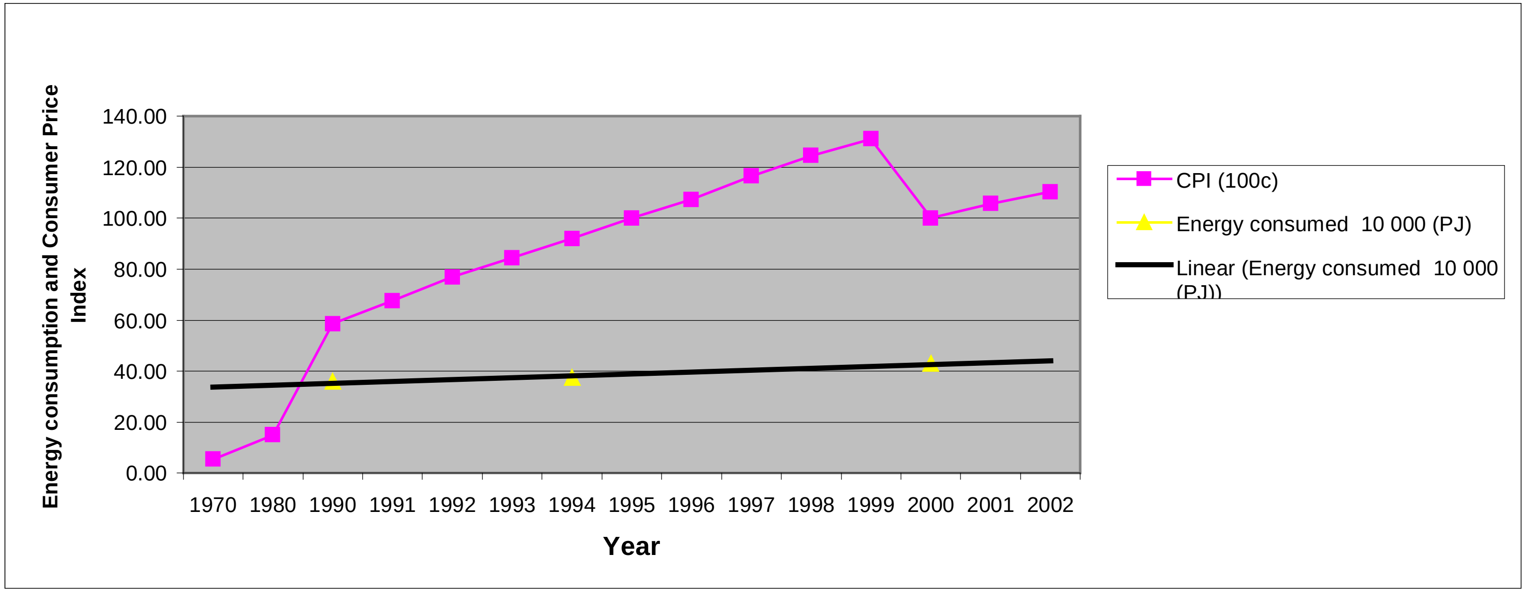


Table 2.5: Energy consumption and consumer price index (1970-2002)

Year		1970	1980	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Consumer Price Index (CPI)	(100c)	5.39	14.95	58.62	67.58	76.96	84.47	92.03	100.00	107.36	116.56	124.60	131.08	100.00	105.70	110.40
Energy consumed	10 000 (PJ)		35.80				37.44						42.98			

Source: DME (2002b); South African Reserve Bank (2003)

Figure 2.6: Energy consumption and consumer price index (1970-2002)



2.4.2. Energy Emissions and Fiscal policies

The Energy White Paper states that fiscal issues have a fundamental effect on energy consumption and the economy in South Africa (DME, 1998). Selective use of fiscal mechanisms can be effective in achieving energy policy objectives such as switching to cleaner types of fuel, reducing energy consumption and regulating energy emissions. Historically economic development and the role of cheap energy as a comparative advantage have largely influenced South Africa's energy prices. Table 2.6 presents public revenue generated by and spent on the energy sector and Table 2.7 presents the source of South Africa's tax revenue.

Table 2.6: Public revenue and expenditure with regard to energy

	1997	1998	1999	2000	2001	2002
Percentage of public revenue generated from fuel and energy	8.1%	8.3%	9.5%	9.8%	9.6%	10.2%
Percentage of public expenditure spent on fuel and energy	0.3%	0.4%	0.3%	0.2%	0.2%	0.3%

Source: South African Reserve Bank (2004)

Table 2.7: South Africa's tax revenue

Tax Instrument	Share of total Tax Revenue
Direct Taxes	
Income Tax	42.19%
Company Tax	12.01%
Tax on dividends paid by companies	0.88%
Other taxes paid by individuals	3.07%
Indirect Taxes	
Value Added Tax	24.08%
Customs and Excise	8.02%
Fuel Levy	7.51%
Other	2.24%
Total	100%

Source: South African Reserve Bank (2004)

Five main categories of current fiscal transfers from the energy sector include:

- Value added tax - productive activities in all sub-sectors are subject to value added tax with the exception of certain petroleum products. Value added tax in the energy sector is levied at 14%;
- Income tax - income tax is currently payable by private sector corporations in the coal, liquid fuel, gas and renewable sectors but not by public utilities such as municipal electricity suppliers. Until recently Eskom as the largest electricity utility was also exempted from paying taxes. Income tax in the energy sector is calculated according to company tax rates. There is no direct link between the source of taxation revenues and their allocation but it is anticipated that electrification subsidies will be offset to a degree by additional income tax to be collected from the electricity industry.
- Special taxes and levies - the fuel tax constitutes about 36% of the pump price of petrol and diesel while customs and excise duty, the road accident fund levy and the equalisation fund levy constitute approximately 7% of the pump price of petrol and diesel. In 2000, the fuel tax together with fuel levies contributed an average of 10% to central government’s total revenue. A levy set at a fraction of a cent per kWh is also applied to electricity sales by generators over a certain size to raise funds for the operation of the National Electricity Regulator;
- Tariffs - historically, substantial tariff protection has been provided to the synthetic fuels industry, with a direct effect on the price of fuel to consumers;
- Implicit taxes - public sector electricity supplies extract sizeable surpluses from some of their electricity customers for purposes of cross-subsidizing other customer classes and in the case of local authorities, other municipal services. In effect these transfers represent a hidden tax, which moreover is not subject to the direct fiscal control of the government. The net effect of these practices is that levies and taxes

make up a high proportion of the retail price of some fuels and a low proportion in other cases. It is estimated that the average revenue from electricity distribution by municipalities could be around R2.4 billion per annum (EIA, 2002).

Two main categories of fiscal transfer to the energy sector include:

- Funding regulators - public sector revenue is used to fund regulators, government can use special purpose levies to fund regulatory and other agencies. It is estimated that 0.3% of total fiscal revenue may be used to fund energy regulators. The Energy White Paper states that government will fund a National Electrification Fund on a budget from a dedicated electrification levy. The levy initially comprises the implicit surcharge for electrification in the current electricity price structure;
- Energy subsidies – Although the Energy White Paper states that government is supposed to introduce an electricity levy to subsidies national electrification, Eskom funds subsidies from its own revenue. Subsidies are estimated at R2 billion per annum. Another form of cross-subsidy is the voltage level cross-subsidy. Eskom charges energy prices according to the voltage level of supply. Consumption subsidies in South Africa are generally small and limited primarily to electricity. This is largely a result of domestic coal prices being slightly below the international market price although it is expected that this may have something to do with the quality of coal. There are some production subsidies mainly for oil. Overall the estimated weighted average rate of energy-price subsidy expressed as a proportion of the reference price is approximately 6% for South Africa (IEA, 1999).

2.5. Conclusion

According to GEAR (1996), South Africa’s macro-economic priorities include economic growth at an annual rate of 6% and 40 000 new jobs annually to alleviate poverty and reduce unemployment. South Africa is also under global environmental pressure to reduce its GHG emissions as a result of high emissions per capita and a reliance on fossil fuels. But the economy will not grow at the targeted growth rate without using energy including fossil fuels. One possible solution to the problem would be to implement environmental fiscal reform by increasing the price of energy based on the external costs of energy induced carbon dioxide emissions. It is expected that this will reduce energy consumption and generating and recycling revenue may offset GHG emissions and the economic burden.

Market based instruments such as carbon dioxide taxes can be used for environmental fiscal reform. Current fiscal transfer from the energy sector includes; value added tax, special taxes and levies, tariffs and implicit taxes while fiscal transfer to the energy sector funds the energy regulators and energy subsidies. There is no environmental fiscal transfer from or into the energy sector in South Africa but the national Treasury is currently investigating this.

Chapter 3: Literature Review

3.1. Introduction

In response to global pressure to reduce greenhouse gas (GHG) emissions, energy emissions reduction policies are being developed and analysed in many countries. Energy consumption, energy emissions reduction, gross domestic product, production and consumption, trade, taxes, employment and technological changes are some of the variables being analysed in these studies. This chapter will review the analysis of carbon dioxide taxes and energy subsidy reform policies, followed by a review of input-output models as they apply to energy emissions analysis and a discussion on South African studies in the field of energy emissions reduction.

3.2. Energy emissions reduction policies

Market based energy emissions reduction policies such as emissions taxes and tradable permits provide incentives for greater efficiency in comparison to the command and control approach. Both these market-based instruments encourage dynamic efficiency but differ with respect to uncertainty (IPCC, 2001a). Permits are quantity-based instruments as the quantitative reduction in emissions is guaranteed but the cost is uncertain and taxes are price based as the price is fixed but the quantity of emissions reduction is uncertain. Despite the political attraction of permits, these instruments are not favoured because they forgo the chance of raising revenue.

Subsidy reform is another instrument that is increasingly being investigated as an option for reducing energy emissions. The IPCC (2001a) states that empirical and theoretical studies indicate that the removal of subsidies from fossil fuels or from electricity that relies on fossil fuels can be beneficial in reducing carbon dioxide emissions. The extent of the impact of reducing subsidies will depend on the specific characteristic of each country, the type of subsidy involved and the international co-ordination to implement similar measures.

3.2.1. Carbon dioxide taxes

The analysis of carbon dioxide taxes commonly focuses on the impact that the policy instrument has on energy consumption, energy emissions reduction, sector production and consumption, gross domestic product and employment but some studies have looked at the impact on trade and others have looked at technological change. Gupta and Hall (1996) indicated that a carbon dioxide tax in India would have limited effectiveness in controlling carbon dioxide emissions unless tax revenues are invested in carbon abating technologies. Machado, *et al.* (2001), applied an energy and environmental hybrid IO model to the 1995 Brazilian economy to evaluate the total impacts of international trade on energy use and carbon dioxide emissions.

In their analysis of sectoral changes from carbon dioxide taxes, Zheng and Ma (1998) found that when a carbon dioxide tax is implemented, economic impacts on the whole economy become more moderate than impacts on individual sectors. Simulations in Zheng and Ma (1998) also show that a 20% reduction in carbon dioxide emissions and no reduction in other taxes decrease real GDP by 0.96% and a 5% reduction in emissions and reduction in other taxes decrease real GDP by 0.016%. This study on sectoral changes from carbon dioxide taxes also found that carbon dioxide emissions are reduced by 10%, economic output in the coal, oil and coke industry declined the most while sectors that consume the least amount of energy increase their economic output slightly.

Carbon dioxide emissions taxes in Europe are used to internalise the negative external effects from production and energy-intensive consumption and additional tax revenue may be used to stimulate employment (European Parliament, 1999; Machado, 2000, Needergaard, 2001). A report for the European parliament (1999) found that environmental tax reform in the Netherlands has had a slightly positive effect on employment, but the impact on emissions is less clear. Decreasing labour costs and investment incentives has resulted in revenue neutral environmental taxes in Denmark but energy emissions and economic targets have not been achieved and in Sweden energy emissions taxes have been effective, as income taxes have been lowered.

A key feature of the analysis by Symons, *et al*. (2001), is equity and how the extra tax payment is distributed across different income groups in five European countries. The study assumes that consumers do not respond to the change in relative prices so that the estimated effect directly impacts on consumers. The study found that a carbon dioxide tax would raise the price of goods consumed in direct relation to the intensity of that good and consumers are faced with increased tax burden from consumption.

Carbon dioxide taxes of 0.15 pence/kWh for coal and natural gas, 0.43 pence/kWh for electricity and 0.07 pence/kWh for liquid petroleum gas have raised revenues of one billion pounds per annum in the United Kingdom (Smith, 2003). The revenue has been used to finance corporate tax incentives for energy efficiency investments and to finance the national employer's insurance fund hence the tax is revenue neutral but its incentive effect is forecasted to reduce UK greenhouse gas emissions by 2 million tonnes of carbon dioxide. Smith (2003) also states that carbon dioxide emissions reduction require high tax rates as energy demand tends to be relatively non-responsive to price.

High carbon dioxide tax rates may be able to facilitate major tax reform elsewhere in the fiscal system as seen in Sweden where revenues generated from carbon dioxide taxes were used to finance tax reform packages involving substantial cuts in Sweden's high income tax rates. Positive effects on gross domestic product and employment from revenue recycling are referred to as a double dividend from carbon dioxide taxes and a number of studies have looked at this (Jacobsen, 2002; Nedergaard, 2001; Budzinski, 2000).

The concept of taxing bads and reducing taxes on goods has been termed the double dividend hypothesis. This hypothesis state that a win-win situation can be achieved when the quality of the environment improves (first dividend) and economic efficiency gains and employment increases (second dividend). The literature indicates that an important point when analysing the double dividend is the recycle principle for tax revenues used in the macroeconomic model.

3.2.2. Energy subsidy reform

The removal of energy subsidies creates an opportunity for freeing up limited public resources and correcting for sub-optimal use and environmental degradation (Hassan and Blignaut, 2004). According to the IPCC's Third Assessment Report (2001b) energy subsidies are introduced to secure domestic energy supplies, ensure that power supply is sufficient to meet demand, provide access to energy for low-income households, maintain or slow the loss of employment in mining communities and retain the international competitiveness of domestic industry.

Several major energy-subsidizing countries have reformed their energy sectors. The removal of most energy controls and regulations in Russia has driven domestic energy prices up from 20-40% in 1991 to more than 70% of world prices by the end of 1995 while China phased out coal subsidies by allowing coal prices to rise to world market levels and are now close to parity with international prices (IPCC, 2001a). Ongoing research by the World Bank and other calculations indicate that the reduction in fossil fuel subsidies, as measured by the price wedge, amounts to $100 billion, energy subsidies in developing countries range between $150 and $200 billion per annum (World Bank, 2002).

The analysis of energy subsidy reform involves two main steps: assessing the scope and magnitude of the subsidy and evaluating the impact on GDP, household consumption, employment, environmental quality and energy markets. Critical elements in assessing the scope and magnitude of subsidies include defining the value of the subsidy.

3.3. Energy emissions input-output models

Input-Output models are classified as equilibrium models. The literature makes the distinction between partial equilibrium models and general equilibrium models or optimal growth models. Partial equilibrium models only focus on equilibria in parts of the economy, such as the equilibrium between energy demand and supply. General equilibrium models are particularly concerned with the conditions, which in certain sectors allow for simultaneous equilibrium in all markets as well as the determinants and properties of such an economy-wide set of equilibria. Economic equilibrium models study the energy sector as part of the overall economy and focus on inter-relations between the energy sector and the rest of the economy hence energy and environmental policy analysis use general equilibrium models more extensively than partial equilibrium models. Input-output, social accounting matrices and computable general equilibrium models are the most frequently used economic equilibrium models in energy and environmental policy analysis.

Input-Output (IO), Social Accounting Matrices (SAM) and Computable General Equilibrium (CGE) models are similar in terms of the questions addressed, data requirements, range of applications and future conceptual refinements. All three models reflect all the inter-sectoral linkages present in an economy as a single matrix presenting the interaction between production, income, consumption and capital accumulation. One of the main uses of these models is to display all flows of goods and services within an economy, simultaneously illustrating the connection between producers and consumers and the interdependence of industries using production functions to link all economic activities directly to final demand. However IO models differ from SAMs and CGEs in that they describe economic sectors using sets of simultaneous linear equations for each industry producing one commodity with fixed co-efficients that does not allow for factor substitution, technological and behavioural change. SAMs and CGEs act as benchmark data sets from which the parameters of the model can be calibrated. The structure of SAM and CGE models usually contain both commodity and industry accounts showing their interconnections via the use and make matrices. Unlike IO models, SAMs and CGEs highlight the issue of income distribution. One of the key reasons for using SAMs and CGE models arises when demand is not important and the income feedback loop can be ignored without affecting the analysis.

IO models were first applied to examine the interactions between the environment and the economy in the late 1960s and early 1970s, while the first energy IO models were presented during the mid 1970s and 1980s. Over time, modelling approaches have become more and more complex to allow for global environmental issues such as climate change and greenhouse gases. This led to theoretical models and empirical studies that combine both the energy and environment perspectives making it hard to distinguish between environmental and economy models and energy and economy models. It has now become usual to refer to energy-environment-economy models.

The earliest energy-environment-economy IO models seem to have been developed in the early 1990s. Basic energy and environmental IO models consider the simultaneous impact of energy or environmental policy instruments on energy consumption, production, the environment and the economy. Analysis must differentiate between primary or secondary energy together with the corresponding energy related pollution. The disaggregated energy sector then allows for the analysis of pollution that is emitted during the production of primary energy or emissions that are emitted during combustion when secondary energy is produced. Pollution emissions are determined according to energy supply and consumption and emission intensities

SAMs and CGEs provide a framework within the context of the national accounts in which the activities of households are accentuated and prominently distinguished. The SAM places greater emphasis on institution accounts than IO models. By combining households, into meaningful groups, the SAM makes it possible to distinguish between and study the effect, interaction and the economic welfare for each household group. The SAM also extends the sectoral linkage concept in the IO matrix to include income distribution and expenditure on final demand. CGE energy and environment models use underlying behavioural relationships derived from utility maximisation by households and cost minimisation by firms to explicitly incorporate links between the energy sector and the rest of the economy. These links arise because energy demand is derived from the demand of other goods and services and energy supply in turn requires inputs of capital, labour and intermediate goods. Explicitly incorporating them provides information about how relative product and policy measures or technological change influences factor prices and the inter-temporal allocation of resources.

Most CGE models are based on a SAM framework. CGE models differ from the SAM in that they allow for the analysis of enhanced institutions, as well as a broader set of interactions and non-linearity and substitution possibilities in response to market signals. In comparison to IO models and SAMs, CGE models are based on more restrictive assumptions since they typically assume optimising behaviour and an economy that is in equilibrium. Since most CGE models are based on a set of social accounts, they explicitly incorporate resource constraints, allow for input substitution and have strong price-quantity integration. CGE models can address a broader set of issues than most IO models. An advantage of CGE is that it models international and interregional competition and behavioural considerations of tax policies. One disadvantage of CGE models is that they require a fairly well developed market. Another disadvantage is the fact that they have a relatively thin empirical base, which requires strong assumptions about trans-boundary flows, production structures and household behaviour.

The literature on energy-environment SAMs and CGE models indicates that very few of these models endogenise environmental concerns. Some models have quasi feedback effects incorporated as constraints rather than being fully endogenised (Bergman, 1990; Breuss & Steininger 1998). The credibility of energy and environmental CGE models and the strength of the SAM don't always allow for policy analysis. McDonald, (2002) designed a simple CGE model to illustrate how environmental externalities can be modelled in the context of a CGE model for Mauritius but the simplicity of the model and the weakness of the Mauritius SAM did not allow for policy analysis. Zhang (1998) and Xie and Saltzman (2000) attempted to use a dynamic CGE model for China to analyse the macro-effects of carbon dioxide emission reduction. This study found that policy analysis using energy and environmental CGE models could be very complex. Nugent and Sarma (2002) used an environmentally extended CGE model to analyse efficiency, equity and environmental protection in India. The model was developed with fifteen production sectors; three of which was abatement. This allowed for some comparative analysis among the sectors.

3.3.1. Input-Output Analysis

Wassily Leontief developed IO analysis for which he was awarded the Nobel Prize in Economic Science in 1973. IO models are also referred to as Leontief models.

Although Francois Quesnay (1758) and Leon Walras (1870) undertook to describe inter-industry linkages as explained by IO analysis, it was only in the 1930s when the United States economy was presented in an IO system, that the practical application of IO analysis techniques gained popularity. In 1936 Leontief extended IO analysis to an analytical framework by integrating IO analysis into national accounts for the United States for 1919 and 1929. His approach to national accounts was to disaggregate the economy into inter-dependant sectors. Leontief focused on how industries trade with each other and how such inter-industry trading influenced the overall demand for labour and capital within the economy.

In 1970, Leontief extended the original IO approach to include environmental repercussions in the economic structure. The basis of extending the original IO model lies in the fact that technical interdependence between pollution can be described in terms of structural co-efficients similar to those used to trace the structural interdependence between all the regular branches of production and consumption (Leontief, 1970). In his environmental model, he extends and partitions the technical co-efficients matrix into:

- additional row(s) with pollution output coefficients for each sector (and type of final demand). Given final demand pollution, pollution output from each sector as well as total pollution output could be calculated.
- additional column(s) with input-output coefficients for a pollution elimination sector. This column traces the effect reduced pollution in a specific sector(s) has on total output levels of other industries.
- additional row(s) show the input requirements of each sector according to the cost of eliminating pollution in that sector.

Both Daly (1968) and Isard, *et al*. (1968) have developed a similar approach to the environmental Leontief model, incorporating environmental activities into an IO framework. Both approaches employ flow matrices within and between economic activities and environmental processes. Daly employs a highly aggregated industry-to-industry characterisation of the economic sub-matrix and a classification of the ecosystem processes. Isard, *et al.* (1968) adopts a commodity by industry accounting scheme, which permits an accounting of multiple commodities, economic and ecological, produced by a single industry. Victor (1972) limits the scope of Isard *et al.* (1968) by not fully integrating economic-ecological models to account for flows of ecological commodities from the environment to the economy and the waste products from the economy into the environment. Energy IO analysis started in the mid-1970s (Bullard and Herendeen, 1975).

Since Leontief first published his work, a number of books and articles on environmental IO analysis have been published (see for example Miller and Blair (1985), Rose (1983), Miernyk (1973) and Miernyk and Sears (1974)). In the late 1960's and the beginning of the 1970's some IO studies addressed material flows in analytical economic models (Ayres and Kneese, 1969; Kneese, *et al*., 1970). A material flow model describes the physical flows of materials and products through the various sectors of an economy such that the material balance is satisfied for each sector.

Allan, *et al*, (2004) reformulated the environmental Leontief model to include additional pollution elimination column(s) for each sector adding input-output coefficients for the pollution elimination sector. This extension to the environmental

Leontief model allows for the empirical analyses of the environmental impacts of economic activities and of the resource requirement implied by the need to clean up and/or dispose of unwanted outputs (Allan, *et al*. 2004).

As modelling approaches became more complex energy and environmental IO models began to evolve into energy emissions IO models. In the last ten years almost all the energy and environment IO models were energy and emission IO models.

3.3.2. Energy-emissions input-output studies

Research on energy emissions IO studies in developing countries has mainly been done in China and India. Studies have looked at economic development, environmental management and energy regulation. Based on China's IO tables for 1981 and 1987, Lin and Polenske (1995) conducted a structural decomposition analysis to explain China's energy use changes between 1981 and 1987 (Zhang, 2001). Using a similar procedure to Lin and Polenske (1995), Garbaccio, *et al*., (1999) concluded that the fall in energy use during 1987-1992 was due mostly to a fall in real energy intensity (Zhang, 2001).
Recent energy emissions IO studies follow the method used by Gay and Proops (1993) and Proops, *et al*. (1993) where the distinction was made between primary and secondary energy. Symons, *et al*., (1994) and Cornwell and Creedy (1996) used IO methods to analyse price effects for the United Kingdom and Australia, respectively. The energy emissions IO model can also be used to show the implications of shifting from one technology to another in the electricity sector as was indicated by Proops, *et al*. (1996). Cruz (2000) and Labandeira and Labeaga (2001) used this approach to develop a structural decomposition of Portuguese and Spanish energy-related carbon

dioxide emissions, respectively, and to analyse the impact of carbon dioxide and energy taxes.

Alternatively some energy emissions IO studies have used a hybrid IO model. The approach used by Hetherington (1996) to develop an energy and environmental IO model for the United Kingdom substitutes energy rows expressed in physical units for energy rows valued in monetary terms in the IO table, before recalculating the Leontief inverse based on the new flows. In this new IO table flows are expressed in hybrid units, energy commodities in physical units and non-energy commodities in monetary units. These studies were used to estimate the price effects of several hypothetical carbon dioxide taxes levied on fossil fuel consumption. Integrating energy and environmental resources into IO analysis does not need any a priori information. Arrous (2000) used price and quantity hybrid units, as described by Miller and Blair in (1985).

This IO table expresses flow in hybrid units, energy and energy emission commodities in physical units and non-energy commodities in monetary units. Bullard and Herendeen (1975) were the first to attempt a hybrid energy IO model. This was in response to the energy crisis in the 1970s. Since energy output into each sector is no longer represented as prices, energy price no longer play any role in calculating energy and energy emission intensities. The hybrid model calculates a technological matrix and a Leontief inverse matrix where rows representing output from the energy sectors or the energy emission sectors are based on physical data and all non-energy sectors are based on monetary prices so that each sector still delivers one unit of demand.

The difference between extended and hybrid models is that the extended model develops a matrix of physical energy emission data, which is separate from the monetary IO table while the hybrid model substitutes physical energy emission data into the monetary IO table. Both models need two data sets that are compatible namely an IO table and an energy emissions IO table. The disadvantage of the hybrid model lies in the fact that when physical quantities are added into the monetary table, the empirical accounts may have problems in representing monetary accounts hence real economic activities. Substituting monetary data with physical data may introduce unwanted indirect effects, since data reflecting direct and indirect effects become mixed. This is likely to exacerbate problems with homogeneity and proportionality assumptions inherent to most IO models. Hybrid models demand detailed knowledge of energy intensities, good data, well-developed IO models and advanced IO experience but integrating energy and emissions data into IO analysis. Hence this study has chosen to use an extended energy emissions IO model rather than a hybrid model.

Although the need for detailed and comprehensive data is a major limitation of the extended energy emissions IO model, the Leontief pollution model with standard A-matrix and additional pollution row of pollution co-efficients makes it possible to understand energy and energy emissions in an economic context. Other limitations of the extended energy emissions IO model include the fact that the analysis assumes constant returns to scale, linear production functions and no resource constraints. This by no means represents the real economic situation and is particularly important when differentiating between average analysis and marginal analysis. However these limitations can be overcome with certain assumptions, which then allow the model to be used for policy analysis. Assumptions include constant returns to scale, linear production and no substitution.

3.4. Energy emissions analysis in South Africa

Since the mid-1990s a few researchers have attempted to study social and environmental externalities of energy production and consumption in South Africa.

Gibson and van Seventer (1996a) found that it was macro-economically desirable to avoid green trade restrictions by internalising environmental externalities especially in the energy-producing sector. The model employed for the simulations is a nine sector, two-class structuralist computable general equilibrium system with both real and financial sectors. This study states that little is known about the precise relationship between growth, distribution and the environment except that it is exceedingly complex and necessitates a structural analysis. Few general analytical results are available but these results clearly indicate that macro and environmental impacts cannot be separately analysed since growth and environmental deterioration often go hand in hand. Placing green trade restrictions on the energy, producing sector would retard export growth and per capita GDP and there is no guarantee that environmental preservation will follow.

In the mid-1990s, the cost of externalities in the electricity sector was estimated using EXMOD, which is a model based on the damage function approach. van Horen (1996) found that the largest contribution to electricity externality estimates was global climate change and it was deduced that the value of electricity externalities was 0.69 c/kWh. Apart from global climate change damage estimates, which were identified as being highly uncertain, human health effects due to particulate emissions were the next largest source of damage costs.

Trikam (2001) undertook a study of GHG mitigation options in the industrial sector in South Africa. The number of tons of carbon dioxide equivalent reduced through mitigation divides the life cycle cost (using a discount rate of 11%) of short-term mitigation options. This allowed the study to develop a mitigation cost curve. In calculating the mitigation costs all capital costs, operating and maintenance costs and fuel costs have been taken into account. It was concluded that although mitigation result in savings for industry, industries will only undertake carbon dioxide mitigation if they can see the benefit in profits. Therefore government needs to initiate mitigation by setting standards and providing incentives to industry.

By internalising the damage cost of carbon dioxide and methane from coal combustion, Blignaut and King (2002) estimated the cost of coal externalities. Given that the study only investigated the externality cost of carbon dioxide and methane, the values presented in the study reflect a lower bound estimate of the environmentally inclusive price for coal. Blignaut and King (2002) argue that previous studies on electricity externalities estimate the social and environmental cost of negative externalities in terms of the price of electricity and not on the source of emissions namely that of coal. Therefore the externality cost of coal combustion should be relayed to the price of coal and not to the commodity or product produced since it does not take note of the fact that there might be other methods of generating electricity other than through the combustion of coal.

As part of a study on macro-economics and sustainable development in southern Africa, Goldblatt, *et al.* (2002) investigated energy and sustainable development in South Africa. The study includes an assessment of externalities, the cost of mitigation and policy options for internalising externalities in the energy sector in South Africa. Goldblatt, *et al.* (2002) found that inappropriate energy policies in pursuit of national self-sufficiency to counter international sanctions have resulted in a high ratio of local and global pollutants per unit of GDP produced. A study by Hassan and Blignaut (2004) specifically investigated energy subsidies. In their study Hassan and Blignaut (2004) indicate that coal; electricity and petroleum products consumers in South Africa enjoy two types of subsidies, a direct financial subsidy on retail prices and an indirect environmental subsidy on negative externalities. According to the International Energy Agency (IEA) (1999), the electricity sector was most affected by the removal of the energy subsidy since a large part of the energy subsidy was a result of cheap coal.

3.4.2. Energy emissions models in South Africa

Local studies indicate that computable general equilibrium (CGE) models have been used most often to analyse energy emissions in South Africa. The CGE model developed by Gibson and van Seventer (1996b) found that there was very little feedback from environmental variables to macro-variables as the interaction between the macro-economy and the environment is complex, highly diverse and uncertain. The short-run framework over emphasises the macro-economic costs of environmental benefits while traditional neoclassical long-run analysis places undue emphasis on individual utility maximisation. The overall result of this study indicated that green trade restrictions reduce employment to the point that intensive environmental degradation increases dramatically.

In 1999 the Industrial Development Co-operation (IDC) used a CGE model called the IDC-GEM to forecast sectoral greenhouse gas emissions for the period 2000-2015. The estimates obtained from this model are reconciled against estimates given by climate mitigation studies. The model calculated emission volumes in line with production growth forecasted by the model. The model had to be adjusted to take into account unavailable information such as information on energy emissions, which was not available for all of the sectors in a format suitable for inclusion in the IDC model.

De Wet (2003) developed a CGE model with a specific coal sector and different labour and household groups for South Africa. In his study De Wet (2003) focuses on the redistributing revenue generated from a carbon dioxide tax and the impact such a tax has on unemployment and household income. The study concludes that a tax on coal will have positive environmental benefits for South Africa but it will have negative consequences for the economy in the form of lower levels of employment, consumption and economic growth. Although welfare increased when the sales tax on electricity, base metals and chemical products increased, it is difficult to prove that a double dividend is achieved by the incorporation of such a policy. The reason for this is that economic growth and employment decreased and although utility has increased, consumption and disposable income has decreased.

Van Heerden *et al*. (2005) used similar methods to determine if a triple dividend exists for South Africa. A CGE model is used to find the potential for a double or triple dividend if the revenues raised from an energy related environmental tax are recycled to households and industry through lowering existing taxes. The study concludes that the best policy combination for cleaner environment as well as poverty alleviation would be a carbon tax recycled through a decrease in taxes on food.

In terms of energy emissions data, the national GHG inventory represents the official database for South Africa. The inventory presents energy emissions data for 1990 and 1994. Blignaut, *et al.* (2004), discusses the procedures and results of constructing a GHG emissions database for South Africa, using the official national energy balance for 1998. The study applies energy balances to compile a comprehensive emissions database, which could be used to model various economic, polices. The database indicates the dominant role of coal in the South African economy. Statistics South Africa (2005) published a discussion document on energy accounts for South Africa. The report contains natural resource accounts for energy in South Africa from 1995 to 2001 and has been compiled in accordance with the recommendations of the System of Integrated Environmental and Economic Accounting.

3.5. Conclusion

South Africa is under tremendous global pressure to reduce high levels of GHG emissions and local pressure to grow the economy and increase employment. This presents the need for a single integrated framework that is able to measure the simultaneous impact of energy consumption, energy emissions and economic growth.

The literature reviewed indicates that IO models, SAMs and CGE models can be used to develop such a framework as they allow for the structural decomposition of the economy. SAMS and CGE models focus on institutional analysis as these models provide a framework within the context of national accounts in which the activities of households are accentuated and prominently distinguished. Given the fact that this study focuses on the inter-industry and total economic impacts and given the lack of institutional data, the IO model is selected for this study. IO models describe economic sectors using simultaneous linear equations for each industry producing one commodity with fixed co-efficients.

The model developed in this study will disaggregate the energy sector according to different primary and final demand energy types including coal, oil, nuclear, biomass, renewable energy, electricity and petroleum products. The addition of the biomass sector to the economy generates new data and values to GDP as does the manner in which electricity and petroleum products are produced based on different primary energy types. The study will then test the viability of an integrated framework for South Africa by developing hypothetical policy scenarios supported by real data.

Carbon dioxide taxes and energy subsidy reform are the most frequently investigated options for energy emissions reduction. Carbon dioxide taxes are favoured because they indirectly tax carbon dioxide emissions based on the carbon content of the energy source and they generate revenue, which could be lead to fiscal reform. Energy subsidy reform is increasingly being explored as an option for energy emissions reduction as this aims to rectify distortions in the energy market and the removal of energy subsidies creates an opportunity for freeing up limited public resources and correcting for sub-optimal use and environmental degradation. Carbon dioxide taxes and energy subsidy reform will be analysed as possible energy-emissions reduction policies for South Africa.

Chapter 4: Approach and Methodology

4.1 Introduction

Input-Output (IO) analysis is selected for analysing energy emissions reduction policies in South Africa as this technique uses the interdependence of industries in an economy to analyse macro-economic variables, inter-industry activity, energy consumption and energy emissions. Three sets of data; namely an augmented monetary energy IO table, a physical energy IO table and a physical energy emissions IO table are integrated to produce a single model. This chapter will develop an augmented energy IO table using economic data, a physical energy IO table using physical energy data and a physical energy emissions IO table using energy data and conversion factors. None of the studies reviewed in the previous chapter indicate that any of these three data sets have been previously developed or used hence this study will undertake to do this. All three sets of data will disaggregate the energy sector according to primary and secondary energy types in order to assess the impact of that the policy scenarios will have on different energy types.

4.2. Augmented energy input-output table for South Africa

The augmented IO table will use a set of energy accounts to modify IO data as determined by the supply and use (SU) tables. The 2000 SU tables for South Africa cover the entire economy and are used to develop the System of national accounts (Statistics South Africa, 2003). Ninety-four different industry groups, 153 product groups in the supply tables and 95 different product groups in the use tables as well as six different components of final demand are distinguished. This study will initially aggregate the 94 industry groups and 153 product groups to produce an aggregated economic IO table with 15 economic sectors, 4 final demand sectors and 4 value added sectors. In order to obtain consistency with the three different databases, economic sectors will be aggregated according to the sectors identified in the energy balance and the GHG inventory. These 15 economic sectors are extended into an augmented IO table using a set of energy accounts.

The energy accounts will differentiate between primary and secondary energy types as each energy type has different energy intensities and pollution intensities per unit mass and per unit of energy delivered. Energy in South Africa is separated according to energy demanded by producers of energy (primary energy) and energy demanded by consumers (secondary energy) as outlined in the national energy balance. Primary energy types for South Africa are identified as coal, crude oil, natural gas, renewable energy, nuclear energy and biomass as outlined in the national energy balance and secondary types are electricity and petroleum products. Once primary and secondary energy types have been differentiated the study will develop a set of primary and secondary economic energy accounts.

The aggregated IO table using only SU data contains the following aggregated sectors; agriculture, coal mining, gold and other mining, food and textiles, wood and paper, petrochemicals, chemicals, iron and metal, machinery and equipment, other manufacturing, electricity, water, construction and accommodation, transport and communication and financial and community services. South Africa's augmented IO table for 2000 has a 20x20 inter-industry matrix with six primary energy sectors for coal, crude oil, natural gas, renewable energy, nuclear energy and biomass and two secondary energy sectors for electricity and petroleum products.

4.3. Physical energy input-output table for South Africa

Miller and Blair (1985) states that the total primary energy intensity of a product should equal the total secondary energy intensity of the product plus the amount of energy lost in energy conversion hence it is important to distinguish between primary and secondary energy in order to avoid double accounting. The energy table in this study uses the energy balance to ensure that this condition is adhered to. When applying an IO approach to energy use, primary energy types are separated from secondary fuels as secondary energy types are dealt with within the inter-industry demand structure (Gay and Proops, 1993).

To maintain the principle of energy conservation and prevent double accounting previous international studies have developed energy IO tables that only include primary energy as all energy emissions in the economy are directly accounted for by primary energy consumed in the economy. However this study will investigate the impact of energy emissions reduction on both primary energy emissions and secondary energy emissions it will therefore include a separate set of energy consumption accounts for secondary energy. This was done for two reasons, firstly to check if primary energy consumed within the economy equals secondary energy plus energy lost during energy conversion. Secondly to assess the distribution of secondary energy emissions among different sectors in the economy. The principle of energy conservation demands that primary energy and secondary energy consumption not be added together and be analysed separately.

Changes in environmental fiscal policy affect households and firms through their consumption and production of goods and services. Like households, firms directly consume energy in the production of goods and services (direct inputs). In addition, these direct inputs may have energy inputs (indirect inputs). As a result, each good and service purchased by a household and firm will have direct and indirect energy inputs. This study used an extended Input Output Table for 2000 (prepared by Statistics South Africa) to model policy changes through the economy to the production and household sectors.

Leontief (1936) was the first to develop this methodology which was applied to input-output analysis. In 1970, Leontief extended the original input-output approach to include environmental repercussions in the economic structure. The basis of extending the original input-output model lies in the fact that technical interdependence between pollution can be described in terms of structural co-efficients similar to those used to trace the structural interdependence between all the regular branches of production and consumption (Leontief, 1970). Allan, *et al*, (2004) reformulated the environmental Leontief model to include additional pollution elimination column(s) for each sector indicating input-output coefficients for the pollution elimination sector. This extension to the environmental Leontief model allows for the empirical analyses of the environmental impacts of economic activities and of the resource requirement implied by the need to clean up and/or dispose of unwanted outputs (Allan, *et al*. 2004). Similar published analyses include Gay and Proops (1993) for the United Kingdom and Casler and Rafiqui (1993) for the United States of America.

An Input-Output Table contains information about sectors of an economy, mapping the flows of inputs from one sector to another or to final demand (that consumed by households or exported, etc.). The rows of a nominal IO Table can be written as:

$$P_i X_i = \sum_i P_i X_{ij} + P_i F_i \qquad (1)$$

Xi = output in sector I

Pi = price of sector I's output

Xij = sector j's requirements of intermediate inputs from sector I

Fi = final demand for sector I's output

We define the *input output coefficient* of sector i into sector j as

$$a_{ij} = \frac{X_{ij}}{X_j} \qquad (2)$$

These are assumed to be constant. In practice, we derive these from the nominal IO table

$$\frac{P_i X_{ij}}{P_j X_j} = \frac{P_i a_{ij}}{P_j} = a_{ij} \qquad (3)$$

We set all prices = 1 to get this result. This amounts to defining the units in which the quantity of each sector's output is measured. Adopting the convention of setting prices = 1 and mindful of the definition of Xij in equation 2, we can thus write

$$X_i = \sum_i a_{ij} X_j + F_i \tag{4}$$

Or in matrix notation

$$X = AX + F \tag{5}$$

A is the coefficient matrix. It has the property that every element is nonnegative and the column sum of any column must be less than 1. The fact that the Leontief inverse is non-negative means that it is feasible to get a mathematical solution for any F. This may not be feasible economically but we could use the estimate as a consistency check. Combining the output coefficients to produce an (I-A) *technology matrix* and inverting, the *Leontief inverse matrix,* $(I-A)^{-1}$ is produced, which gives the direct and indirect inter industry requirements for the economy:

$$X = (I - A)^{-1} F \tag{6}$$

As we show below, we can do this quite simply and easily on the computer (even in Excel). However, it is sometimes useful and enlightening to take a slower approach – the Neumann iteration method.

Equation 6 can be expanded to produce the following

$$(I-A)^{-1} \cong I + A + A^2 + A^3 + \ldots. + A^n \qquad (7)$$

$$X = (I + A + A^2 + A^3 + \ldots + A^n)F = F + AF + A^2F + A^3F + \ldots. + A^nF \qquad (8)$$

This illustrates the material balance issue. Starting with the vector of final demands, we can work out the successive rounds of gross outputs necessary to achieve it. As we include further and further rounds, this converges on an 'equilibrium'.

This model is used for policy analysis as follows. The economy is considered to be in equilibrium as described by equation 6. Given demand we obtain the corresponding supply. A base run for the model is computed using equation 6. This base run is then used to benchmark equilibrium. Once specified, the input-output model will generate production and pollution levels as an equilibrium solution. The parameters values obtained can be used to solve for alternative equilibria associated with a modified policy regime, in practice, a new demand. We will refer to these as counterfactual equilibria. Policy appraisal is then undertaken by contrasting benchmark and counterfactual equilibria. For example, if a tax t is applied and is passed on in its entirety to consumers, then the tax on goods consumed in final demand is td, the tax on the inputs to these goods is tAd, the tax on inputs to these is tA^2d and so on. Combining, total tax is

$$tF + tAF + tA^2F + tA^3F + tA^4F + \ldots = t(I-A)^{-1}.F \qquad (9)$$

A number of adjustments had to be made to the input-output analyses for our purposes. Firstly, the input-output table was extended to decompose the energy components of a fuel sector, petroleum and coal products into its constituent parts because we want to focus on the differential effects of policy changes of individual energy components. This has been done utilising the Energy Balance for 2002 published by the Department of Minerals and Energy in South Africa. Second, the IO table is extended to include energy emissions. These were calculated broadly following IPCC Guidelines. Local emission factors were utilized where possible. In the absence of such factors, IPCC default factors were used. The resulting expanded energy and emissions matrix is used to find the effects (both direct and indirect) of a change in the policy on each sector of the economy.

Total energy requirements f can be considered as the sum of the production energy requirement f_{ind} and the final demand energy requirement f_{dem}.

The production energy requirement, f_{ind} equals the product of energy intensity corresponding to direct production demand, represented by C, the inter-industry inverse matrix, represented by $(I-A)^{-1}$ and final demand matrix, represented by y.

The final demand energy requirement f_{dem} equals the product of energy intensity corresponding to direct consumption demand represented by P, final demand which is the sum of household consumption, government consumption, investment and savings and exports represented by H and final demand matrix, represented by y.

Therefore:

$$f = f_{ind} + f_{dem}$$

Where:

$f_{ind} = \boldsymbol{C}\,(\boldsymbol{I}-\boldsymbol{A})^{-1}\boldsymbol{y}$ since $f_{ind}\,(\boldsymbol{I}-\boldsymbol{A})^{-1} = \boldsymbol{C}\,\boldsymbol{y}$

$f_{dem} = \boldsymbol{PHy}$

Hence:

$$f = \boldsymbol{C}\,(\boldsymbol{I}-\boldsymbol{A})^{-1}\boldsymbol{y} + \boldsymbol{PHy} \qquad (10)$$

Where:

$\boldsymbol{C}$ is a (6x20) matrix whose element (c_{fi}) represents the physical quantity of energy f used by sector $\boldsymbol{i}$ (designated as energy intensity corresponding to direct production demand),

$(\boldsymbol{I}-\boldsymbol{A})^{-1}$ is the inter-industry (20x20) inverse matrix

$\boldsymbol{y}$ is a (20x1) final demand matrix.

$\boldsymbol{P}$ is a (6x20) matrix, which has six non-zero elements, one for each fuel type, expressing the physical quantity of energy used per unit of final demand (designated as "energy intensity corresponding to direct consumption demand).

$\boldsymbol{H}$ is a (20x20) diagonal matrix, with six non-zero elements, which are the ratios of the sum of household consumption, government consumption, investment and savings and exports. The final demand for energy corresponding to investment and savings (gross fixed capital formation plus changes in stocks) is not consumed and consequently does not correspond to energy consumed. Final consumption pertains to energy that is consumed locally hence it is only necessary to consider final consumption made up of household consumption and government consumption.

Equation (2) can be decomposed to show the progressive adjustments of energy requirements to final demand as:

$$f = [PHy + Cy] + [CAy + CA^2 y + \ldots + CA^{n-1} y] \qquad (11)$$

Where:

PHy represents the direct consumption demand for energy

Cy represents the total production demand for energy

CAy represents the direct requirements and the sum of all the others $[CAy + CA^2y + \ldots]$ represents the total indirect requirements for energy of production demand.

Therefore the elements of matrix $[C\ (I\text{-}A)^{-1}]$ represent the energy intensities corresponding to total production demand and the energy intensities corresponding to direct and indirect production demand.

A similar set of secondary energy requirements can be considered as the sum of the secondary energy consumed and the final demand energy requirements (given by the 2 vector $[f_{dem} = PHy]$ for secondary energy).

4.4. Physical energy emissions input-output table for South Africa

Correspondingly it is considered that total primary energy emissions by an economy (given by the scalar c) can be considered as the sum of the production energy emissions $[c_{ind} = e'_{ind}C(I\text{-}A)^{-1}y]$ and final demand energy emissions $[c_{dem} = e'_{dem}\ PHy]$, i.e:

$$\boldsymbol{c = c_{ind} + c_{dem}}$$

$c = \boldsymbol{e'_{ind}C(I\text{-}A)^{-1}y + e'_{dem}PHy}$ ó $c = [\boldsymbol{e'_{ind}C(I\text{-}A)^{-1} + e'_{dem}PH}]\boldsymbol{y}$ (12)

Where ***e'*** is the transpose of a 6-vector, for primary energy emissions and a 2-vector for secondary energy emissions, ***e*** whose element e_f represents the amount of energy emission per unit of fuel *f*. The total energy emissions as a result of an iterative process that shows the progressive adjustments of energy emissions to final demand and fossil fuel requirements can be shown as:

$$c = [e'_{dem}PHy + e'_{ind}Cy] + [e'_{ind}CAy + e'_{ind}CA^2y + \ldots + e'_{ind}CA^{n-1}y + \ldots] \qquad (13)$$

International studies that have used IO analysis indicate that final demand for energy exports is ignored since energy exports do not affect domestic energy emissions as energy exports leave the country to be consumed elsewhere. The reasoning behind this is that energy emissions are calculated as the emissions produced during energy production or fossil fuel combustion and if energy is not produced locally then these energy emissions cannot be counted in the domestic economy. Accordingly the final demand vector is modified to exclude the investment and export components by pre-multiplying by a suitable scaling matrix to produce ***H*** therefore resulting in a modified final demand vector ***Hy*** (20x1).

Some studies include fugitive emissions in the model, which are emissions that arise from sources other than energy combustion. The model for South Africa will not include fugitive emissions given that the study is focussing solely on domestic emissions produced during energy combustion.

The integrated energy emissions input-output model for South Africa therefore combines the augmented energy IO table, the physical energy IO table and the phyiscal energy emissions IO table as explained by the following equations:

X = intermediate demand $(I-A)^{-1}$ + final demand (y)

f = production energy requirement (f_{ind}) + final demand energy requirement (f_{dem})

c = production energy emissions (c_{ind}) + final demand energy emissions (c_{dem})

The integrated energy emission input-output model developed for South Africa is therefore:

X + f + c = intermediate demand $(I-A)^{-1}$ + production energy requirement (f_{ind}) + production energy emissions (c_{ind}) + final demand (y) + final demand energy requirement (f_{dem}) + final demand energy emissions (c_{dem})

4.5. Energy emission policy analysis for South Africa

According to the problem statement, five target variables were selected for analysis in this study; gross domestic product, employment, household consumption, energy consumption and energy emissions reduction. The model assumes that government spending, investment and savings, exports taxes less subsidies, gross operating surplus and imports are all exogenous. Technological change and tax rates are also assumed to be exogenous to the model. Five energy emissions reduction policies are selected for analysis in this study.

4.5.1. Carbon dioxide taxes

The purpose of a carbon dioxide tax is to discourage carbon dioxide emissions through the levy of a charge on each kilogram of carbon dioxide emitted. The charge is indirect as there is no direct attempt to measure individual emissions of firms or households and to levy the charge directly on emission measurements. Instead the tax is levied on the carbon content of fuels, through an extended system of energy excises on the basis that this is a close proxy for carbon dioxide emissions, which result from the energy used.

The price of each energy source is increased by the carbon dioxide tax and the increase in price is higher for energy with higher carbon dioxide content. By raising the price of energy relative to other industrial inputs and relative to household spending, the carbon dioxide tax acts to discourage the use of energy in general. Also by raising the price of energy in proportion to their carbon content, the tax encourages substitution away from high carbon energy sources towards lower carbon energy. Both the reduction in overall energy use and the substitution towards lower carbon fuels have the effect of reducing carbon dioxide emissions.

For a carbon dioxide consumption tax, the price increase can be introduced into the model and analysed by assuming that the purchaser’s price of each energy type is equal to the producer’s price plus other indirect taxes less subsidies plus the carbon dioxide tax or the energy subsidy. Assuming that the price increase is given by:

$t = m \boldsymbol{c}$

Where

$\boldsymbol{c}$ is the (20x1) vector indicating energy emission intensities

m is the general tax rate (1x1) on carbon dioxide from which product taxes are obtained then t (1x20) is interpreted as derived tax on goods produced. Therefore to estimate the price effects of carbon dioxide taxation, carbon dioxide intensities for all producing sectors that is emissions per Rand produced in every sector is needed.

$$\boldsymbol{c}' = [e'_{ind}C(I\text{-}A)^{-1} + e'_{dem}PH]y \qquad (14)$$

This is directly calculated from: $c = [e'_{ind}C(I\text{-}A)^{-1} + e'_{dem}PH]y$

The carbon dioxide tax paid by the purchaser (consumption taxes) is determined by the carbon dioxide content of energy consumed and the rate of tax. Ad valorem carbon dioxide taxes are introduced into the energy-emissions IO model in the following way:

$$P_{1\,(i,\,j)} = P_{0\,(j)} + ITX_{(j)} + A_{(j)}\,TC \qquad (15)$$

Where $P_{1\,(i,\,j)}$ is the purchaser's price paid by sector i for energy type j, $P_{0\,(j)}$ is the producer's price of energy type j, $ITX_{(j)}$ is the indirect taxes less subsidies of energy type j, c is the energy emissions vector for energy type j and TC is the carbon dioxide tax,. This study is based on the assumption that all prices are set to one in the background.

The carbon dioxide tax paid by sector i for energy type j is:

$$RTC_{1\ (i,\ j)} = TC \times c_{(i,\ j)} \qquad (16)$$

Similarly the purchaser's price of energy for direct demand consumers is defined as:

$$P_{1\ (i,\ j)} = P_{0\ (j)} + ITX_{\ (j)} + TC \qquad (17)$$

The carbon dioxide tax paid by consumers for energy used is:

$$RTC_{1\ (j)} = TC \times c_{\ (i,\ j)} \qquad (18)$$

By adding (8) and (9) we arrive at the total carbon dioxide tax revenue:

$$t = \Sigma_j \Sigma_i\ RTC_{1\ (i,\ j)} + RTC_{1\ (j)} \qquad (19)$$

4.5.2. Energy subsidy reform and the energy-environment IO model

The energy subsidy received by the purchaser is determined by the difference between average international energy prices and local energy prices. Energy subsidy reform is introduced into the energy-environment IO model in the following way:

$$P_{1\ (i,\ j)} = P_{0\ (j)} + ITX_{\ (j)} + A_{\ (j)}\, S \qquad (20)$$

Where $P_{1\ (i,\ j)}$ is the purchaser's price paid by sector i for energy type j, $P_{0\ (j)}$ is the producer's price of energy type j, $ITX_{(j)}$ is the indirect taxes less subsidies of energy type j, c is the energy emissions vector for energy type j and S is the subsidy. The subsidy received by sector i for energy type j is:

$$RTS_{1\ (i,\ j)} = S \times C_{1\ (i,\ j)} \qquad (21)$$

Similarly the purchaser's price of energy for direct demand consumers is defined as:

$$P_{1\ (i,\ j)} = P_{0\ (j)} + ITX_{\ (j)} + S \qquad (22)$$

The carbon dioxide tax paid by consumers for energy used is:

$$RTS_{1\ (j)} = S \times C_{1\ (i,\ j)} \qquad (23)$$

By adding (13) and (14) we arrive at the total revenue obtained by removing the subsidy:

$$t = \Sigma_j \Sigma_i\ RTS_{1\ (i,\ j)} + RTS_{1\ (j)} \qquad (24)$$

Chapter 5: Energy-Emissions Input-Output Model for South Africa

5.1. Introduction

The year 2000 is selected as the baseline year for this study. This was largely determined by the availability of official data. At the commencement of this study the most recent official economic IO data for South Africa was the 2000 supply and use (SU) tables published by Statistics South Africa (Statistics South Africa, 2003).

Energy production and consumption data for 2000 are obtained from the National Energy Balance which is published by the Department of Minerals and Energy annually(DME, 2002b). Although this data is often questioned for reliability, this database does apply international methodology for collating and reporting data and it is recognised as South Africa's official energy database.

South Africa's National GHG Inventory provides the most recent official energy emissions data but this is currently only available for 1990 and 1994 (DEAT, 2000a). Energy pollution data are calculated for 2000 using energy emission co-efficients from some local studies and IPCC data (IPCC, 2001a). These energy emission co-efficients addresses the lack of official energy emissions data for 2000. Energy emissions calculated in this study are found to be consistent with estimates extrapolated using energy emissions intensities applied in the 1990 and 1994 National GHG Inventory.

The information in the economic, energy and environmental databases are not reported in a consistent format as all three databases follow different international reporting structures. The SU table for South Africa is estimated according to recommendations by the, 1993 United Nation's System of National Accounts (Statistics South Africa, 2003b). South Africa's National Energy Balance follows the format prescribed by the International Energy Agency (IEA) and the National GHG Inventory for South Africa follows the 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines (DEAT, 2003a; IPCC, 1996).

The 2000 SU tables disaggregate activities according to the international Standard Industrial Classification (SIC) codes. SIC codes classify industries or economic activities in the System of National Account (SNA) so that entities can be standardised according to the activity they carry out. The National Energy Balance documents energy supply data on production, imports, exports and stock exchanges and energy consumption data according to each sector. Energy production data (top-down) are reconciled with energy consumption data (bottom-up). IPCC Guidelines classify GHG emissions according to energy, industrial processes, agriculture, land-use change, forestry and waste. The Revised 1996, IPCC Guidelines for National GHG Inventories allows countries to use either the reference (top-down) or the sectoral (bottom-up) approach when reporting GHG emission data follows the 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines (DEAT, 2003a; IPCC, 1996).

Although there are some international attempts by developed countries to collect, collate and report environmental data according to SIC codes, this is currently not the case for South Africa. This chapter first presents economic data used to develop the integrated energy and emissions model. This is followed by energy and emissions data. The manner in which the different formats of the data were integrated into one model is explained under the discussion on energy emissions.

5.2. The economic data

Given that SU tables provide the most up to date official economic data for South Africa for 2000 and that there is no official IO table for the baseline year, this study uses these data to develop an economic IO table. According to Statistics South Africa (2003), SU tables form the basis for the estimation of IO tables both at current prices and at constant prices and they form an integral part of the SNA.

Final demand in both the initial and the augmented economic IO tables comprises of household consumption, government expenditure, investment and savings and exports while value added comprises employment/wages, taxes less subsidies, gross operating surplus and imports. Household consumption, government expenditure and exports are directly obtained from the use table, while the investments and savings sector combine fixed capital formation, change in inventories from the SU tables as well as residuals which are used to balance the tables. Employment, taxes less subsidies and gross operating surplus are also directly obtained from the use table while imports were taken directly from the supply table.

Table 5.1 presents the initial aggregated economic IO table with 15 economic sectors, 4 final demand sectors and 4 value added sectors. In order to augment this table into the 20x20 economic energy IO table a set of energy accounts is needed.

Table 5.1: Initial economic IO table for 2000 for South Africa

(R million)

	Agriculture	Coal	Gold & other mining	Food & Textiles	Wood & paper	Petrochemicals	Chemicals	Iron & Metal	Machinery & Equipment	Other Manufacturing
Agriculture	2290.09	12.57	22.44	34050.80	5070.08	6.51	1100.22	52.91	624.11	254.92
Coal	1.98	0.99	191.90	215.15	16.81	3892.65	197.36	4091.17	32.06	0.93
Gold & other mining	147.32	20.14	60.12	44.9s9	122.62	10386.60	4842.81	10471.23	478.38	1964.56
Food & Textiles	6343.50	135.04	481.49	29579.55	277.75	1.10	1010.35	20.60	3404.49	604.33
Wood & Paper	522.65	57.31	1091.86	2131.65	16039.90	66.25	1079.13	325.03	580.67	2183.23
Petroleum products	2765.48	340.19	967.23	805.71	144.96	3100.49	3759.29	1907.86	925.96	118.64
Chemicals	5894.47	1185.10	4515.28	5825.13	5275.67	1602.52	31463.61	1575.86	8829.01	1329.04
Iron & metals	412.57	341.12	1545.47	1171.37	242.86	176.58	1728.99	26986.30	15426.68	1991.63
Machinery & Equipment	2860.92	1852.53	5599.29	1443.13	1049.77	717.34	2093.61	1295.63	43869.59	158.21
Other manufacturing	0.00	13.59	43.00	61.66	28.88	31.71	110.03	37.67	206.54	261.26
Electricity	438.11	346.70	3283.63	1140.07	241.35	794.92	2020.69	3178.31	413.34	128.57
Water	203.24	19.89	399.75	362.82	38.87	202.30	376.50	53.46	62.24	11.06
Construction & Accommodation	463.17	279.96	1087.89	375.28	71.72	49.59	291.40	170.30	172.80	22.68
Transport & Communications	3120.67	3676.58	12049.95	1120.77	312.84	2139.82	3628.06	3075.97	463.92	81.51
Financial & Community Services	2290.09	12.57	22.44	34050.80	5070.08	1247.44	1100.22	52.91	624.11	254.92
Employment	8903.76	4607.14	21110.13	18261.54	10138.01	1666.88	16721.86	12282.15	17020.59	2347.69
Taxes less subsidies	-208.22	269.64	699.94	508.09	201.26	86.52	303.93	247.16	172.06	56.38
Gross operating surplus	17364.19	5497.39	22766.98	16367.67	6458.64	9869.16	12364.90	14569.25	9242.35	1311.67
Imports	3365.18	383.61	29047.50	12087.05	6314.14	2294.53	29925.41	10534.90	93139.99	3840.62
Total	**56767.53**	**20559.93**	**111450.10**	**134671.52**	**55057.95**	**38332.91**	**122376.73**	**95149.44**	**198995.00**	**17329.33**

Source: Statistics South Africa (2003b)

Table 5.1: Initial economic IO table for 2000 for South Africa (continued)

(R million)

	Electricity	Water	Construction & Accommodation	Transport & Communication	Financial & Community	Household consumption	Government Expenditure	Investment & Savings	Exports	Total
Agriculture	11.56	0.00	561.69	2.78	332.17	17576.04	0.00	-11589.22	6387.86	56767.53
Coal	4305.45	138.64	11.17	13.62	104.55	238.45	0.00	-1416.68	8523.74	20559.94
Gold & other mining	4.18	2.90	1317.82	106.54	203.35	0.00	0.00	1623.27	79653.27	111450.10
Food & Textiles	43.87	2.33	4789.67	1174.76	1938.43	186914.61	0.00	-116743.14	14692.78	134671.51
Wood & Paper	66.63	66.76	9607.14	1837.58	7947.05	7069.93	0.00	-4543.21	8928.39	55057.95
Petroleum products	125.87	46.76	3867.06	10610.83	3498.89	22416.88	0.00	-25410.08	8340.89	38332.91
Chemicals	107.03	320.51	13345.31	2921.04	10575.14	29023.91	0.00	-18287.51	16875.60	122376.73
Iron & metals	259.48	117.96	6704.22	532.44	827.04	897.50	0.00	6375.94	29411.30	95149.44
Machinery & Equipment	1603.96	411.23	8624.06	12210.93	17287.00	34051.84	0.00	32653.45	31212.52	198995.01
Other manufacturing	5.03	200.62	1184.57	809.09	2612.30	14008.72	0.00	-8442.67	6157.32	17329.33
Electricity	1698.47	500.70	2114.94	1913.18	1690.32	11137.44	0.00	-702.96	919.54	31257.32
Water	139.43	4457.13	525.00	390.51	1067.83	2334.23	0.00	-517.21	0.00	10127.05
Construction & Accommodation	1704.72	28.39	26059.39	6743.17	9355.94	22121.37	0.00	192640.27	6739.17	268377.21
Transport & Communications	332.21	206.31	18892.24	12896.41	13389.21	42851.50	0.00	35279.62	15056.47	168574.06
Financial & Community Services	11.56	0.00	561.69	2.78	332.17	162097.58	166330.00	-39447.48	9733.16	467440.08
Employment	6704.99	1056.51	65568.65	34104.24	176821.37	0.00	0.00	27642.49	0.00	424958.00
Taxes less subsidies	283.52	-92.65	4141.85	853.87	12266.61	2544.89	0.00	66346.63	11324.00	100005.49
Gross operating surplus	12536.21	2168.42	61431.41	45841.31	120176.46	0.00	0.00	5127.49	0.00	363093.51
Imports	0.00	18.71	5212.30	23804.08	8134.86	1367.11	0.00	0.00	0.00	229470.00
Total	**31257.32**	**10127.05**	**268377.21**	**168574.06**	**467440.08**	**556652.00**	**166330.00**	**140589.00**	**253956.00**	**2913993.15**

Source: b (2003)

5.2. Energy Accounts for South Africa

The IO table developed in the previous section has three energy sectors namely coal, petrochemicals and electricity. The energy IO table will further disaggregate these three energy sectors in order to develop a more detailed augmented energy IO table. Firstly energy production will be differentiated from energy consumption then primary energy will be separated from secondary energy. The initial energy sectors aggregate primary energy and secondary energy, which makes it difficult to determine the exact source and quantity of energy produced and consumed in the economy. Separate primary and secondary energy accounts are needed for energy emissions calculations.

The energy IO table as presented in Table 5.2 disaggregates the initial energy sectors into coal, crude oil, natural gas, nuclear energy, renewable energy and biomass as is primary energy consumed in the economy while the two main secondary energy sectors in the energy IO table are electricity and petroleum products. The augmented energy IO table retains coal sector entries from the initial IO table but the initial IO table aggregates; crude oil, natural gas and petroleum products as petrochemicals and nuclear energy and electricity are aggregated as the electricity sector. This study will develop a set of energy accounts that will be used to disaggregate these two sectors. Biomass and renewable energy are not accounted for in the initial IO table. The augmented energy IO table quantifies and includes biomass and renewable energy as economic sectors. As a result economic output in the augmented energy IO table differs from economic output in the initial IO table by a value that equals the value of biomass and renewable energy in the economy.

Energy accounts are calculated using data from the SU tables, National Energy Balance for 2000 and national energy prices statistics for 2000 from the national Department of Minerals and Energy (DME) and compared against industry data. Data in the SU tables and the National Energy Balance are used to verify the energy accounts developed by this study.

Although it is possible to obtain comparative data from different sources for the base year 2000, when compared to other national and international data, a number of discrepancies are identified. The main reason for these discrepancies appears to result from the way in which data are collected and collated by different organisations. Differences also arise from the manner in which sectors are defined. This study subscribes to the international SIC classification, which defines sectors in the SU tables. Data in different studies are not only reported in different formats but in different units as well. Conversion factors are used to convert some of the data. There is no consistency in the way data in international studies are reported as different currencies and different exchange rates are used.

5.2.1. Coal

Coal is a primary energy source in South Africa. Since the SU tables have a coal-mining sector, data entries for this sector are obtained directly from the initial 15x15 IO table.

5.2.2. Crude Oil

The SU tables aggregate crude oil, natural gas and petroleum products as petrochemicals. Since this study has defined crude oil and natural gas as a primary energy source and petroleum products as secondary energy the three sectors had to be disaggregated from petrochemicals. Using data from the national energy balance it is possible to determine the total quantity of crude oil used by the South African economy in 2000. The energy balance indicates that approximately 18 412 586 tonnes of local and imported crude oil was used in 2000. According to the DME (2002d), the real prices of crude oil in 2000 were R1 576.50/tonne. For 2000, the total value of oil was calculated as R 29 027.77 million. The SU tables indicate that the petrochemicals sector has an output of R 38 332.91 million.

Crude oil output

The national energy balance is used to determine what proportion of crude oil comprises petrochemicals, which is an aggregate of crude oil, natural gas and petroleum products classified in the SU tables. Crude oil outputs are obtained as a proportion of petrochemical derived from the SU tables.

Crude oil input

The national energy balance is used to determine what proportion of crude oil comprises petrochemicals, which is an aggregate of crude oil, natural gas and petroleum products classified in the SU tables. Crude oil input requirements are obtained as a proportion of petrochemical derived from the SU tables.

5.2.3. Natural gas

According to the National Energy Balance, the amount of natural gas consumed in 2000 was 65 024.10 TJ. Energy price statistics from the DME (2002d) indicates that the average price of natural gas in 2000 was R 60.74/TJ hence the amount of natural gas consumed in South Africa is calculated as R3.95 million. This correlates with industry data obtained from the petrochemical industry in the Western Cape (Mbendi, 2002).

Natural gas output

All of the natural gas output of R 3.95 million is dedicated to the State owned Mossgas liquid fuels synthesis plants and accounts for about 1.5% of total primary energy supply. This is assigned as an output to the petroleum products sector.

Natural gas input

The national energy balance is used to determine what proportion of natural gas comprises petrochemicals which is an aggregate of crude oil, natural gas and petroleum products classified in the SU tables. Natural gas inputs are obtained as a proportion of petrochemical derived from the SU tables. This is compared against industry data, although the input sectors correlate with those used in the study, the actual industry values appear to be higher. This difference is assumed to be a result of different data collection methods as well differences in the way sectors are defined. For the sake of consistency data derived from the SU tables are used in this study.

5.2.4. Petroleum products

A set of petroleum products accounts was disaggregated from petrochemicals in the initial IO table. Crude oil and natural gas accounts have already been developed. The difference between petrochemicals in the initial IO table and crude oil and natural gas sectors is R 9305.14. This difference is calculated as petroleum products. The national energy balance indicates that 20 068 895.19 kiloliters of petroleum product was used in 2000. This translates into R 463.65 per kilolitre of petroleum product in 2000, which is consistent with the average price of R 461.66 per kilolitre of petroleum products as indicated by the DME (2002d).

5.2.5. Nuclear energy

South Africa's only nuclear energy production plant is located at Koeberg and is owned and operated by Eskom. According to Eskom (2000), the annual real price of energy produced at Koeberg during 1999-2000 inclusive of the provision for spent fuel management was R 20.16/MWh. With an annual output of 13 576 388 MWh, total annual production of nuclear energy from Koeberg equals R273.70 million.

Nuclear Energy output

All the energy generated at the nuclear energy plant at Koeberg is sold to Eskom for electricity generation. Therefore all nuclear energy output goes to the electricity sector.

Nuclear Energy input

Since Koeberg is the country's only nuclear energy plant, input data were obtained from annual reports for Eskom (Eskom, 2003). Uranium is the main source of nuclear energy. According to the Nuclear Energy Corporation of South Africa, in 2000 uranium sales amounted to R300 million, and 48% was used for local electricity production (National Nuclear Regulator, 2002). Since 48% of total uranium production is used for local electricity production, it is assumed that Koeberg consumed R144 million of uranium in 2000. Using industry reports from Eskom it is assumed that R49.70 million is spent on employment costs and R80 million spent on machinery and equipment (Eskom, 2002).

5.2.6. Electricity

Electricity in the initial IO table is aggregated as nuclear energy and electricity. A new set of electricity accounts are obtained for the energy IO table by subtracting nuclear energy from the electricity sector in the initial IO table.

5.2.7. Renewable Energy

Internationally renewable energy sources include; solar, wind, hydro, wood, bagasse and agricultural wood waste but commercially viable renewable energy technologies in South Africa are restricted to solar and hydro. The renewable energy market in South Africa is still very under developed. As a result there is insufficient data regarding local production structures and prices to provide estimates with adequate accuracy. As explained below, this study used data from a number of sources to estimate economic output from renewable energy technologies. It was estimated that in South Africa in

2000 as R142.68 million with R129.44 million from the solar industry and R13.24 million from the hydropower industry.

Solar

The overriding market driver for photovoltaic (PV) systems in South Africa is the need for electricity services in off-grid areas in the country. The direct production costs of PV systems ranges between R30-40/W and annual levels of production are estimated at 3.5 MW/annum (DME, 2002a). With an estimated production cost of R35/W, the annual total cost of producing PV systems in 2000 is estimated at R122.50 million per annum. Energy production from the installed capacity is estimated to be 21 GWh/annum (DME, 2002a). This corresponds to approximately 0.0106% of total electricity produced in South Africa. Therefore annual renewable energy turnover is estimated at R129.44 million. This correlates with the total costs of production of R122.50 million. Approximately 50% of PV systems produced in South Africa is made for export (DME, 2002a). Based on personal communication with local PV manufacturers, this study determines sectors and quantities of PV systems purchased and estimated a production structure for PV systems (Solarcon, 2003; Energy Africa, 2003). This study therefore assumes that domestic households, purchase 15% of total PV systems manufactured, 10% is purchased by the water sector and 25% is purchased by the telecommunications sector (Energy Africa, 2003). The production of PV panels requires insulated glass (27% of total production accounts for domestic production and 23% of total production was imported), metal (which accounts for 22% of total production costs), plastic (which accounts for 3% of total production costs) and employment (which accounts for 25% of total production costs) (Energy Africa, 2003).

Hydropower

With 10 MW as the cut-off for distinguishing large hydro from small hydro schemes, in 2000 there were six small scale and two large-scale dams in South Africa. Of the six small hydro schemes, Eskom owns and runs two (total capacity is 19 MW), three of the six schemes are owned and run by municipalities (total capacity of 4 MW) and one is privately owned (total capacity of 3 MW) (NER, 2000). In existing generation some small hydro facilities and co-generating bagasse plants provide the only renewable electricity to date. The total hydro capacity in South Africa in 2000 was 668 MW or 5851680 MWh (NER, 2000). Cost for a typical micro-hydro system varies depending on the project. As a guide the cost of kilowatthour of grid electricity generated from hydropower was estimated to be R146.70/kWh (ITDG, 2000). According to Eskom's 2000 annual report and the DME (2002b) approximately 5% of total electricity consumed in South Africa is generated by hydropower. This was estimated as R13.24 million per annum. This study assumed that all the hydropower output generated was sold to the electricity sector. This study has calculated that inputs used to generate hydropower are negligible.

Renewable energy output

The average basic turnover from renewable energy technologies (solar and hydro) in South Africa is estimated at R142.68.44 million. This study has estimated that the electricity sector uses R12.84 million and the water sector uses R10.50 million of total renewable energy output. R36.01 million of renewable energy output is sold to the telecommunications sector and R21.70 is sold for household consumption. R 82.19 million worth of renewable energy output goes to exports.

Renewable energy input

This study has estimated renewable energy production costs R2.6 million for chemicals, R19.25 million for iron and steel, R 21.88 million for other manufacturing, R0.40 million for electricity, R88.51 million for employment costs and R10.20 for imports.

5.2.8. Biomass

This study defines biomass as fuel wood and bagasse as identified in the national energy balance. The energy balance differentiates between biomass consumed by households in the form of fuel wood and agricultural waste consumed by industries as bagasse. The 1996 Forestry Green Paper for South Africa estimates that fuel wood in South Africa has an annual average turnover of R8139.94 million (DEAT, 1996). Bagasse is used solely for the generation of electricity and it constitutes approximately 2.5% of the total amount of electricity used by the sugar industry (NER, 2000). Total biomass produced and consumed in the economy is estimated at R8141.55 million.

Biomass output

The National Electricity Regulator (NER) (2000) indicates that cogeneration by industry from bagasse constitutes 2.5% of total electricity consumed by the sugar industry. Given that the total amount of electricity consumed by the sugar industry amounts to R64.5 million, electricity generated by bagasse amounts to R1.61 million (Mbendi, 2002). Since bagasse is only used by the sugar industry for electricity, the energy IO table indicates this as electricity used by the industry. Hence R8 139.94 million of biomass was sold as fuel wood mainly to households. DME data indicates that the price of wood fuel in 2000 was R5.59/kg and 1 456 million kg of wood is consumed for fuel (DME, 2002d).

Biomass input

The 1996 Forestry Green Paper for South Africa states that all the fuel wood consumed in the country comes from the informal agriculture and forestry sector. All the bagasse comes from waste material sugar for sugar processing. Therefore agriculture and forestry contributes R 8 139.94 million and food and textiles contributes R 1.61 million to the biomass industry.

Table 5.2: Augmented energy IO table for 2000 for South Africa
(R million)

	Agriculture	Coal	Crude Oil	Natural gas	Nuclear Energy	Renewable Energy	Biomass	Gold & other mining	Food & Textiles	Wood & paper	Petroleum products	Chemicals	Iron & metals	Machinery & Equipment
Agriculture	2290.09	12.57	4.93	0.00	0.00	0.00	8139.94	22.44	34050.80	5070.08	1.58	1100.22	52.91	624.11
Coal	1.98	0.99	2947.73	0.35	0.00	0.00	0.00	191.90	215.15	16.81	944.57	197.36	4091.17	32.06
Crude Oil	2094.17	257.61	347.86	0.00	0.00	0.00	0.00	732.44	610.13	109.77	751.03	2846.74	1444.74	701.19
Natural gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.95	0.00	0.00	0.00
Nuclear Energy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Renewable Energy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.61	0.00	0.00	0.00	0.00	0.00
Gold & other mining	147.32	20.14	7865.30	0.94	144.00	0.00	0.00	60.12	44.99	122.62	2520.36	4842.81	10471.23	478.38
Food & Textiles	6343.50	135.04	0.83	0.00	0.00	0.00	1.61	481.49	29579.55	277.75	0.27	1010.35	20.60	3404.49
Wood & Paper	522.65	57.31	50.17	0.01	0.00	0.00	0.00	1091.86	2131.65	16039.90	16.08	1079.13	325.03	580.67
Petroleum products	671.31	82.58	2000.00	0.00	0.00	0.00	0.00	234.79	195.58	35.19	1.60	912.55	463.12	224.77
Chemicals	5894.47	1185.10	1213.52	0.14	0.00	2.62	0.00	4515.28	5825.13	5275.67	388.86	31463.61	1575.86	8829.01
Iron & metals	412.57	341.12	133.72	0.02	0.00	19.25	0.00	1545.47	1171.37	242.86	42.85	1728.99	26986.30	15426.68
Machinery & Equipment	2860.92	1852.53	543.21	0.06	80.00	0.00	0.00	5599.29	1443.13	1049.77	174.07	2093.61	1295.63	43869.60
Other manufacturing	0.00	13.59	24.01	0.00	0.00	21.88	0.00	43.00	61.66	28.88	7.69	110.03	37.67	206.54
Electricity	438.11	346.70	601.96	0.07	0.00	0.40	0.00	3283.63	1140.07	241.35	192.89	2020.69	3178.31	413.34
Water	203.24	19.89	153.19	0.02	0.00	0.00	0.00	399.75	362.82	38.87	49.09	376.50	53.46	62.24
Construction & Accommodation	463.17	279.96	37.55	0.00	0.00	0.00	0.00	1087.89	375.28	71.72	12.03	291.40	170.30	172.80
Transport & Communications	3120.67	3676.58	1620.39	0.19	0.00	0.00	0.00	12049.95	1120.77	312.84	519.24	3628.06	3075.97	463.92
Financial & Community	1878.44	1520.45	944.63	0.11	0.00	0.00	0.00	6486.26	9119.08	3011.81	302.70	9358.57	4273.68	3930.21
Employment	8903.76	4607.14	1262.25	0.15	49.70	88.51	0.00	21110.13	18261.54	10138.01	404.48	16721.86	12282.15	17020.59
Taxes	-208.22	269.64	65.52	0.01	0.00	0.00	0.00	699.94	508.09	201.26	20.99	303.93	247.16	172.06
Gross Surplus	17364.19	5497.39	7473.47	0.89	0.00	0.00	0.00	22766.98	16367.67	6458.64	2394.81	12364.90	14569.25	9242.35
Imports	3365.18	383.61	1737.54	0.98	0.00	10.02	0.00	29047.50	12087.05	6314.14	552.05	29925.41	10534.90	93139.99
Total	**56767.53**	**20559.93**	**29027.77**	**3.95**	**273.70**	**142.68**	**8141.55**	**111450.10**	**134673.13**	**55057.95**	**9301.19**	**122376.73**	**95149.44**	**198995.01**

Table 5.2: Augmented energy IO table for 2000 for South Africa (continued)

(R million)

	Other Manufacturing	Electricity	Water	Buildings & Accommodation	Transport & Communication	Financial & Community	Household consumption	Government Expenditure	Investment & Savings	Exports	Total
Agriculture	254.92	11.56	0.00	561.69	2.78	332.17	17576.04	0.00	-19729.16	6387.86	**56767.53**
Coal	0.93	4305.45	138.64	11.17	13.62	104.55	238.45	0.00	-1416.68	8523.74	**20559.94**
Crude Oil	89.84	95.32	35.41	2928.35	8035.10	2649.55	16975.28	0.00	-17992.93	6316.18	**29027.77**
Natural gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**3.95**
Nuclear Energy	0.00	313.70	0.00	0.00	0.00	0.00	0.00	0.00	-40.00	0.00	**273.70**
Renewable Energy	0.00	12.84	10.50	0.00	36.01	0.00	21.70	0.00	-20.56	82.19	**142.68**
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8139.94	0.00	**8141.55**
Gold & other mining	1964.56	4.18	2.90	1317.82	106.54	203.35	0.00	0.00	1479.27	79653.27	**111450.10**
Food & Textiles	604.33	43.87	2.33	4789.67	1174.76	1938.43	186914.61	0.00	-116743.14	14692.78	**134673.12**
Wood & Paper	2183.23	66.63	66.76	9607.14	1837.58	7947.05	7069.93	0.00	-4543.21	8928.39	**55057.95**
Petroleum products	28.80	30.55	11.35	938.71	2575.73	849.34	5441.60	0.00	-7421.10	2024.71	**9301.19**
Chemicals	1329.04	107.03	320.51	13345.31	2921.04	10575.14	29023.91	0.00	-18290.13	16875.60	**122376.73**
Iron & metals	1991.63	259.48	117.96	6704.22	532.44	827.04	897.50	0.00	6356.69	29411.30	**95149.44**
Machinery & Equipment	158.21	1603.96	411.23	8624.06	12210.93	17287.00	34051.84	0.00	32573.45	31212.52	**198995.02**
Other manufacturing	261.26	5.03	200.62	1184.57	809.09	2612.30	14008.72	0.00	-8464.55	6157.32	**17329.33**
Electricity	128.57	1236.44	500.70	2114.94	1877.17	1690.32	11115.74	0.00	-375.13	837.35	**30983.62**
Water	11.06	139.43	4457.13	525.00	390.51	1067.83	2334.23	0.00	-517.21	0.00	**10127.05**
Construction & Accommodation	22.68	1704.72	28.39	26059.39	6743.17	9355.94	22121.37	0.00	192640.27	6739.17	**268377.21**
Transport & Communications	81.51	332.21	206.31	18892.24	12896.41	13389.21	42851.50	0.00	35279.62	15056.47	**168574.06**
Financial & Community	662.41	1324.70	475.82	34418.72	11807.68	79211.55	162097.58	166330.00	-39447.48	9733.16	**467440.08**
Employment	2347.69	6566.78	1056.51	65568.65	34104.24	176821.37	0.00	0.00	27642.49	0.00	**424958.00**
Taxes	56.38	283.52	-92.65	4141.85	853.87	12266.61	2544.89	0.00	66346.63	11324.00	**100005.49**
Gross Surplus	1311.67	12536.21	2168.42	61431.41	45841.31	120176.46	0.00	0.00	5127.49	0.00	**363093.51**
Imports	3840.62	0.00	8.21	5212.30	23804.08	8134.86	1367.11	0.00	0.48	0.00	**229469.99**
Total	**17329.33**	**30983.62**	**10127.05**	**268377.21**	**168574.06**	**467440.08**	**556652.00**	**166330.00**	**140589.00**	**253956.00**	**2922279.00**

5.3. Physical energy data

Appendix A indicates how sectors in the energy IO table were matched against sectors in the national energy balance to develop physical energy accounts.

5.3.1. Physical energy input output data

A physical energy IO table is developed according to physical energy accounts, which was derived from the National Energy Balance for 2000 (DME, 2000b). The 2000 National Energy Balance database for South Africa provides aggregates. Data was disaggregated according to physical units and in energy units (Appendices C1 and C2). Aggregated data are divided into the six primary energy types namely, coal, crude oil, natural gas, nuclear energy, renewable energy and biomass and two final demand energy types namely electricity and petroleum products as indicated by the energy IO table. The national energy balance is further disaggregated into different types of each primary and secondary fuel type. This study uses both disaggregated and aggregated energy data to determine energy consumed in the economy and related energy emissions.

Energy supply is determined from indigenous production, imports less exports, international marine bunkers and stock changes. This is balanced against domestic energy supplied to all the sectors within the economy, which is divided into four sectors namely energy transformation, industry, transport and other sectors. The energy transformation sector comprises of electricity production, crude oil production, natural gas production and coal transformation. Electricity production is defined according to public electricity, auto-producer electricity, public heat and power, auto producer heat and power, public heat, auto producer heat, heat pumps and electric boilers. Oil refineries describe oil production and gas works define natural gas production. Coal transformation is defined by coal transformation and liquefaction. Almost all coal consumed in the economy is transformed into either electricity (90% of all electricity is produced from coal) or petroleum products (70% of all petroleum products are produced from coal).

The industry sector in the national energy balance comprises of iron and steel, chemical and petrochemical, non-ferrous metals, non-metallic minerals, transport equipment, machinery, mining and quarrying, food and tobacco, paper, pulp and print, wood and wood products, construction, textiles and leather, other industry. The transport sector comprises of international civil aviation, domestic air transport, road, rail, pipeline transport, international navigation and other unspecified transport. Other sectors comprise agriculture, commerce and public services, residential and unspecified sectors. Table 5.3 presents physical energy IO data used to develop the energy emissions IO model.

Table 5.3: Physical energy IO table for 2000 for South Africa

	Energy (Terrajoules)									
	Primary Energy							Secondary Energy		
	Coal	Crude Oil	Natural Gas	Nuclear Energy	Renewable Energy	Biomass	Total	Petroleum Products	Electricity	Total
Agriculture	1864.43	0.00	0.00	0.00	0.00	0.00	**1864.43**	48008.95	14235.74	**62244.69**
Coal	5979.20	0.00	963.57	0.00	0.00	0.00	**6942.77**	3486.40	17281.79	**20768.19**
Crude Oil	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**
Natural gas	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**
Nuclear Energy	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**
Renewable Energy	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**
Gold & other mining	31625.83	0.00	5096.64	0.00	0.00	0.00	**36722.48**	18440.65	91408.69	**109849.34**
Food & Textiles	0.00	0.00	1269.19	0.00	0.00	0.00	**1269.19**	0.00	3655.55	**3655.55**
Wood & paper	0.00	0.00	3035.68	0.00	0.00	0.00	**3035.68**	0.00	6861.60	**6861.60**
Petroleum	1021185.92	773930.82	25193.99	0.00	0.00	0.00	**1820310.72**	-1084625.84	49582.79	**-1035043.06**
Chemicals	31855.03	0.00	12349.18	0.00	0.00	0.00	**44204.21**	0.00	9505.58	**9505.58**
Iron & Metal	178886.20	0.00	12403.24	0.00	0.00	0.00	**191289.44**	0.00	129423.82	**129423.82**
Machinery & Equipment	0.00	0.00	1157.32	0.00	0.00	0.00	**1157.32**	0.00	440.71	**440.71**
Other Manufacturing	90511.81	0.00	2443.05	0.00	0.00	0.00	**92954.86**	12213.54	75172.91	**87386.46**
Electricity	2002336.61	0.00	0.00	141927.27	4834.80	47000.00	**2196098.68**	0.00	-687692.19	**-687692.19**
Water	30170.60	0.00	814.35	0.00	0.00	0.00	**30984.95**	4071.18	25057.64	**29128.82**
Buildings & Accommodation	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	10548.86	122.44	**10671.29**
Transport & Communication	0.00	0.00	28.91	0.00	0.00	0.00	**28.91**	584476.41	19479.63	**603956.04**
Financial & Community	20802.23	0.00	268.98	0.00	0.00	0.00	**21071.21**	2628.76	81185.40	**83814.16**
Household consumption	41604.46	0.00	0.00	0.00	0.00	190400.00	**232004.46**	25214.12	103248.00	**128462.13**
Non-energy use	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	22351.89	0.00	**22351.89**
Statistical diff	-31097.46	0.00	0.00	0.00	0.00	0.00	**-31097.46**	0.00	63593.12	**63593.12**
Total	**3425724.88**	**773930.82**	**65024.10**	**141927.27**	**4834.80**	**237400.00**	**4648841.87**	**-353185.07**	**2563.20**	**-350621.87**

5.4. Physical energy emissions data

An energy emissions IO table is developed using physical energy IO data from the previous section and energy emission co-efficients to determine total energy emissions per energy sector. This study uses a similar approach for estimating energy emissions as that adopted by the National GHG Inventory for South Africa (DEAT, 2002a). Energy carbon dioxide, methane and nitrous oxide emissions are estimated according to local emission factors supported by IPCC default factors (IPCC, 1996). Energy emissions are converted into carbon dioxide equivalents to obtain total carbon dioxide equivalents for carbon dioxide, methane and nitrous oxide emissions.

The 1996 IPCC Guidelines classify emissions according to energy, industrial processes, agriculture, land-use change, forestry and waste. The Revised 1996 IPCC Guidelines for National GHG Inventories allows countries to use either the reference or the sectoral approach when reporting emission data. The reference approach calculates emissions based on the supply of energy to a country’s economy. In contrast the sectoral approach was based on the combustion of energy in the economy. The major difference between methodologies employed by each approach lies in the energy data and the emission factors used. In theory both approaches should produce identical results but in practice this is seldom the case.

The reference approach captures refining, flaring and other fugitive emissions that do not result directly from end-use fossil fuel combustion. Apparent consumption of fuels is calculated from indigenous production minus exports plus imports. Net stock changes are either added or subtracted. International marine and aviation bunkers (fuels for international transport) are subtracted from total supply. These figures are accounted for separately. The production of secondary fuels is excluded because carbon contained in these fuels is already included in primary fuels but carbon dioxide content of exported secondary fuels is included in the inventory. Stored carbon from non-energy purposes is subtracted from total carbon emissions. Emissions from biomass are not included in this approach because the IPCC assumes that such emissions are equal to zero as a result of carbon sequestration during re-growth.

The sectoral approach requires that each industry in the economy report on emissions within that industry. The sectoral approach is based on actual surveyed consumption. For many countries, country specific data currently does not exist, as it is still being collated and complied. In order to assist with the lack of reliable emission data, the 1996 IPCC guidelines provide default emission factors. Where there is no local data available these sector specific emission factors are used to compile inventories.

Although both approaches are relatively simple, calculations can be time consuming and tedious. Errors may occur because of the many unit conversions that are required and the difficulty in obtaining data sets from different sources. Appropriate co-efficients for each fuel type are applied to total fuel consumption in order to get the total volume of emissions. The 1996 IPCC Guidelines together with data from the IEA are based on well-established internationally accepted accounting methodologies and undergo constant review and adjustments. In most instances repeated attempts using the reference approach produce the same results since this based on energy supply. However because this approach is based on energy supply it does produce slight over-estimates in comparison to the sectoral approach. For some countries especially developing countries, statistical differences in basic data or unexplained different approaches can lead to significant discrepancies between both approaches.

In order to ensure comparability between national inventories the IPCC (1996) recommends that countries report energy data using the IEA reporting convention. National energy statistics are collected and collated as the national energy balance. This database documents energy supply data on production, imports, exports and stock exchanges and energy consumption data according to each sector. Emissions are then calculated on the energy content of each energy type in the energy balance. Detailed fuel production statistics are typically provided in physical units. In order to develop GHG emission inventories energy in units of physical volume must be converted into energy content units using energy conversion factors.

South Africa's GHG inventory (2000) uses both the reference and the sectoral approaches to develop inventories for 1990 and 1994 (DEAT, 2000a). Few industries in South Africa report on actual GHG emissions. The South African GHG inventory has used local data where possible and IPCC default emission factors where it was not possible to obtain reliable local data. South Africa's GHG inventory includes data for carbon dioxide, methane and nitrous oxide emissions for 1990 and 1994 (DEAT, 2000a; IPCC, 1996). Total emissions in the inventory are calculated as carbon dioxide equivalents.

Although the National GHG Inventory is the official emissions database for South Africa, this study chose to calculate energy emissions using energy emission co-efficients. Three main reasons for this are; the inventory reporting format differs from the energy IO table, the way in which sectors are defined in the energy IO table and the inventory are not consistent and the inventory has not been update for 2000. Estimates obtained in this study were however compared against extrapolated inventory data. Energy emissions are calculated by multiplying energy activity in the national energy balance by emission factor as listed in Appendix C1. Total carbon dioxide equivalent energy emissions are determined according to a global warming factor of 21 for methane and 310 for nitrous oxide.

5.4.1. Carbon dioxide emissions

Carbon dioxide emissions for coal are obtained from a local study. Blignaut and King (2002) estimate the total volume of carbon dioxide emissions (tonnes CO_2) from the volume of coal consumed (tonnes) per coal consuming sector for South Africa in 2000. The total amount of coal consumed in Blignaut and King (2002) correlates closely with domestic consumption as indicated by the national energy balance. Energy co-efficients (TJ/t) are obtained for each sector by diving energy consumption per sector in energy units (TJ) by corresponding energy consumption per volume in each sector in (tonnes) as presented in the national energy balance. Thereafter carbon dioxide co-efficients are obtained for carbon dioxide emissions/energy consumption (tonnes CO_2/TJ) for coal as indicated in Appendices C2 and C3. Appendix C4 presents total energy carbon dioxide emissions.

5.4.2. Methane emissions

Methane emissions are estimated using conversion factors from the IPCC Guidelines are presented in Appendices C5 and C6 (IPCC, 1996). Appendix C7 indicates total methane emissions and Appendix C8 presents methane emissions as carbon dioxide equivalents.

5.4.3. Nitrous oxide emissions

All nitrous oxide emission co-efficients listed in Appendix C8 are IPCC default emissions. Appendix C9 indicates total nitrous emissions and Appendix C11 presents carbon dioxide equivalents.

5.4.4. Total energy emissions

Carbon dioxide equivalents for carbon dioxide, methane and nitrous oxide emissions are added to produce total energy emissions in Table 5.4. As a result of the many conversions that are necessary for estimating emissions, the margin of error is high. Consistency tables are used as checks for the conversions. Table E1 is used to determine co-efficients for converting energy in volume to energy in energy units. These conversion factors correspond to the energy conversion factors obtained by the DME and used in this study (DME, 2002b). Tables E2 and E3 are used to determine energy emissions per volume of energy consumed and energy units respectively. Both tables indicate the emission factors that were used to calculate energy emissions per unit of energy consumed. The emission factors are consistent with the factors that were used to determine overall emissions per sector.

Table 5.5 compares the results obtained in this study with results published in local and international literature. Coal consumption data used in this study is not substantially different from figures used in Blignaut and King (2002). This study uses energy balance data while the Blignaut and King (2002) study compiled data from industry reports. Energy emission co-efficients from coal combustion quoted in both studies are the same and are largely dependent on the amount of coal consumed.

Energy emissions published by DEAT (2000) for 1990 and 1994 indicate that even though energy consumption has increased proportional to GDP, the ratio of carbon dioxide equivalent has decreased. There are two possible reasons for this, one is that data collection may have improved during the period 1990 to 2000 and another is that the economy could have produced less carbon dioxide equivalent per unit of GDP.

Energy emissions for South Africa that have been published by the Department of Energy (DOE) (2002) and Energy Information Administration (EIA) (2002) in the United States have small discrepancies with the results obtained in this study. These international estimates indicate that South Africa consumed less coal and more crude oil than the statistics published by the DME (2002d). The amount of natural gas consumed in the economy is relatively similar. Also both data sets indicate that the overall amount of energy consumed in the economy is less than the total amount of consumed energy published by the DME (2002b) hence the total amount of energy emissions are less than that estimated by the study.

Table 5-4: Physical energy emissions IO table for 2000 for South Africa

	Energy emissions (CO_2 eq)									
	Primary Energy							Secondary Energy		
	Coal	Crude Oil	Natural Gas	Nuclear Energy	Renewable Energy	Biomass	Total	Petroleum Products	Electricity	Total
Agriculture	143283.57	0.00	0.00	0.00	0.00	0.00	**143283.57**	4196035.45	3396023.85	**7592059.30**
Coal	511466.69	0.00	54192.49	0.00	0.00	0.00	**565659.18**	304715.38	4122677.00	**4427392.38**
Crude Oil	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**
Natural gas	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**
Nuclear Energy	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**
Renewable Energy	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	**0.00**
Gold & other mining	2705304.97	0.00	286640.78	0.00	0.00	0.00	**2991945.75**	1611733.53	21806109.17	**23417842.70**
Food & Textiles	0.00	0.00	71380.42	0.00	0.00	0.00	**71380.42**	0.00	872053.64	**872053.64**
Wood & paper	0.00	0.00	170729.81	0.00	0.00	0.00	**170729.81**	0.00	1636877.22	**1636877.22**
Petroleum	64718290.54	56952794.83	1414821.36	0.00	0.00	0.00	**123085906.73**	-94797491.87	11828280.92	**-82969210.95**
Chemicals	2424754.50	0.00	694531.58	0.00	0.00	0.00	**3119286.08**	0.00	2267616.00	**2267616.00**
Iron & Metal	11017138.18	0.00	697571.92	0.00	0.00	0.00	**11714710.09**	0.00	30874853.73	**30874853.73**
Machinery & Equipment	0.00	0.00	65089.01	0.00	0.00	0.00	**65089.01**	0.00	105134.58	**105134.58**
Other Manufacturing	6803505.52	0.00	137399.82	0.00	0.00	0.00	**6940905.34**	1067477.24	17932964.06	**19000441.30**
Electricity	174569678.06	0.00	0.00	0.00	0.00	87890.00	**174657568.06**	0.00	-164053236.19	**-164053236.19**
Water	2267835.17	0.00	45799.94	0.00	0.00	0.00	**2313635.11**	355825.75	5977654.69	**6333480.43**
Buildings & Accommodation	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	921981.83	29207.87	**951189.70**
Transport & Communication	0.00	0.00	1622.78	0.00	0.00	0.00	**1622.78**	51083880.73	4646987.08	**55730867.81**
Financial & Community	1610284.63	0.00	15127.73	0.00	0.00	0.00	**1625412.36**	229756.69	19367279.66	**19597036.35**
Household consumption	3220569.26	0.00	0.00	0.00	0.00	1435616.00	**4656185.26**	2203741.96	24630451.40	**26834193.35**
Non-energy use	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	1953579.89	0.00	**1953579.89**
Statistical diff	-2281665.61	0.00	0.00	0.00	0.00	0.00	**-2281665.61**	0.02	15170532.58	**15170532.60**
Total	**267710445.48**	**56952794.83**	**3654907.64**	**0.00**	**0.00**	**1523506.00**	**329841653.94**	**-30868763.40**	**611467.25**	**-30257296.15**

Table 5.5: Estimated energy emissions compared against other studies

	Energy consumed				**Tonnes of Emissions**				**GDP**	**CO_2 eq/GDP**	**Emissions/Energy consumed**	
	Native units of volume		Energy units		CO_2	CH_4	N_20	CO_2 Equivalent	R million	CO_2 eq/R million	CO_2 eq/native unit energy	
E-E IO Table for 2000												
Coal	161168950.92	tonnes	3425724.88	TJ	253400682.53	3812012.41	4796.01	334939707.75		377.16	2.08	tCO2/ton coal
Crude Oil	18412585.73	tonnes	773930.82	TJ	56760086.06	2321.79	464.36	56952794.83		64.13	3.09	tCO2/ton oil
Natural Gas	65024.10	TJ	65024.10	TJ	3648183.69	224.20	6.50	3654907.64		4.12	56.21	tCO2/TJ
Nuclear Energy	0.00	MWh	141927.27	TJ	0.00	0.00	0.00	0.00		0.00	0.00	tCO2/MWh
Renewable Energy	0.00	MWh	4834.80	TJ	0.00	0.00	0.00	0.00		0.00	0.00	tCO2/MWh
Biomass	237400.00	TJ	237400.00	TJ	0.00	58530.00	949.60	1523506.00		1.72	6.42	tCO2/TJ
Total	4648841.87	TJ	4648841.87	TJ	313808952.28	3873088.40	6216.48	397070916.22	888057.00	447.12	85.41	tCO2/TJ
Petroleum products	20602074.02	kl	-353185.07	TJ	-25902592.85	-27936.94	-14127.40	-30868763.40		-34.76	-1.50	tCO2/kl
Electricity	211382000.00	MWh	2563.20	TJ	605197.15	185.06	7.69	611467.25		0.69	0.00	tCO2/MWh
Total	-350621.87	TJ	-350621.87	TJ	-25297395.69	-27751.88	-14119.71	-30257296.15		-34.07	86.30	tCO2/TJ
Blignaut and King, 2002												
2000												
Coal	160633726.00	tonnes			252344938.00	3820585.00		332577223.00	888057.00	374.50		
	160633726.00	tonnes			252344938.00	3820585.00	4471.31	334063987.60		376.17	2.08	tCO2/ton coal
DEAT, 2000a (Greenhouse gas inventory sectoral approach)												
1990 Total energy					252019000.00	3469600.00	5100.00	260886000.00	273148.00	955.11		
1994 Total energy					287851000.00	3757000.00	5880.00	297564000.00	471023.00	631.74		
DOE USA, 2002 (reference approach)												
2000												
Coal	157228450.00	tonnes						308908080.00	888057.00	347.85	1.96	tCO2/ton coal
Crude Oil	20735120.00	tonnes						65565960.00		73.83	3.16	tCO2/ton oil
Natural Gas	62842.13	TJ						9600000.00		10.81	152.76	tCO2/TJ
2000	4322500.00	TJ						378031030.00	888057.00	425.68	87.46	tCO2/TJ
1994	3857000.00	TJ						343817920.00	471023.00	729.94	89.14	tCO2/TJ
1990	3192000.00	TJ						296586960.00	273148.00	1085.81	92.92	tCO2/TJ
Energy Information Administration, 2004												
2000												
Total	4408000.00	TJ						385695060.00	888057.00	434.31	87.50	tCO2/TJ

Table 5.6: Energy emissions input-output model for 2000 for South Africa Augmented Energy IO model (R million)

	Agriculture	Coal	Crude Oil	Natural gas	Nuclear Energy	Renewable Energy	Biomass	Gold & other mining	Food & Textiles	Wood & paper	Petroleum products	Chemicals	Iron & metals	Machinery & Equipment
Agriculture	2290.09	12.57	4.93	0.00	0.00	0.00	8139.94	22.44	34050.80	5070.08	1.58	1100.22	52.91	624.11
Coal	1.98	0.99	2947.73	0.35	0.00	0.00	0.00	191.90	215.15	16.81	944.57	197.36	4091.17	32.06
Crude Oil	2094.17	257.61	347.86	0.00	0.00	0.00	0.00	732.44	610.13	109.77	751.03	2846.74	1444.74	701.19
Natural gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.95	0.00	0.00	0.00
Nuclear Energy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Renewable Energy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.61	0.00	0.00	0.00	0.00	0.00
Gold & other mining	147.32	20.14	7865.30	0.94	144.00	0.00	0.00	60.12	44.99	122.62	2520.36	4842.81	10471.23	478.38
Food & Textiles	6343.50	135.04	0.83	0.00	0.00	0.00	1.61	481.49	29579.55	277.75	0.27	1010.35	20.60	3404.49
Wood & Paper	522.65	57.31	50.17	0.01	0.00	0.00	0.00	1091.86	2131.65	16039.90	16.08	1079.13	325.03	580.67
Petroleum products	671.31	82.58	2000.00	0.00	0.00	0.00	0.00	234.79	195.58	35.19	1.60	912.55	463.12	224.77
Chemicals	5894.47	1185.10	1213.52	0.14	0.00	2.62	0.00	4515.28	5825.13	5275.67	388.86	31463.61	1575.86	8829.01
Iron & metals	412.57	341.12	133.72	0.02	0.00	19.25	0.00	1545.47	1171.37	242.86	42.85	1728.99	26986.30	15426.68
Machinery & Equipment	2860.92	1852.53	543.21	0.06	80.00	0.00	0.00	5599.29	1443.13	1049.77	174.07	2093.61	1295.63	43869.60
Other manufacturing	0.00	13.59	24.01	0.00	0.00	21.88	0.00	43.00	61.66	28.88	7.69	110.03	37.67	206.54
Electricity	438.11	346.70	601.96	0.07	0.00	0.40	0.00	3283.63	1140.07	241.35	192.89	2020.69	3178.31	413.34
Water	203.24	19.89	153.19	0.02	0.00	0.00	0.00	399.75	362.82	38.87	49.09	376.50	53.46	62.24
Construction & Accommodation	463.17	279.96	37.55	0.00	0.00	0.00	0.00	1087.89	375.28	71.72	12.03	291.40	170.30	172.80
Transport & Communications	3120.67	3676.58	1620.39	0.19	0.00	0.00	0.00	12049.95	1120.77	312.84	519.24	3628.06	3075.97	463.92
Financial & Community	1878.44	1520.45	944.63	0.11	0.00	0.00	0.00	6486.26	9119.08	3011.81	302.70	9358.57	4273.68	3930.21
Employment	8903.76	4607.14	1262.25	0.15	49.70	88.51	0.00	21110.13	18261.54	10138.01	404.48	16721.86	12282.15	17020.59
Taxes	-208.22	269.64	65.52	0.01	0.00	0.00	0.00	699.94	508.09	201.26	20.99	303.93	247.16	172.06
Gross Surplus	17364.19	5497.39	7473.47	0.89	0.00	0.00	0.00	22766.98	16367.67	6458.64	2394.81	12364.90	14569.25	9242.35
Imports	3365.18	383.61	1737.54	0.98	0.00	10.02	0.00	29047.50	12087.05	6314.14	552.05	29925.41	10534.90	93139.99
Total	**56767.53**	**20559.93**	**29027.77**	**3.95**	**273.70**	**142.68**	**8141.55**	**111450.10**	**134673.13**	**55057.95**	**9301.19**	**122376.73**	**95149.44**	**198995.01**

Energy IO model (Terrajoules)

	Agriculture	**Coal**	**Crude Oil**	**Natural gas**	**Nuclear Energy**	**Renewable Energy**	**Biomass**	**Gold & other mining**	**Food & Textiles**	**Wood & paper**	**Petroleum products**	**Chemicals**	**Iron & metals**	**Machinery & Equipment**
Coal	1864.43	5979.20	0.00	0.00	0.00	0.00	0.00	31625.83	0.00	0.00	1021185.92	31855.03	178886.20	0.00
Crude Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	773930.82	0.00	0.00	0.00
Natural Gas	0.00	963.57	0.00	0.00	0.00	0.00	0.00	5096.64	1269.19	3035.68	25193.99	12349.18	12403.24	1157.32
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Renewable Energy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Primary	1864.43	6942.77	0.00	0.00	0.00	0.00	0.00	36722.48	1269.19	3035.68	1820310.72	44204.21	191289.44	1157.32
Petroleum Products	48008.95	3486.40	0.00	0.00	0.00	0.00	0.00	18440.65	0.00	0.00	1084625.84	0.00	0.00	0.00
Electricity	14235.74	17281.79	0.00	0.00	0.00	0.00	0.00	91408.69	3655.55	6861.60	49582.79	9505.58	129423.82	440.71
Total Secondary	62244.69	20768.19	0.00	0.00	0.00	0.00	0.00	109849.34	3655.55	6861.60	1134208.63	9505.58	129423.82	440.71

Emissions IO model (tons of CO_2 equivalent)

	Agriculture	**Coal**	**Crude Oil**	**Natural gas**	**Nuclear Energy**	**Renewable Energy**	**Biomass**	**Gold & other mining**	**Food & Textiles**	**Wood & paper**	**Petroleum products**	**Chemicals**	**Iron & metals**	**Machinery & Equipment**
Coal	143.28	511.47	0.00	0.00	0.00	0.00	0.00	2705.30	0.00	0.00	64718.29	2424.75	11017.14	0.00
Crude Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56952.79	0.00	0.00	0.00
Natural Gas	0.00	54.19	0.00	0.00	0.00	0.00	0.00	286.64	71.38	170.73	1414.82	694.53	697.57	65.09
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Renewable Energy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Primary	**143.28**	**565.66**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**2991.95**	**71.38**	**170.73**	**123085.91**	**3119.29**	**11714.71**	**65.09**
Petroleum Products	4196.04	304.72	0.00	0.00	0.00	0.00	0.00	1611.73	0.00	0.00	-92843.91	0.00	0.00	0.00
Electricity	3396.02	4122.68	0.00	0.00	0.00	0.00	0.00	21806.11	872.05	1636.88	11828.28	2267.62	30874.85	105.13
Total Secondary	**7592.06**	**4427.39**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**23417.84**	**872.05**	**1636.88**	**-81015.63**	**2267.62**	**30874.85**	**105.13**

Table 5.6: Energy emissions input-output model for 2000 for South Africa (continued)

Augmented Energy IO model (R million)

	Other Manufacturing	Electricity	Water	Buildings & Accommodation	Transport & Communication	Financial & Community	Household consumption	Government Expenditure	Investment & Savings	Exports	Total
Agriculture	254.92	11.56	0.00	561.69	2.78	332.17	17576.04	0.00	-19729.16	6387.86	**56767.53**
Coal	0.93	4305.45	138.64	11.17	13.62	104.55	238.45	0.00	-1416.68	8523.74	**20559.94**
Crude Oil	89.84	95.32	35.41	2928.35	8035.10	2649.55	16975.28	0.00	-17992.93	6316.18	**29027.77**
Natural gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**3.95**
Nuclear Energy	0.00	313.70	0.00	0.00	0.00	0.00	0.00	0.00	-40.00	0.00	**273.70**
Renewable Energy	0.00	12.84	10.50	0.00	36.01	0.00	21.70	0.00	-20.56	82.19	**142.68**
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8139.94	0.00	**8141.55**
Gold & other mining	1964.56	4.18	2.90	1317.82	106.54	203.35	0.00	0.00	1479.27	79653.27	**111450.10**
Food & Textiles	604.33	43.87	2.33	4789.67	1174.76	1938.43	186914.61	0.00	-116743.14	14692.78	**134673.12**
Wood & Paper	2183.23	66.63	66.76	9607.14	1837.58	7947.05	7069.93	0.00	-4543.21	8928.39	**55057.95**
Petroleum products	28.80	30.55	11.35	938.71	2575.73	849.34	5441.60	0.00	-7421.10	2024.71	**9301.19**
Chemicals	1329.04	107.03	320.51	13345.31	2921.04	10575.14	29023.91	0.00	-18290.13	16875.60	**122376.73**
Iron & metals	1991.63	259.48	117.96	6704.22	532.44	827.04	897.50	0.00	6356.69	29411.30	**95149.44**
Machinery & Equipment	158.21	1603.96	411.23	8624.06	12210.93	17287.00	34051.84	0.00	32573.45	31212.52	**198995.02**
Other manufacturing	261.26	5.03	200.62	1184.57	809.09	2612.30	14008.72	0.00	-8464.55	6157.32	**17329.33**
Electricity	128.57	1236.44	500.70	2114.94	1877.17	1690.32	11115.74	0.00	-375.13	837.35	**30983.62**
Water	11.06	139.43	4457.13	525.00	390.51	1067.83	2334.23	0.00	-517.21	0.00	**10127.05**
Construction & Accommodation	22.68	1704.72	28.39	26059.39	6743.17	9355.94	22121.37	0.00	192640.27	6739.17	**268377.21**
Transport & Communications	81.51	332.21	206.31	18892.24	12896.41	13389.21	42851.50	0.00	35279.62	15056.47	**168574.06**
Financial & Community	662.41	1324.70	475.82	34418.72	11807.68	79211.55	162097.58	166330.00	-39447.48	9733.16	**467440.08**
Employment	2347.69	6566.78	1056.51	65568.65	34104.24	176821.37	0.00	0.00	27642.49	0.00	**424958.00**
Taxes	56.38	283.52	-92.65	4141.85	853.87	12266.61	2544.89	0.00	66346.63	11324.00	**100005.49**
Gross Surplus	1311.67	12536.21	2168.42	61431.41	45841.31	120176.46	0.00	0.00	5127.49	0.00	**363093.51**
Imports	3840.62	0.00	8.21	5212.30	23804.08	8134.86	1367.11	0.00	0.48	0.00	**229469.99**
Total	**17329.33**	**30983.62**	**10127.05**	**268377.21**	**168574.06**	**467440.08**	**556652.00**	**166330.00**	**140589.00**	**253956.00**	**2922279.00**

Energy IO model (TJ)

	Other Manufacturing	Electricity	Water	Buildings & Accommodation	Transport & Communication	Financial & Community	Household consumption	Government Expenditure	Investment & Savings	Exports	Total
Coal	90511.81	2002336.61	30170.60	0.00	0.00	20802.23	41604.46	0.00	0.00	0.00	3456822.34
Crude Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	773930.82
Natural Gas	2443.05	0.00	814.35	0.00	28.91	268.98	0.00	0.00	0.00	0.00	65024.10
Nuclear	0.00	141927.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	141927.27
Renewable Energy	0.00	4834.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4834.80
Biomass	0.00	47000.00	0.00	0.00	0.00	0.00	190400.00	0.00	0.00	0.00	237400.00
Total Primary	**92954.86**	**2196098.68**	**30984.95**	**0.00**	**28.91**	**21071.21**	**232004.46**	**0.00**	**0.00**	**0.00**	**4679939.33**
Petroleum Products	12213.54	0.00	4071.18	10548.86	584476.41	2628.76	25214.12	0.00	0.00	0.00	1793714.73
Electricity	75172.91	687692.19	25057.64	122.44	19479.63	81185.40	103248.00	0.00	0.00	0.00	1314354.47
Total Secondary	**87386.46**	**687692.19**	**29128.82**	**10671.29**	**603956.04**	**83814.16**	**128462.13**	**0.00**	**0.00**	**0.00**	**3108069.20**

Emissions IO model (tons of CO_2 equivalent)

	Other Manufacturing	Electricity	Water	Buildings & Accommodation	Transport & Communication	Financial & Community	Household consumption	Government Expenditure	Investment & Savings	Exports	Total
Coal	6803.51	172288.01	2267.84	0.00	0.00	1610.28	3220.57	0.00	0.00	0.00	267710.45
Crude Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56952.79
Natural Gas	137.40	0.00	45.80	0.00	1.62	15.13	0.00	0.00	0.00	0.00	3654.91
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Renewable Energy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	0.00	87.89	0.00	0.00	0.00	0.00	1435.62	0.00	0.00	0.00	1523.51
Total Primary	**6940.91**	**172375.90**	**2313.64**	**0.00**	**1.62**	**1625.41**	**4656.19**	**0.00**	**0.00**	**0.00**	**329841.65**
Petroleum Products	1067.48	0.00	355.83	921.98	51083.88	229.76	2203.74	0.00	0.00	0.00	-30868.76
Electricity	17932.96	-148882.70	5977.65	29.21	4646.99	19367.28	24630.45	0.00	0.00	0.00	611.47
Total Secondary	**19000.44**	**-148882.70**	**6333.48**	**951.19**	**55730.87**	**19597.04**	**26834.19**	**0.00**	**0.00**	**0.00**	**-30257.30**

5.5. Energy emissions IO model

The energy emissions model as presented in Table 5.6 comprises of an energy IO model in million Rands, a physical energy IO model in terrajoules and a physical energy emissions IO model in tons of carbon dioxide equivalent. The structure of the model is explained according to inter-industry and macro economic interactions.

5.5.1. Economic structure of the energy emissions IO model

As in the set of national accounts for 2000, final demand and value added contributes 38.24 % to total output. Final demand is made up of household consumption, government expenditure, investment and savings and exports while value added comprises employment, taxes less subsidies, gross operating surplus and imports.

Sectors with the largest final demand are financial and community services, construction and accommodation and machinery and equipment while nuclear energy, natural gas and biomass have the smallest final demand. Sectors with the largest value added are financial and community services, construction and accommodation and machinery and equipment. Nuclear energy, biomass and natural gas have the smallest value added.

According to Appendix E3 the amount of energy used per unit of labour is highest for petroleum products, crude oil and natural gas industries and lowest in the nuclear and renewable energy and biomass industries. More energy is consumed per labour output in the petroleum products, crude oil, and natural gas sectors than in the nuclear energy, renewable energy and biomass sectors.

Nuclear energy, natural gas and petroleum products employ less labour to produce value added whereas renewable energy, financial and community services and construction and accommodation are the most labour intensive when compared against value added.

Petroleum products has the highest energy to value added followed by crude oil and electricity while nuclear energy and biomass has the lowest energy to value added ratio. This indicates that petroleum products, electricity and crude oil contribute more to value added than nuclear energy and biomass.

Economic multipliers

Biomass, renewable energy, and nuclear energy has the largest simple and total output multipliers while machinery and equipment, natural gas and gold and other mining had the lowest simple and total output multipliers as indicated in Appendix E4.

Since the wage rate equals one, labour income and employment multipliers are the same. Biomass, renewable energy, and nuclear energy have the largest simple labour income and employment multipliers. Sectors with the lowest multipliers are machinery and equipment, natural gas and gold and other mining. This indicates that with every one unit increase, biomass, renewable energy and nuclear energy sectors have the largest increase in output, income and employment while machinery and equipment, natural gas and gold and other mining sectors have the lowest simple and total multipliers.

Backward and Forward Linkages

Backward and forward linkages are used to explain the relationship that each sector has with the rest of the sectors in the economy. Appendix E5 indicates that biomass has the strongest direct backward linkage followed by nuclear energy and water. Sectors with the weakest direct backward linkages are renewable energy financial and community services and electricity. Biomass also has the strongest direct plus indirect backward linkage followed by agriculture and food and textiles. Sectors with the weakest direct plus indirect backward linkages are natural gas, nuclear energy, renewable energy and food and textiles.

The gold and other mining, agriculture, financial and community sectors has the strongest direct forward linkages while biomass, natural gas and renewable energy have the weakest forward linkages. Sectors with the strongest direct plus indirect forward linkages are chemicals, machinery and equipment and financial and community services. Sectors with the weakest direct plus indirect forward linkages are natural gas, renewable energy and biomass.

5.5.2. Energy structure of the energy emissions IO model

In comparison to other sectors in the economy the energy sector’s contribution to total economic output is relatively small as indicated by Appendices F1 and F2. The primary energy sector accounted for 1.78% of total economic output and the secondary energy sector accounted for 1.74% % of total economic output. This is in comparison to 16.00%, which is the financial and community services sector contribution to total economic output. Household consumption has the highest demand for energy in the economy. Transport and communications and the iron and metals sectors follow this. According to inputs into the energy sector, labour accounts for the highest inputs, followed by the gold and mining sector and the coal sector.

Energy linkages

Backward and forward linkages for natural gas, nuclear energy, renewable energy and biomass equal zero indicating that there was not much movement between these energy sectors and the rest of the economy. Coal and crude oil have relatively moderate backward and forward linkages with the rest of the economy indicating that these energy sectors have a moderate impact and are moderately impacted on by other industries in the economy. Electricity and petroleum products have the largest backward linkage among all the sectors; the forward linkage in these sectors is relatively smaller. This indicates that although these two sectors impact heavily on other industries in the economy, they are not as heavily dependent on other industries.

5.5.3. Energy emissions structure of the energy emissions IO model

Coal emissions account for 84.36% of total primary energy emissions. Crude oil emissions makes up 14.34% of the total percentage of primary energy emissions and natural gas emissions are responsible for the remaining 0.92% of the total primary energy emissions. Petroleum products are responsible for 36.62% of total secondary energy emissions and electricity makes up the remaining 63.38% of secondary energy emissions. Table 5.6 indicates that 0.001% (30257.30 tonnes) of total primary energy emissions is not accounted for as secondary energy emissions. This is explained as statistical energy loss in the national energy balance. The energy emissions structure corresponds with energy consumption in South Africa where coal is responsible for 77% and oil accounts for 13% of total primary energy consumed in the economy

The electricity industry is responsible for the largest percentage of total primary energy emissions followed by the petroleum products industry and the iron and metals industry. Crude oil, natural gas, nuclear and renewable energy, buildings and accommodation and transport and communication are responsible for zero percent of total energy emissions. The electricity industry is also responsible for the largest percentage of total secondary energy followed by the petroleum products industry. The transport and communications, iron and metals and household consumption sectors have the highest demand for secondary energy. Crude oil, natural gas, nuclear, renewable energy, machinery and equipment, food, textiles, buildings and accommodation have a relatively low demand for secondary energy.

As indicated by Table 5.6 coal emissions largely account for primary energy emissions, followed by natural gas. The electricity sector contributes the most to coal emissions followed by petroleum products. Petroleum products are also responsible for generating almost all crude oil and natural gas emissions. Secondary energy emissions in all sectors are mainly the result of electricity use. Transport and communication accounts for the most amounts of petroleum products emissions while iron metals account for the highest electricity emissions. Buildings and construction and transport are the only two sectors in the economy where secondary energy emissions from the petroleum products sector are greater than secondary energy emissions from electricity.

Pollution multipliers

Pollution-pollution multipliers are calculated by dividing energy emissions in each economic sector by the total energy emissions in each energy sector. According to Appendix E6 direct pollution-pollution multipliers indicate that coal had the largest primary energy emission pollution-pollution multipliers in the economy and electricity and agriculture have the largest direct coal pollution-pollution multiplier followed by the financial and community services, water, other manufacturing gold and other mining and coal sectors. Crude oil, natural gas, nuclear energy, renewable energy, biomass, food and textiles, wood and paper, machinery and equipment, construction and accommodation and transport and communication have no direct coal pollution-pollution multipliers. This indicates that agriculture and electricity are directly responsible for most of the coal emissions while sectors with zero direct coal pollution-pollution multipliers consume little or no coal.

Direct crude oil pollution-pollution multipliers are only observed in the petroleum products sector. Food and textiles, wood and paper, machinery and equipment and transport and communication have the largest direct natural gas sector pollution-pollution multiplier and direct primary energy pollution-pollution multipliers from biomass are only observed in the household sector. This indicates that the petroleum products sector is responsible for most of the crude oil emissions. Food and textiles, wood and paper, machinery and equipment and transport and communication are responsible for most of the natural gas emissions and the household sector is responsible for all the biomass emissions in the economy.

Direct secondary pollution-pollution multipliers for petroleum products are observed in petroleum products, transport and communication and constriction and accommodation. Electricity has relatively high direct secondary energy pollution-pollution multipliers in all sectors except the non-fossil fuels based energy sectors.

Indirect pollution-pollution multipliers indicate the sectors that are responsible for generating energy emissions through the indirect use of energy. Indirect coal pollution-pollution multipliers are highest in the electricity and petroleum products sectors and lowest in natural gas, renewable energy and biomass sectors. The petroleum products sector has the highest indirect crude oil pollution-pollution multiplier followed by transport and communications while natural gas, nuclear energy, renewable energy and biomass have the lowest indirect crude oil pollution-pollution sectors. Indirect natural gas pollution-pollution multipliers are highest in the petroleum products and chemical sectors and lowest in nuclear energy, renewable energy and biomass sectors. The biomass sector only has indirect pollution-pollution multipliers in the electricity, financial and community services, machinery and equipment and coal sectors.

The highest electricity indirect pollution-pollution multiplier occurs in the household sector followed by wood and paper and gold and other mining. The lowest electricity indirect pollution-pollution multiplier occurs in the natural gas sector followed by petroleum products and crude oil. The largest secondary indirect petroleum products pollution-pollution multiplier is found in the construction and accommodation sector followed by the transport and communication sector while the lowest petroleum products indirect pollution-pollution multiplier occurs in the machinery and equipment sector, followed by the natural gas sector and the chemicals sector

Pollution-output multipliers are estimated by dividing energy emission in each economic sector by the total output in that sector. Direct pollution-output multipliers for coal are the largest primary energy pollution-output multipliers. Electricity has the largest direct coal pollution-output multiplier followed by petroleum products. Gold mining, chemicals, water and household consumption had the smallest pollution-output multiplier in the coal sector. The petroleum products sector is the only sector with a direct pollution-output multiplier for crude oil. Natural gas, renewable energy, nuclear energy and biomass have zero direct pollution-output multipliers. This indicates that while the electricity sector is largely responsible for direct coal pollution-output multipliers and petroleum products sector is responsible for crude oil pollution-output multipliers, natural gas, renewable energy, nuclear energy and biomass have no effect on direct pollution-output.

The iron and metals sector has the largest direct electricity pollution-output multiplier followed by household consumption and gold and other mining. All non-fossil fuel based energy, machinery and equipment and construction and accommodation have zero direct pollution-output electricity emission multipliers. Transport and communication has the highest direct petroleum products pollution-output multiplier, followed by machinery and equipment. Except for coal, other manufacturing, water, construction and accommodation, financial and community services and household consumption, all other sectors have zero direct pollution-output multipliers in the petroleum products sector.

The largest indirect coal pollution-output multiplier is observed in the electricity sector, followed by petroleum products and iron and metals. The machinery and equipment sector has the smallest indirect coal pollution-output multiplier. Petroleum product had the largest indirect crude oil pollution-output multiplier. Except for agriculture, crude oil, transport and communication and household consumption, all other sectors had no indirect crude oil pollution-output multiplier. Only the petroleum products sector has an indirect natural gas pollution-output multiplier. Nuclear energy, renewable energy and biomass have no indirect total emissions multipliers.

The iron and metals sector has the largest indirect total electricity pollution-output multiplier followed by household consumption and financial and community services. Together with all non-fossil fuel based energy, machinery and equipment and construction and accommodation have zero direct electricity pollution-output multipliers. Natural gas had the smallest indirect electricity pollution-output multiplier followed by machinery and equipment. Transport and communication sector had the highest indirect petroleum products pollution-output emissions multiplier followed by coal. Sectors with the lowest indirect petroleum products pollution-output multipliers included; machinery and equipment and crude oil.

5.5.4. Conclusion

Financial and community services, construction and accommodation and machinery and equipment have the largest final demand and value added while nuclear energy, natural gas and biomass have the smallest final demand and value added. Renewable energy is labour intensive but not energy intensive as this energy sector has the highest labour to value added and the lowest energy to labour and energy to value added ratios. The petroleum products sector is the least labour intensive and the most energy intensive as it has a low labour to value added ratio and high energy to labour and energy to value added ratios. For every one unit increase in biomass, renewable energy and nuclear energy results in the largest increase in output, income and employment while machinery and equipment, natural gas and gold and other mining sectors have the lowest increase in simple and total output, income and employment multipliers.

There is not much movement between natural gas, nuclear energy, renewable energy and biomass and the rest of the economy. Coal and crude oil have a relatively moderate impact and are moderately impacted on by other industries in the economy. Although almost all other industries in the economy depend heavily on electricity and petroleum products, they are not as heavily dependent on other industries.

Coal is responsible for the largest direct primary energy emissions followed by crude oil while natural gas, nuclear energy, renewable energy and biomass have the lowest direct impact. The electricity sector accounts for the highest indirect impact on coal emissions and petroleum products have the highest indirect impact on crude oil emissions. The petroleum products sector has the highest indirect impact on natural gas emissions.

The electricity sector is largely responsible for the direct impact on coal emissions in terms of total output and petroleum products sector is accounts for all crude oil emission from output. Natural gas, renewable energy, nuclear energy and biomass have no effect on direct emission output ratio. The iron and metals sector has the largest direct impact on electricity emissions per output and transport and communication has the highest direct impact on petroleum products emission per output. The largest indirect coal pollution per output impact is in the electricity sector, followed by petroleum products and iron and metals, while machinery and equipment has the smallest indirect impact on coal emissions per output. Petroleum products have the largest indirect crude oil pollution per output and the petroleum products sector is the only sector with an indirect impact on natural gas emissions per output.

The iron and metals sector has the largest indirect electricity emission per output followed by household consumption and financial and community services while natural gas has the smallest indirect electricity emissions per output followed by machinery and equipment. Nuclear energy, renewable energy and biomass have no indirect petroleum products emissions per output. Machinery and equipment and crude oil have the lowest indirect petroleum products emissions per output.

Chapter 6: Energy Emissions Reduction Policy Analysis

6.1. Introduction

Low energy prices are often recognised as one of the main reasons for the sub-optimal use of energy resources and environmental degradation as conventional energy pricing methods do not internalise externalities or account for the full economic costs associated with extraction, processing and use of energy. Externalities cause economic gains to be optimised at the expense of the environment. One of the major sources of market failure is a result of externalities not being internalised as part of total costs. Subsidies are also known to lead to inefficiencies through over production and sub-optimal use of goods and services. Perverse energy subsidies are responsible for higher economic inefficiency in resource allocation. Subsidy reform frees up existing financial resources from misallocation and corrects for sub-optimal resource use and environmental degradation.

This chapter proposes two energy emissions reduction polices; namely carbon dioxide taxes determined from energy externality costs and energy subsidy reform based on current energy subsidies. Existing literature will be used to develop energy-emissions reduction policy scenarios, which will be analysed by the energy emissions IO model. The model will analyse the impact of the policies according to changes in gross domestic product (GDP), employment, household consumption, energy consumption and energy emissions.

6.2. Policy scenarios

South Africa's energy emissions are largely the result of coal combustion hence the carbon dioxide tax is estimated according to the full cost of coal combustion. Full costs are determined as the sum of private, environmental and social costs. As a result of cheap coal prices, it is argued that electricity and coal based petroleum products are indirectly subsidised.

6.2.1. Carbon dioxide tax for South Africa

Blignaut and King (2002) estimate that the average full cost of coal combustion in South Africa was R 128.69/tonne of carbon dioxide equivalent across all sectors in the economy. Using data from Eskom, the average full cost of coal was R123.43/ tonne of carbon dioxide equivalent and data calculated by the study estimates a value of R117/tonne of carbon dioxide equivalent. While data from Sasol estimates a value of R116.14/tonne of carbon dioxide equivalent and the study calculates R129.05/tonne of carbon dioxide equivalent.

The average cost of environmental and social coal combustion externalities was R71.80/tonne of carbon dioxide equivalent, the cost of environmental and social electricity externalities was R78.46/tonne of carbon dioxide equivalent and the cost of petroleum products externalities was R54.73/tonne of carbon dioxide equivalent (Blignaut and King, 2002). These are lower bound estimates and since this study aims to compare the way in which different instruments will behave in the economy this study will use a value of R100/tonne of carbon dioxide equivalent. Based on an average between electricity and petroleum externalities this study assumes that approximately 25% or R25 will cover the administration costs of implementing the tax and R75 will represent the average environmental and social costs of coal combustion. Only fossil fuel based energy types will be taxed. Although natural gas is a fossil fuel based energy source, it will not be taxed as this is viewed as a clean energy source and the government has plans to increase the consumption of natural gas in the economy.

6.2.2. Energy subsidy reform in South Africa

Hassan and Blignaut (2004) indicates that the price difference between South Africa and other developing countries results in an implicit coal subsidy of R 33 175 million while the International Energy Agency (IEA) (1999) estimates a considerably lower direct subsidy based on the price gap between the observed price and the average production cost price as R 277 million. Both Hassan and Blignaut (2004) and the IEA (1999) indicate that the major reason for low coal prices paid by Eskom and Sasol who are responsible for 90% of all domestic consumption of coal was poor quality coal and low production costs. Since this study will only analyse direct financial subsidies to final consumers, the coal subsidy of R 33 175 will be ignored.

According to Hassan and Blignaut (2004), when compared to other developing countries, the price difference amounts to an implicit subsidy of US$ 0.03/kWh for both industrial and household users. This study estimates that in 2000 the direct subsidy on electricity consumed by industrial users was R30 071 million and that consumed by households was R6 833 million. The total financial subsidy was therefore R 36 904 million. Using an average sales price of 17.28c/kWh, real price of

8.91c/kWh and total sales of 177 404 518 MWh, the implicit financial subsidy in real prices in 2000 was R19 028 million. Since total electricity sales in real prices for 2000 was R 3 065 550 million, the financial subsidy for electricity was 6.2%. This corresponds to the energy subsidy of 6% given by the IEA (1999).

International comparison of the price of petrol and diesel show that both these fuels are relatively cheap in South Africa. The relatively low fuel tax is stated as being one of the main reasons for the low price of fuel when compared internationally. The difference between average international fuel prices for developing countries and the South African prices amounts to R1.25 for diesel and R2.20 for petrol. If this is considered as a subsidy on fuel the total implicit subsidy on diesel in 2000 was R7 815.75 million and for petrol it was R22 323.76 million.

According to Hassan and Blignaut (2004), the total implicit subsidy on fuels equals R30 140 million, which was, also more than 67% of the value of total diesel and fuel sales in 2000. Although the IEA (1999) estimated that direct subsidies for both petrol and diesel are zero based on average production costs, Blignaut and Hassan (2004) indicate that this is not true as producers and suppliers benefit from direct subsidies. Since subsidies in the petroleum products sector benefit producers and suppliers not the final consumer and given that this study is analyzing the impact of consumption based policy options, it will assume zero subsidies on petroleum products.
Energy subsidy reform will only be analysed in the electricity sector where the subsidy of R19 028 million will be removed.

6.2.3. Scenarios for energy emission reductions in South Africa

- A tax of R100/ton of carbon dioxide to be imposed on primary carbon dioxide from all coal consumed in the economy
- A tax of R100/ton of carbon dioxide to be imposed on primary carbon dioxide from all crude oil consumed in the economy
- A tax of R100/ton of carbon dioxide to be imposed on secondary carbon dioxide from all electricity consumed in the economy
- A tax of R100/ton of carbon dioxide to be imposed on secondary carbon dioxide from all petroleum products consumed in the economy.
- Removal of an electricity subsidy of R19 028 million.

The scenarios are analysed according to target variables, which are calculated by the model. Different policy scenarios will be compared against each other by expressing variables in terms of the change in economic output.

6.3. Expected policy impacts

It is expected that increasing consumer prices resulting from the carbon dioxide tax and the removal of the energy subsidy will increase the cost of overall production in the economy, which will result in a decrease in the supply of most commodities. An increase in government revenue without the accompanying increase in government spending will decrease overall demand. An increase in coal consumer prices is expected to decrease domestic demand of coal, which is expected to decrease domestic production prices. Crude oil is imported and the price of oil is set by international markets hence the increase in the domestic availability of crude oil will not affect international production prices. However the increased consumer price is expected to reduce domestic demand for oil. An increase in electricity and petroleum products prices as a result of increased consumer prices of coal and oil and the taxes on electricity and petroleum products is expected to reduce the demand for final demand energy, which may result in surplus final demand energy. This is expected to reduce the production price of secondary energy. It is expected that the increase in both primary and secondary energy prices will take effect fairly quickly and the economy will react almost immediately. Elevated energy prices will induce energy conservation, increase energy supply to a certain extent and increase innovation to reduce the energy intensity of production and consumption.

It is expected that the export of coal will increase as a result of the decrease in domestic demand of coal and reduced production prices. Crude oil imports are expected to decrease as a result of a decrease in crude oil demand. Currently coal prices in South Africa are market regulated, it is anticipated that government intervention may cause distortions in the pricing structure. No change is expected in the electricity and petroleum products trade balance as both energy types are domestically produced and consumed.

6.4. Results of policy analysis

Inter-industry impacts, changes to sectoral output; macro economic variables; energy consumption and energy emissions reduction are presented for each of the policy scenarios using the energy emissions model developed in the previous chapter.

Carbon dioxide tax on coal

The tax on coal raises the price of intermediate coal inputs for all coal consuming industries which results in a decrease in the production and demand for products from these industries and a decrease in total inter-industry output. In comparison to the other scenarios the tax on coal results in the largest decrease in inter-industry activity. Industry specific analysis indicates that the electricity sector (the largest coal consuming industry) has the largest decrease in total output followed by petroleum products (the second largest coal consuming industry) while biomass and natural gas sectors (the smallest coal consuming industries) have the smallest decrease in total output.

The tax on coal results in the largest decrease in value added, income and employment. Decreasing value added and income leads to a decrease in consumer prices. The decrease in employment and consumer prices decreases household consumption. Since government expenditure, investment and savings and exports are fixed variables, the reduction in household consumption translates into a decrease in GDP.

Increasing coal prices results in a decrease in taxes less subsidies indicating a decrease in tax burden. Since there is no revenue recycling or government spending of tax revenue this results in a decrease in GDP. An increase in the price of coal leads to reduced inter-industry production, which translates into a decrease in exports. Reduced inter-industry production cause imports to become less competitive which leads to a decrease in imports. Investments and savings and government expenditure also decrease as a result of the decrease in total production and the increase in coal prices.

Marginal change in sectoral output is calculated as the difference in GDP divided by the difference in sectoral output. As a result of the tax on coal, the electricity sector has the highest marginal decrease followed by the petroleum products sector. Natural gas and biomass have the lowest marginal decrease in sectoral output. The marginal excess burden on taxes, which indicates that the change in GDP divided by the change in tax revenue, is moderate, compared to the other scenarios. Marginal decrease in employment is the highest for this scenario which means that the decrease in GDP is high when compared to the decrease in employment while marginal decrease in household consumption is the second highest. Marginal decrease in primary consumption is lowest and secondary energy consumption moderate. Marginal decrease in primary and secondary energy emissions is the second lowest. This scenario generates additional tax revenue, which is 2.89% of GDP.

Carbon dioxide tax on oil

The tax on oil raises the price of intermediate oil inputs for all oil consuming industries resulting in a decrease in production and demand for products from these industries. In comparison to the other scenarios the tax on oil results in the third largest decrease in inter-industry activity. Industry specific analysis indicates that the petroleum products sectors (largest oil consuming sector) has the largest decrease in total output followed by the gold and other mining sector (second largest oil consuming sectors) while biomass and natural gas sectors (smallest oil consuming sectors) have the smallest decrease in total output.

The tax on oil has the smallest decrease in value added which is a result of the smallest decrease in income. Decreasing value added and income leads to a decrease in consumer prices. The decrease in employment and consumer prices decreases household consumption. Since government expenditure, investment and savings and exports are fixed variables, the reduction in household consumption translates into a decrease in GDP.

Increasing oil prices result in a decrease in taxes less subsidies indicating a decrease in tax burden. Since there is no revenue recycling or government spending of tax revenue there is an overall decrease in total output. An increase in the price of oil leads to reduced inter-industry production which translates into a decrease in exports. Reduced inter-industry production cause imports to become less competitive which leads to a decrease in imports. Investments and savings increase and government expenditure decreases as a result of the increasing oil prices.

As a result of the tax on crude oil, the petroleum products sector has the highest marginal decrease followed by the gold and other mining sector. Natural gas and biomass have the lowest marginal decrease in sectoral output. This scenario has the second lowest marginal excess burden on taxes. Marginal decrease in employment is the lowest and marginal decrease in household consumption is the second lowest. Marginal decrease in primary energy consumption is the second lowest and in secondary energy consumption is the highest. Marginal decrease in primary and secondary energy emissions is moderate. This scenario generates additional tax revenue, which is 0.62% of GDP.

Carbon dioxide tax on electricity

The tax on electricity raises the price of intermediate electricity inputs for all electricity consuming industries resulting in a decrease in the demand for products from these industries and also a decrease in primary factors. In comparison to the other scenarios the tax on electricity results in the second smallest decrease in inter-industry activity. Industry specific analysis indicates that the iron and metals sector (largest electricity consuming sector) has the largest decrease in total output followed by financial and community services sector (second largest consuming electricity sector) while biomass and natural gas sectors have the smallest decrease in total output.

The tax on electricity has the second largest decrease in value added. This decrease in value added results in the second largest decrease in income, which translates into the second largest decrease in employment. Decreasing value added and income leads to a decrease in consumer prices. The decrease in employment and consumer prices decreases household consumption. Since government expenditure, investment and savings and exports are fixed variables, the reduction in household consumption translates into a decrease in GDP.

Increasing electricity prices result in a decrease in taxes less subsidies indicating a decrease in tax burden. Since there is no revenue recycling or government spending of tax revenue there is an overall decrease in total output. An increase in the price of electricity leads to reduced inter-industry production, which translates into a decrease in exports. Reduced inter-industry production cause imports to become less competitive which leads to a decrease in imports. Investments and savings increase and government expenditure decreases as a result of the increasing electricity prices.

As a result of the tax on electricity has the iron and metals sector has the highest marginal decrease followed by the financial and community services sector. Natural gas and biomass have the lowest marginal decrease in sectoral output. This scenario has the highest marginal excess burden on taxes. Marginal decrease in employment is the second highest and marginal decrease in household consumption is the highest. Marginal decrease in primary energy consumption is the second lowest while the marginal decrease in secondary energy is the highest. Marginal decrease in primary energy emissions is the highest and in secondary energy emissions is the second highest. This scenario generates additional tax revenue, which is 1.33% of GDP.

Carbon dioxide tax on petroleum products

The tax on petroleum products raises the price of intermediate petroleum products inputs for all petroleum product-consuming industries resulting in a decrease in the demand for products from these industries and also a decrease in primary factors. In comparison to the other scenarios the tax on petroleum products results in the lowest decrease in inter-industry activity. Industry specific analysis indicates that the transport and communications sector (largest petroleum products sector) has the largest decrease in total output followed by financial and community services sector (second largest petroleum products sector) while biomass and natural gas sectors have the smallest decrease in total output (smallest petroleum products sector).

The tax on petroleum products has the second smallest decrease in value added. This decrease in value added decreases income and employment. The decrease in the price of income results in a decrease in the consumer price. The decrease in employment and consumer price results in the second smallest decrease in household consumption. If government expenditure, investment and savings and exports are fixed variables, the reduction in consumption results in a decrease in gross domestic product.

Increasing petroleum products prices result in a decrease in taxes less subsidies indicating a decrease in tax burden. Since there is no revenue recycling or government spending of tax revenue there is an overall decrease in total output. An increase in the price of petroleum products leads to reduced inter-industry production, which translates into a decrease in exports. Reduced inter-industry production cause imports to become less competitive which leads to a decrease in imports. Investments and savings and government expenditure also decrease as a result of the increasing petroleum products prices.

As a result of the tax on petroleum products, the transport and communication sector has the highest marginal decrease followed by the gold and other mining sector. Natural gas and biomass have the lowest marginal decrease in sectoral output.This scenario has the second highest marginal excess burden on taxes. Marginal decrease in employment is the second lowest and marginal decrease in household consumption is the lowest. Marginal decrease in primary energy is the highest while the marginal decrease in secondary energy is second highest. Marginal decrease in primary energy emissions is the highest and in secondary energy emissions is the second highest. This scenario generates additional tax revenue, which is 0.65% of GDP.

Energy subsidy reform

Energy subsidy reform raises the price of intermediate electricity inputs for all electricity consuming industries resulting in a decrease in the demand for products from these industries and also a decrease in primary factors. In comparison to the other scenarios energy subsidy reform has the second smallest decrease in inter-industry activity. Industry specific analysis indicates that the electricity sector has the largest decrease in total output followed by the coal-mining sector while biomass and natural gas sectors have the smallest decrease in total output. It was expected that the removal of the electricity subsidy may have a similar inter-industry impact as the tax on electricity but this is not the case. The removal of the electricity subsidy has the largest decrease in output in the electricity and coal mining sectors indicating that these sectors benefit the most from the electricity subsidy while the tax has the largest negative impact on the iron and metals and financial and community services sectors.

The removal of the energy subsidy on electricity has the third largest decrease in value added. This decrease in value added results in the third largest decrease in income, which translates into the third largest decrease in employment. This decrease in the price of income decreases the consumer price. The decrease in employment and consumer price results in the third largest decrease in household consumption. If government expenditure, investment and savings and exports are fixed variables, the reduction in consumption results in a decrease in gross domestic product.

Energy subsidy reform results in a decrease in taxes less subsidies indicating a decrease in tax burden. Since there is no revenue recycling or government spending of tax revenue there is an overall decrease in total output. An increase in the price of electricity leads to reduced inter-industry production, which translates into a decrease in exports. Reduced inter-industry production cause imports to become less competitive which leads to a decrease in imports. Investments and savings and government expenditure also decrease as a result of the increasing electricity prices.

In this scenario the electricity sector having the highest marginal decrease followed by the coal-mining sector. Natural gas and biomass have the lowest marginal decrease in sectoral output. This scenario has the lowest marginal excess burden on taxes. The marginal decrease in employment and household consumption is moderate. Marginal decrease in primary energy is the lowest and in secondary energy is moderate. Marginal decrease in primary and secondary energy emissions is the lowest. This scenario generates additional tax revenue, which is 2.09% of GDP.

Table 6-1: Baseline and scenario final demand and total output

				Coal Tax		Oil Tax		Electricity Tax		Petroleum Products Tax		Electricity subsidy removal	
		Final Demand Baseline	Total output Baseline	Final Demand	Total output	Final Demand	Total output	Final Demand	Total output	Final Demand	Total output	Final Demand	Total output
1	Agriculture	4234.74	56767.53	4249.07	56604.15	4234.74	56734.58	3895.14	56177.91	3815.14	56258.76	4234.74	56668.25
2	Coal mining	7345.51	20559.94	7294.36	17048.64	7345.51	19872.33	6933.24	19671.17	7315.04	20454.34	7345.51	17721.97
3	Crude Oil	5298.53	29027.77	5298.53	28124.30	5298.53	28472.45	5298.53	28630.90	5298.53	28692.25	5298.53	28804.58
4	Natural gas	3.95	3.95	3.95	3.95	3.95	3.95	3.95	3.95	3.95	3.95	3.95	3.95
5	Nuclear Energy	-40.00	273.70	-40.00	86.63	-40.00	271.29	-40.00	268.87	-40.00	272.46	-40.00	71.54
6	Renewable Energy	83.33	142.68	83.33	133.86	83.33	142.33	83.33	140.94	83.33	141.29	83.33	133.98
7	Biomass	8139.94	8141.55	8139.94	8141.55	8139.94	8141.55	8139.94	8141.55	8139.94	8141.55	8139.94	8141.55
8	Gold & other mining	81132.54	111450.10	80862.01	108576.37	81132.54	109687.65	78951.93	107981.91	80971.36	111101.91	81132.54	111140.68
9	Food & Textiles	84864.25	134673.12	84864.25	134389.44	84864.25	134620.80	84777.05	134280.96	84864.25	134505.63	84864.25	134491.02
10	Wood & Paper	11455.11	55057.95	11455.11	54563.13	11455.11	54966.62	11291.42	54237.29	11455.11	54878.93	11455.11	54819.01
11	Petroleum products	45.21	9301.19	-6426.62	2651.93	-5650.07	3539.90	-1137.62	7998.81	45.21	9175.05	45.21	9217.29
12	Chemicals	27609.39	122376.73	27366.91	120459.62	27609.39	121768.30	27382.63	120925.43	27609.39	121970.83	27609.39	121655.29
13	Iron & metals	36665.48	95149.44	35563.77	92682.25	36665.48	94976.16	33578.00	90235.18	36665.48	94977.65	36665.48	94534.66
14	Machinery & Equipment	97837.81	198995.02	97837.81	196383.54	97837.81	198500.99	97827.29	197984.61	97837.81	198297.35	97837.81	196945.82
15	Other manufacturing	11701.50	17329.33	11021.15	16571.97	11701.50	17312.05	9908.20	15447.05	11594.75	17182.65	11701.50	17293.70
16	Electricity	11577.96	30983.62	-5650.84	12507.41	11577.96	30745.55	11577.96	30506.15	11577.96	30861.07	-7450.04	11016.47
17	Water	1817.02	10127.04	1590.23	9434.36	1817.02	10042.58	1219.25	8971.09	1781.43	10020.33	1817.02	9932.69
18	Construction & Accommodation	221500.81	268377.21	221500.81	266982.70	221500.81	268272.47	221497.89	268111.14	221408.61	267982.99	221500.81	267019.32
19	Transport & Communications	93187.59	168574.06	93187.59	166502.86	93187.59	167790.94	92722.89	166952.33	88079.20	162841.77	93187.59	167514.96
20	Financial & Community Services	298713.26	467440.08	298552.23	464586.78	298713.26	466819.06	296776.53	463832.05	298690.28	466688.15	298713.26	465631.22
Sum		1003173.91	1804752.01	976753.58	1756435.44	997478.63	1792681.53	990687.54	1780499.27	997196.77	1794448.93	984145.91	1772757.92

Table 6-2: Difference between baseline output and scenario output

				Coal Tax		Oil Tax		Electricity Tax		Petroleum Products Tax		Electricity subsidy removal	
		Final Demand Baseline	Total Output Baseline	Diff in Output	Diff/ Baseline Output	Diff in Output	Diff/ Baseline Output	Diff in Output	Diff/ Baseline Output	Diff in Output	Diff/ Baseline Output	Diff in Output	Diff/ Baseline Output
1	Agriculture	4234.74	56767.53	-163.38	-0.0091	-32.95	-0.0018	-589.61	-0.0327	-508.77	-0.0282	-99.28	-0.006
2	Coal mining	7345.51	20559.94	-3511.29	-0.1946	-687.61	-0.0381	-888.77	-0.0492	-105.60	-0.0059	-2837.97	-0.157
3	Crude Oil	5298.53	29027.77	-903.46	-0.0501	-555.32	-0.0308	-396.87	-0.0220	-335.51	-0.0186	-223.18	-0.012
4	Natural gas	3.95	3.95	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.000
5	Nuclear Energy	-40.00	273.70	-187.07	-0.0104	-2.41	-0.0001	-4.83	-0.0003	-1.24	-0.0001	-202.16	-0.011
6	Renewable Energy	83.33	142.68	-8.82	-0.0005	-0.35	0.0000	-1.74	-0.0001	-1.39	-0.0001	-8.70	0.000
7	Biomass	8139.94	8141.55	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.000
8	Gold & other mining	81132.54	111450.10	-2873.73	-0.1592	-1762.45	-0.0977	-3468.19	-0.1922	-348.19	-0.0193	-309.42	-0.017
9	Food & Textiles	84864.25	134673.12	-283.68	-0.0157	-52.32	-0.0029	-392.16	-0.0217	-167.49	-0.0093	-182.10	-0.010
10	Wood & Paper	11455.11	55057.95	-494.82	-0.0274	-91.33	-0.0051	-820.66	-0.0455	-179.02	-0.0099	-238.93	-0.013
11	Petroleum products	45.21	9301.19	-6649.26	-0.3684	-5761.29	-0.3192	-1302.38	-0.0722	-126.14	-0.0070	-83.91	-0.005
12	Chemicals	27609.39	122376.73	-1917.11	-0.1062	-608.43	-0.0337	-1451.30	-0.0804	-405.89	-0.0225	-721.44	-0.040
13	Iron & metals	36665.48	95149.44	-2467.19	-0.1367	-173.29	-0.0096	-4914.27	-0.2723	-171.79	-0.0095	-614.79	-0.034
14	Machinery & Equipment	97837.81	198995.02	-2611.48	-0.1447	-494.03	-0.0274	-1010.41	-0.0560	-697.67	-0.0387	-2049.20	-0.114
15	Other manufacturing	11701.50	17329.33	-757.36	-0.0420	-17.28	-0.0010	-1882.28	-0.1043	-146.67	-0.0081	-35.63	-0.002
16	Electricity	11577.96	30983.62	-18476.21	-1.0238	-238.07	-0.0132	-477.47	-0.0265	-122.55	-0.0068	-19967.15	-1.106
17	Water	1817.02	10127.04	-692.69	-0.0384	-84.47	-0.0047	-1155.95	-0.0641	-106.71	-0.0059	-194.36	-0.011
18	Construction & Accommodation	221500.81	268377.21	-1394.51	-0.0773	-104.74	-0.0058	-266.07	-0.0147	-394.22	-0.0218	-1357.89	-0.075
19	Transport & Communications	93187.59	168574.06	-2071.20	-0.1148	-783.12	-0.0434	-1621.72	-0.0899	-5732.28	-0.3176	-1059.10	-0.059
20	Financial & Community Services	298713.26	467440.08	-2853.30	-0.1581	-621.02	-0.0344	-3608.03	-0.1999	-751.93	-0.0417	-1808.86	-0.100
Sum		976753.58	1756435.44	-48316.57	-2.6772	-12070.48	-0.6688	-24252.73	-1.3438	-10303.07	-0.5709	-31994.08	-1.773

Table 6-5: Percentage change scenario macro-economic variables

			Value added				Final Demand			Energy Use		Energy Emissions	
	GDP	Employment	Taxes less subsidies	Gross Operating Surplus	Imports	Household consumption	Government expenditure	Investment and Savings	Exports	Primary	Secondary	Primary	Secondary
Carbon dioxide tax on coal	0.918	0.833	0.7282	1.043	1.335	0.833	0.610	0.6672	1.7475	42.725	10.848	43.798	12.128
Carbon dioxide tax on oil	0.193	0.178	0.1478	0.216	0.388	0.178	0.133	-0.1105	0.6612	8.907	3.587	8.210	2.381
Carbon dioxide tax on electricity	0.788	0.774	0.7130	0.811	1.002	0.692	0.772	-0.3295	1.8008	3.871	2.105	3.640	2.099
Carbon dioxide tax on petroleum products	0.380	0.332	0.2261	0.454	0.632	0.365	0.161	0.8578	0.5259	0.478	1.861	0.471	1.239
Energy subsidy reform	0.624	0.553	0.4996	0.726	0.740	0.571	0.387	0.9263	0.6515	35.310	7.124	37.407	9.951

Table 6-6: Ranked decrease of scenario macro-economic variables

			Value added				Final Demand			Energy Use		Energy Emissions	
	GDP	Employment	Taxes less subsidies	Gross Operating Surplus	Imports	Household consumption	Government expenditure	Investment and Savings	Exports	Primary	Secondary	Primary	Secondary
Carbon dioxide tax on coal	1	1	1	1	1	1	2	3	2	1	1	1	1
Carbon dioxide tax on oil	5	5	5	5	5	5	5	5	3	3	3	3	3
Carbon dioxide tax on electricity	2	2	2	2	2	2	1	4	1	4	4	4	4
Carbon dioxide tax on petroleum products	4	4	4	4	4	4	4	2	5	5	5	5	5
Energy subsidy reform	3	3	3	3	3	3	3	1	4	2	2	2	2

Table 6-7: Marginal change in sectoral output

		Coal Tax	Oil Tax	Electricity Tax	Petroleum Products Tax	Energy subsidy reform
1	Agriculture	-0.0002	0.0000	-0.0007	-0.0006	-0.0001
2	Coal mining	-0.0040	-0.0008	-0.0010	-0.0001	-0.0032
3	Crude Oil	-0.0010	-0.0006	-0.0004	-0.0004	-0.0003
4	Natural gas	0.0000	0.0000	0.0000	0.0000	0.0000
5	Nuclear Energy	-0.0002	0.0000	0.0000	0.0000	-0.0002
6	Renewable Energy	0.0000	0.0000	0.0000	0.0000	0.0000
7	Biomass	0.0000	0.0000	0.0000	0.0000	0.0000
8	Gold & other mining	-0.0032	-0.0020	-0.0039	-0.0004	-0.0003
9	Food & Textiles	-0.0003	-0.0001	-0.0004	-0.0002	-0.0002
10	Wood & Paper	-0.0006	-0.0001	-0.0009	-0.0002	-0.0003
11	Petroleum products	-0.0075	-0.0065	-0.0015	-0.0001	-0.0001
12	Chemicals	-0.0022	-0.0007	-0.0016	-0.0005	-0.0008
13	Iron & metals	-0.0028	-0.0002	-0.0055	-0.0002	-0.0007
14	Machinery & Equipment	-0.0029	-0.0006	-0.0011	-0.0008	-0.0023
15	Other manufacturing	-0.0009	0.0000	-0.0021	-0.0002	0.0000
16	Electricity	-0.0208	-0.0003	-0.0005	-0.0001	-0.0226
17	Water	-0.0008	-0.0001	-0.0013	-0.0001	-0.0002
18	Construction & Accommodation	-0.0016	-0.0001	-0.0003	-0.0004	-0.0015
19	Transport & Communications	-0.0023	-0.0009	-0.0018	-0.0065	-0.0012
20	Financial & Community Services	-0.0032	-0.0007	-0.0041	-0.0008	-0.0020
Sum		-0.0544	-0.0137	-0.0274	-0.0116	-0.0362

Table 6-8: Marginal change in macro-economic variables

Marginal change in MEB							
Scenario	GDP	Taxes less subsidies	%Change in GDP	Change in GDP	Change in taxes less subsides	MEB	Rank
Baseline	888057.00	100005.49					
Coal tax	879906.31	125726.23	-0.92	8150.70	-25720.74	-0.317	3
Oil tax	886344.01	105552.99	-0.19	1712.99	-5547.50	-0.309	4
Electricity tax	881061.66	111778.78	-0.79	6995.34	-11773.29	-0.594	1
Petroleum products tax	884686.67	105756.55	-0.38	3370.34	-5751.06	-0.586	2
Energy subsidy reform	882514.01	118533.86	-0.62	5542.99	-18528.36	-0.299	5
Marginal change in employment							
Scenario	GDP	Employment	%Change in GDP	Change in GDP	Change in employment	MEB	Rank
Baseline	888057.00	424958.00					
Coal tax	879906.31	421420.20	-0.92	8150.70	3537.80	2.304	1
Oil tax	886344.01	424202.35	-0.19	1712.99	755.66	2.267	5
Electricity tax	881061.66	421667.53	-0.79	6995.34	3290.48	2.126	2
Petroleum products tax	884686.67	423549.25	-0.38	3370.34	1408.75	2.392	4
Energy subsidy reform	882514.01	422607.52	-0.62	5542.99	2350.49	2.358	3
Marginal change in household consumption							
Scenario	GDP	Household consumption	%Change in GDP	Change in GDP	Change in HH consumption	MEB	Rank
Baseline	888057.00	556652.00					
Coal tax	879906.31	552015.91	-0.92	8150.70	4636.10	1.758	2
Oil tax	886344.01	555661.00	-0.19	1712.99	991.00	1.729	4
Electricity tax	881061.66	552800.98	-0.79	6995.34	3851.02	1.816	1
Petroleum products tax	884686.67	554621.35	-0.38	3370.34	2030.65	1.660	5
Energy subsidy reform	882514.01	553474.97	-0.62	5542.99	3177.04	1.745	3

Marginal change in primary energy consumption							
Scenario	GDP	Primary Energy	%Change in GDP	Change in GDP	Change in primary energy	MEB	Rank
Baseline	888057.00	4679939.33					
Coal tax	879906.31	2680433.99	-0.92	8150.70	1999505.34	0.00408	3
Oil tax	886344.01	4263100.77	-0.19	1712.99	416838.56	0.00411	2
Electricity tax	881061.66	4498785.46	-0.79	6995.34	181153.86	0.03862	4
Petroleum products tax	884686.67	4657579.86	-0.38	3370.34	22359.47	0.15073	1
Energy subsidy reform	882514.01	3027451.11	-0.62	5542.99	1652488.22	0.00335	5

Marginal change in secondary energy consumption							
Scenario	GDP	Secondary energy	%Change in GDP	Change in GDP	Change in secondary energy	MEB	Rank
Baseline	888057.00	3108069.20					
Coal tax	879906.31	2770909.15	-0.92	8150.70	337160.04	0.0242	4
Oil tax	886344.01	2996569.62	-0.19	1712.99	111499.58	0.0154	5
Electricity tax	881061.66	3042642.66	-0.79	6995.34	65426.53	0.1069	1
Petroleum products tax	884686.67	3050241.93	-0.38	3370.34	57827.27	0.0583	2
Energy subsidy reform	882514.01	2886642.94	-0.62	5542.99	221426.26	0.0250	3

Marginal change in primary energy emissions							
Scenario	GDP	Primary energy emissions	%Change in GDP	Change in GDP	Change in primary energy emissions	MEB	Rank
Baseline	888057.00	329841653.94					
Coal tax	879906.31	185376323.37	-0.92	8150.70	144465330.57	0.000056	4
Oil tax	886344.01	302761851.20	-0.19	1712.99	27079802.74	0.000063	3
Electricity tax	881061.66	317833805.07	-0.79	6995.34	12007848.87	0.000583	2
Petroleum products tax	884686.67	328287352.88	-0.38	3370.34	1554301.06	0.002168	1
Energy subsidy reform	882514.01	206457666.10	-0.62	5542.99	123383987.85	0.000045	5

Marginal change in secondary energy emissions							
Scenario	GDP	Secondary energy emissions	%Change in GDP	Change in GDP	Change in secondary energy emissions	MEB	Rank
Baseline	888057.00	453195935.04					
Coal tax	879906.31	398230996.28	-0.92	8150.70	54964938.76	0.000148	4
Oil tax	886344.01	442405523.23	-0.19	1712.99	10790411.81	0.000159	3
Electricity tax	881061.66	443684783.67	-0.79	6995.34	9511151.37	0.000735	1
Petroleum products tax	884686.67	447579647.46	-0.38	3370.34	5616287.58	0.000600	2
Energy subsidy reform	882514.01	408099416.33	-0.62	5542.99	45096518.71	0.000123	5

Table 6-9: Additional tax revenue

Scenario	Taxes less subsidies	Additional taxes less subsides	Additional tax as % of GDP
Baseline	100005.49		
Coal tax	125726.23	25720.74	2.90
Oil tax	105552.99	5547.50	0.62
Electricity tax	111778.78	11773.29	1.33
Petroleum products tax	105756.55	5751.06	0.65
Energy subsidy reform	118533.86	18528.36	2.09

6.5. Discussion of policy analysis

The results of the policy analysis indicate that increases in the price of intermediate inputs, decreases inter-industry output, specifically those industries that are the largest consumers of the energy source being taxed. This decreases total economic output and GDP, employment, household consumption, energy consumption and energy emissions. These findings confirm the results of the study undertaken by Gibson and van Seventer (1996a), which states that macro-economically it is in South Africa's interest to avoid green trade restrictions by internalizing environmental externalities especially in the energy producing sector. The study by Gibson and van Seventer (1996a), also highlights the fact that green trade restrictions in the energy producing sector retard export growth and per capita GDP but that there is no guarantee of environmental benefits.

The research undertaken by this study indicates that carbon dioxide taxes and energy subsidy reform result in positive environmental benefits for South Africa as the domestic demand for energy decreases resulting in a decrease in total GHG emissions. Policies were analysed according to real and marginal decreases. In order to compare the changes resulting from decreasing levels of GDP, marginal decreases were calculated for employment, household consumption, energy consumption and energy emissions reduction. The marginal excess burden of revenue generated from the carbon dioxide taxes and energy subsidy reform was also calculated. In terms of decreasing GDP, employment and household consumption, the lower the marginal burden the better the policy.

Table 6-10: Ranked decrease in real target variables

Scenario	Gross Domestic Product	Employment	Household Consumption	Primary energy consumption	Primary energy emission reduction
Carbon dioxide tax on coal	1	1	1	1	1
Carbon dioxide tax on oil	5	5	5	3	3
Carbon dioxide tax on electricity	2	2	2	4	4
Carbon dioxide tax on petroleum products	4	4	4	5	5
Energy subsidy reform	3	3	3	2	2

Table 6-11: Ranked real, social and environmental impacts

Gross Domestic Product descending from lowest negative economic impact	Employment and Household Consumption descending from lowest negative social impact	Energy consumption and energy emissions reduction descending from highest positive environmental impact
Carbon dioxide tax on oil	Carbon dioxide tax on oil	Carbon dioxide tax on coal
Carbon dioxide tax on petroleum products	Carbon dioxide tax on petroleum products	Energy subsidy reform
Energy subsidy reform	Energy subsidy reform	Carbon dioxide tax on electricity
Carbon dioxide tax on electricity	Carbon dioxide tax on electricity	Carbon dioxide tax on petroleum Products
Carbon dioxide tax on coal	Carbon dioxide tax on coal	Carbon dioxide tax on oil

In real terms and in the interest of choosing the best alternative for energy emissions reduction first, economic growth and poverty alleviation second the tax on electricity is selected as the best option as this scenario offers the second lowest decrease in real energy emissions and the second highest decrease in economic growth. Under these conditions energy subsidy reform is selected as the second best option as this scenario offers the second highest real energy emissions reduction and the third highest decrease in economic growth.

Table 6-12: Ranked decrease in marginal target variables

Scenario	Gross Domestic Product	Employment	Household Consumption	Primary energy consumption	Primary energy emission reduction
Carbon dioxide tax on coal	3	1	2	3	4
Carbon dioxide tax on oil	4	5	4	2	3
Carbon dioxide tax on electricity	1	2	1	4	2
Carbon dioxide tax on petroleum products	2	4	5	1	1
Energy subsidy reform	5	3	3	5	5

Table 6-13: Ranked marginal economic, social and environmental impacts

Marginal Excess Burden of taxes descending from lowest negative economic impact	Marginal employment descending from lowest negative social impact	Marginal household consumption descending from lowest negative social impact	Primary energy consumption descending from highest positive environmental impact	Primary energy emissions reduction descending from highest positive environmental impact
Energy subsidy reform	Carbon dioxide tax on oil	Carbon dioxide tax on petroleum products	Energy subsidy reform	Energy subsidy reform
Carbon dioxide tax on oil	Carbon dioxide tax on petroleum products	Carbon dioxide tax on oil	Carbon dioxide tax on electricity	Carbon dioxide tax on coal
Carbon dioxide tax on coal	Energy subsidy reform	Energy subsidy reform	Carbon dioxide on oil	Carbon dioxide tax on oil
Carbon dioxide tax on petroleum products	Carbon dioxide tax on electricity	Carbon dioxide tax on coal	Carbon dioxide on coal	Carbon dioxide tax on electricity
Carbon dioxide tax on electricity	Carbon dioxide tax on coal	Carbon dioxide tax on electricity	Carbon dioxide tax on petroleum products	Carbon dioxide tax on petroleum products

Comparing marginal burdens of energy emissions reduction policies in terms of decreasing levels of marginal excess burden of taxes, energy subsidy reform is selected as the best option as this scenario has moderate marginal decreases in employment and household consumption, low marginal excess burden on taxes and a high marginal decrease in energy consumption and energy emissions. The tax on crude oil is selected as the second best alternative as this scenario has low marginal decreases in employment and household consumption, low marginal excess burden on taxes, low marginal decrease in energy consumption and a moderate marginal decrease in energy emissions.

The results from this study indicate in comparison to other policy options a carbon dioxide tax on coal would not offer a good alternative as the negative impact on economic growth, household consumption and employment would be substantial even though the environmental benefits are higher. As in the study by De Wet (2004) the results from this study conclude that a tax on coal has positive environmental benefits for South Africa but it has negative consequences for the economy in the form of lower levels of employment, household consumption and economic growth.

In terms of overall benefit to the economy, employment and the environment both the real analysis and marginal analysis indicate that the energy subsidy reform currently offers the best results. This correlates with findings by the International Energy Agency (IEA) (1999), which also found that the electricity sector was most affected by the removal of the energy subsidy since a large part of the energy subsidy was a result of cheap coal. However Blignaut and King (2002) argue that previous studies on electricity externalities estimate the social and environmental cost of negative externalities in terms of the price of electricity and not on the source of emissions namely that of coal. Therefore the externality cost of coal combustion should be relayed to the price of coal and not to the commodity or product using electricity since there may be other cleaner methods of generating electricity other than through the combustion of coal. A direct carbon dioxide tax on electricity in this study does however provide the best overall results in terms of real changes.

Given the low real and marginal environmental benefits of a tax on petroleum products, this option was not identified as an option. Although the carbon dioxide tax on crude oil did indicate that this was the second best option in terms of overall marginal changes.

Chapter 7: Summary, Conclusions and Implications

Global environmental pressure to reduce GHG emissions and national developmental objectives to increase economic development and reduce unemployment make it necessary to simultaneously analyse energy consumption, energy emissions reduction, economic growth and unemployment. This study developed an integrated empirical framework for assessing the impact of energy emissions reduction in South Africa by structurally decomposing the energy sector into key energy producers and consumers in the economy in order to assess the inter-energy industry linkages. A previous study by Gibson and van Deventer (1996a) on green trade restrictions on the energy producing sector in South Africa states that although little is known about the precise relationship between growth, distribution and the environment except that it is complex and that any analysis of the this topic necessitates structural decomposition.

An augmented energy IO table was developed using primary and secondary energy accounts and national accounts data. Using the national energy balance, a physical energy IO table was developed according to energy consumption in the economy. An energy emissions inventory was developed using physical energy data and emission default factors from the 1996 IPCC guidelines (IPCC, 1996a). The approach used for the energy emission inventory is the same methodology applied to GHG inventories as required by the United Nations Framework Convention on Climate Change. An energy emissions IO table was then derived from the inventory. The energy emissions IO table reports all GHG emissions in terms of carbon dioxide equivalents. Conversion factors were used to convert the GHG emissions into carbon dioxide equivalents. The augmented energy IO table, energy IO table and energy emissions IO table were integrated into single energy emissions model.

The energy emissions IO model has twenty sectors including six primary energy sectors and two secondary energy sectors In response to the problem statement, five target variables were selected for analysis; gross domestic product, employment, household consumption, energy consumption and energy emissions reduction. The model assumed that government spending, investment and savings, exports taxes less subsidies, gross operating surplus and imports are all exogenous. Technological change variables and tax rates are also assumed to be exogenous to the model. Employment and household consumption are endogenised.

Recent literature indicates that it is important to endogenise labour supply, labour market imperfections and efficiency wage models with unemployment. It is expected that the simultaneous analysis of involuntary unemployment and endogenous labour supply will allow for a more holistic analysis of the employment problem in South Africa which will identify more channels of intervention and can then be assessed using models such as the one developed in this study. Although this presents a need for sensitivity analysis around central parameters in the labour market, this study focussed its analysis on real and marginal changes in energy consumption, energy emissions reduction, tax revenue, employment and GDP.

The analysis of sectoral output indicates that the financial and community services, construction and accommodation and machinery and equipment sectors have the largest final demand and value added while nuclear energy, natural gas and biomass have the smallest final demand and value added. Renewable energy is labour intensive but not energy intensive as this energy sector has the highest labour to value added and the lowest energy to labour and energy to value added ratios. The petroleum products sector is the least labour intensive and the most energy intensive as it has a low labour to value added ratio and high energy to labour and energy to value added ratios.

Biomass, renewable energy and nuclear energy have the largest income and output multipliers, while machinery and equipment, natural gas and gold and other mining sectors have the lowest income and output multipliers. Coal is responsible for the largest direct primary energy emissions followed by crude oil. The electricity sector accounts for the highest indirect impact on coal emissions and petroleum products have the highest indirect impact on crude oil emissions.

Local studies on energy externalities and energy subsidies were used to develop energy emissions reduction policies. Carbon dioxide taxes and energy subsidy reform were selected for analysis in South Africa. Five policy scenarios were presented for analysis. Four carbon dioxide taxes were imposed on coal, crude oil, electricity and petroleum products respectively and the energy subsidy reform would be applied to the electricity subsidy. In response to the problem statement, target variables selected for analysis in this study are energy consumption, energy emissions reduction, gross domestic product, employment and household consumption.

When the carbon dioxide tax on coal was introduced, electricity and petroleum products resulted in the largest decrease in total output while total output in the petroleum products and gold and other mining sectors decreased the most with the a tax on oil. The tax on electricity caused the largest negative impact on the iron and metals and financial and community services sectors and the tax on petroleum products affected transport and communication and financial and community services most negatively. Energy subsidy reform where the current electricity subsidy is removed results in the largest decrease in total output of electricity and coal mining.

According to real changes the tax on coal offers the highest reduction in real energy emissions but it has the highest decrease in economic growth it is concluded that a coal tax will not be the best option for carbon dioxide emissions reduction in South Africa. The tax on oil offers a low reduction in energy emissions hence it is concluded that this is not the best option despite the lowest reduction in economic growth. Despite the petroleum products tax having the lowest decrease in economic growth, this scenarios also has a low reduction of real energy emissions therefore this scenario is not recognised as an option for carbon dioxide emissions reduction in South Africa.

The tax on coal indicates high marginal decreases in employment and household consumption, moderate marginal excess burden on taxes and moderate marginal decrease in energy consumption and energy emissions while the tax on crude oil indicates low marginal decreases in employment and household consumption, low marginal excess burden on taxes, low marginal decrease in energy consumption and a moderate marginal decrease in energy emissions.

When comparing policy impacts on secondary energy the tax on electricity indicates high marginal decreases in employment and household consumption, high marginal excess burden on taxes, low marginal decrease in primary energy, high marginal decrease in secondary energy and a high marginal decrease in energy emissions and the tax on petroleum products indicates low marginal decreases in employment and household consumption, low marginal excess burden on taxes and a high marginal decrease in energy consumption and energy emissions.

Energy subsidy reform indicates moderate marginal decreases in employment and household consumption, low marginal excess burden on taxes and a low marginal decrease in energy consumption and energy emissions.

Since the electricity tax offers a moderate reduction in real energy emissions and decrease in economic growth therefore it is deduced that the electricity tax option could be an option for carbon dioxide emissions reduction in South Africa. Energy subsidy reform offers the second highest reduction in real energy emissions and a moderate decrease in economic growth, this scenario is recognised as a possible option for carbon dioxide reduction in South Africa. The comparison of marginal burdens of energy emissions reduction policies indicates that energy subsidy reform offers the best option as this scenario has moderate marginal decreases in employment and household consumption, low marginal excess burden on taxes and a low marginal decrease in energy consumption and energy emissions. The tax on crude oil is selected as the second best alternative as this scenario has low marginal decreases in employment and household consumption, low marginal excess burden on taxes, low marginal decrease in energy consumption and a moderate marginal decrease in energy emissions.

The results of this study indicate that energy subsidy reform offers the best option for reducing energy emissions and simultaneously causing moderate negative economic and social impact in comparison to other policy options analysed in the study. But it is unlikely that such a strategy will be adopted for South Africa without strong opposition from industry and the private sector as energy subsidy reform implies higher energy prices which will translate into higher input cost and lower profits. Trikam (2001) confirms this as he states that industry will only undertake to mitigate their emissions if they can see the benefit in their profits. In addition it has be proven that energy policies in pursuit of national self-sufficiency and energy security has resulted in higher levels of local and global emissions per unit of GDP in South Africa (Goldblatt, 2000). This is of particular importance as South Africa appears to be running out of electricity capacity and plans to build new coal fired power stations are already underway. The results of this study indicate that the second best option for reducing energy emissions while moderately affecting the economy and employment is a carbon dioxide on electricity.

Recommendations

The study has employed traditional IO analysis, which is static therefore the study did not investigate the dynamics of how technological change will affect final demand. It is recommended that further work be done to investigate the possibility of a dynamic energy emissions IO model and to compare the results using a static model with a dynamic model. Since the IO model in this study uses fixed co-efficients, there is no substitution in supply and demand. An advantage of Computable General Equilibrium models is that these models can be used to analyse the impact of substitution.

The model developed by the study could be extended into a Social Accounting Matrix (SAM). This will allow institutions to be analysed in more detail. This study focussed more on the inter-industry aspects of energy emissions reduction however a SAM could investigate different levels of welfare as well other institutions such as government in more detail. This will add value to the discussion on poverty burdens and will be useful for investigating the distributional aspects of environmental fiscal reform.

Greenhouse gas inventories are relatively new in South Africa. It is recommended that industry be pressured into putting more effort into compiling more accurate and detailed greenhouse gas inventories. Industry should also improve its environmental reporting specifically for natural resource consumption, waste management and air and water emissions.

Although energy in this study encompassed both fossil fuel and non-fossil fuel based energy, it is recommended that further work be carried out to investigate the impact of substituting non-fossil fuel energy for fossil fuels. This would require further investigation into technology transfer and uptake, investment, process and production of renewable and nuclear energy and biomass. This will be particularly useful in analysing behavioural changes that would result from environmental fiscal reform.

This study used energy externalities to determine a tax. Further work is needed to develop a more detailed tax using either damage cost of shadow pricing methods. It is recommended that the design and technical aspects of taxes be investigated in more detail taking full cognisance of South Africa's energy, environmental, economic and social policies and strategies. It is also recommended that the energy subsidy be analysed in terms of different energy types in South Africa.

Environmental taxes generate public revenue. It is unclear how the government may choose to manage an environmental tax and how the revenue generated will be redistributed. This study recommends that further work needs to be done on this subject especially in terms of a double dividend for South Africa.

This study did not attempt to undertake sensitivity analysis around central parameters or the calculation of uncertainty, it recommended that further work be carried out to test robustness,

Given the current changes taking place in the field of energy policy in South Africa in order to promote the use of cleaner fuels, it is recommended that the model developed in this study be used to analyse the impact of other energy related emissions such as lead and sulphur. The same model can be applied with minor modifications and specifications such as estimating the levels of different pollutants such as sulphur and lead. This could be done effortlessly but applying the correct pollution co-efficients.

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