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A dissertation submitted to the University of Cape Town in fulfilment of the requirements for the Degree of Master of Science in Engineering (Chemical Engineering)

Greenhouse Gas Intensity of South Africa's Production and Consumption

A study of the relationship between economic growth, income distribution and greenhouse gas emission in South Africa

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March 2013

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Declarations

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Abstract

Accelerating environmental depletion, and a large share of the world's population still living in poverty in a virtual rich world, are two of the biggest problems facing the world today (UN, 2012). South Africa faces challenges in both of these areas. According to The World Bank (2012b) and the World Energy Council (2007), South Africa is one of the most Greenhouse Gas (GHG) intensive economies in the world. At the same time, at least 25% of the population continue to live in poverty (Republic of South Africa, 2010). This dissertation aims to contribute to the description and understanding of the extent to which these problems are interdependent. What causes South Africa's economy to be so GHG intensive? And what impact will the increased affluence of South Africa's population have on GHG emissions?

In regard to GHG emission South Africa clearly faces challenges posed by its energy production and in all probability by its economic structure, particularly with regard to export. The consumption behaviour of the population is heterogeneous due to the high income disparity between different population groups. Little is known about the GHG intensity of private household consumption and its distribution among income groups.

In order to quantify the effects, and determine both the source and the causes of GHG emissions, an Environmentally Extended Input Output (EEIO) analysis based on South Africa's Final Supply and Use Table (SUT) 2005/2006 and Energy Balance 2006 has been conducted. 104 sectors and different final consumption categories were analysed in terms of their direct and indirect GHG emissions arising from combustion of fuels. In addition, detailed information about the consumption pattern of different income groups, taken from the 2005 Income and Expenditure Survey (IES) has been used to decompose general household consumption and to determine the total GHG emission and GHG intensity of each income group. The effects of economic growth and income distribution have been studied based on the assumption that today's poor, once they have migrated to a higher income group, will have similar consumption patterns to those who are already in that particular income group.

The results of the study show that the GHG intensity of South Africa's industry sectors varies considerably. The intensity ranges from 4.2 kg carbon dioxide equivalent per Rand output (kgCO2eq/ZAR) by Sector 'Electricity and gas' to as little as 0.005 kgCO2eq/ZAR by sector 'Activities auxiliary to financial intermediation'. If after sales GHG emissions are considered, coal is the most GHG intense, with potentially 9.9 kgCO2eq/ZAR.

It is shown that South Africa's exports are more GHG intense in the ratio of caused GHG emissions to gained GDP than – in decreasing order – domestic household consumption, capital formation and government expenditure. Private household consumption and related production cause 52% to 60% of total GHG emissions. Consumption by the tenth income decile emits about 15 times more GHG than that of the first income decile, although the GHG intensity decreases from low to high income groups. The overall elasticity of total GHG emission to expenditure in South Africa is about 0.68 from the first to tenth income decile. This elasticity is higher than that reported for all European countries and Brazil but about the same as the elasticity in India. GHG emission disparity is less than income disparity: a factor 97 is between the first and the tenth income decile. Apart from a decrease in GHG intensity, this can be explained in terms of expenditure exceeding income in low-income households while expenditure falls below income in high-income households.

Due to the fact that higher income leads to less GHG emission per Rand spent, a relative decoupling of private expenditure growth and household consumption based GHG will in all probability be observed, irrespective of the income distribution. However, the simulations indicate that a lower Gini-coefficient might result in higher GHG emissions from household consumption since low and middle income households, which on average have a more GHG intense consumption pattern than affluent households, would spend more money without sufficiently altering their consumption pattern to compensate for this. The detailed results of the simulation for changed consumption patterns induced by income growth identify power generation, transport infrastructure and housing as important sectors which need to be targeted by environmental policy makers because of an unfavourable combination of high carbon intensity and expected growth rate.

In addition to the findings for particular industry sectors and income groups, this dissertation demonstrates the systemic approach towards understanding the complexities of sustainable development, specifically the link between poverty reduction, economic growth and GHG emission reduction. The study is a multi-disciplinary one and includes literature from various fields and disciplines, and discusses the findings in a broad context.

Acknowledgment

To the many who have aided and encouraged me in this research I would like to offer my sincere thanks.

But, my deepest thanks, and love, go to my wife, Sarah, whose selfless work and loving support made my studies and writing possible.

I owe particular thanks to Professor Harro von Blottnitz, from whom I have learned much and who has enabled me to go beyond my aims.

Dedicated to

Golo and Jodok

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1. Introduction

1.1. Background

Eradicating poverty and hunger is the first goal of the Millennium Development Goals, another is to ensure environmental sustainability (UN, 2012). These two goals are highly interdependent and cannot in any sustainable way be pursued independently (Lusigi, 2008; Mueller, 2006; UN, 2012).

South Africa is facing challenges in fulfilling both of these goals. In 2006, at least every fourth person in South Africa was living in poverty (Leibbrandt et al., 2010; The World Bank, 2012b). At the same time, there have been, and continue to be, increasing demands on South Africa's environmental resources. South Africa's total primary energy consumption increased from 4.5 to 5.5 exajoules between 1999 and 2009 (EIA, 2012), and future water demand is expected to grow from 2.1 billion m^3 per year in 2005 to 3.2 billion m^3 per year by 2030 (Amis and Nel, 2011).

In order to eradicate poverty in South Africa, substantial economic growth is required and is hopefully achievable. However, a number of pressing questions accompany this assumption. Firstly, how will the extent of economic growth needed to address poverty impact the environment? Secondly, assuming that such economic growth is achievable, what aspects of the environment are most likely to be affected by an additional 12 million consumers? Finally, what should be the focus of the research and policy-making necessary to achieve the goals of eradicating poverty along with maintaining a sustainable environment?

This study is based on the assumption of an increased focus on sustainable consumption in Africa where strong economic growth is expected to continue, as observed among certain African countries in recent years (AfDB, 2012), thus elevating the status of environmental discourses in relation to growth discourses. These are important issues not only for Africa, but also for international organisations investing their efforts and resources in African countries. Knowledge makers in Africa should be aware of and prepared for future environmental impacts by consumption, and have at least some indication of the local expression of these effects. Whatever the outcome of such a discussion, an accurate description of the current situation regarding energy requirements and GHG emission would be a prerequisite for sound discussion and planning of targets and strategies to meet these challenges.

1.2. Problem Statement

It is astonishing that, although global warming and related issues are prominent in the international arena, relatively little is known about the sources and causes of GHG emission in South Africa. While the South African energy balance (Subramoney et al., 2010) provides information about the supply and use of various energy sources and distinguishes about two dozen sectors, available information remains limited to the direct use of energy and does not include data about GHG emissions. The available information also does not contribute in any way to understanding the causes of energy demand. Recently completed exploratory work by Mason-Jones and Notten (2011) complements the energy data for South Africa with related greenhouse gas emissions data, and calculates for the mentioned sectors in the energy balance indirect energy use and GHG emissions as well as intensity factors. However, their work suffers from a high aggregation of sectors, whilst final consumption is neglected. A study done by the United Nations University, in cooperation with other institutes (Arndt et al., 2011), has created a first comprehensive overview. However, the study only exists at this point as a discussion paper and is primarily concerned with the effect of a carbon tax in South Africa and is therefore somewhat limited in terms of an analysis of the current situation.

As mentioned above, one of the major trends in international affairs currently is the strong economic growth in developing countries. The related question, what does this increasing affluence of private household mean for the environment, has been extensively studied for industrialised countries but only very few examples of studies of this kind have been carried out for developing countries.

Much remains still to be done, to achieve a comprehensive description of South Africa's current economic system and its influence on the environment. Further research is needed in order to understand its functionality and to be able to predict its response to changes.

1.3. Objectives and Scope

This dissertation aims to contribute to the description of the GHG emissions of production and consumption in South Africa. With a smooth transition of cause and effect in mind, I will try to close the cycle of production and consumption by describing South Africa's economy in terms of production as well as in terms of different consumption categories with regard to GHG emission. The determining of key figures, such as those for GHG intensity, direct and indirect GHG emission for each sector and consumption category, will make up the description.

I also attempt to contribute to the understanding of the effects of economic growth and income distribution on GHG emission. In this complex area, a generally accepted doctrine has not to date been established, nor are there clear and consistent results emerging from different countries. In this study, general household consumption is segregated into consumption according to different income groups. This allows the researcher to allocate GHG emissions to the different income groups and enables studying the effects of economic growth and income distribution on GHG emissions by assuming that a certain income level is associated with a particular consumption pattern.

The scope of the study is limited to South Africa. Only available data are used, and no new data have been collected. Only those GHG emissions arising from combusting fuels are considered. Other sources of GHG emissions such as those from land use change or from volatile organic compounds (VOC) fluctuation by mining activities being excluded. The description of the effects of economic growth is limited to the direct household income – consumption pattern – GHG emission causality. Future expected developments in technology, social behaviour and environmental policies are omitted from the study.

1.4. Research approach

In order to gain a comprehensive overview of the source and cause of direct and indirect GHG emission in South Africa, an Environmentally Extended Input Out (EEIO) analysis was carried out. The EEIO analysis is a suitable and well established method for analysing the economy of a country in terms of environmental impacts. Based on the data in South Africa's Supply and Use table and Energy Balance 2005/2006, an EEIO analysis was derived in order to allocate South Africa's direct and indirect GHG emission to 104 economic sectors. Merging this information with the detailed consumption pattern of South Africa's population given in South Africa's Income and Expenditure Survey (IES) 2005/2006, the direct and indirect caused GHG emissions were allocated to fifteen income groups. The effects of economic growth and income distribution on GHG emission were studied based on the assumption that today's poor will have similar consumption patterns once they have migrated to a higher income group to those who are already in that particular income group.

1.5. Structure of the dissertation

This dissertation is presented in five chapters. The 'Introduction' situates the research in a broader context and leads to the problem statement motivating this research, and defines the scope of the research. The 'Literature review' is used to link the study to the literature relating to the topic and also to discuss the methodology, its uses and findings to date. The 'Methodology' chapter aims to provide a comprehensive insight into the applied methodology and should enable to reconstruct or revise current assumptions and to reproduce the study. The 'Results' chapter is divided into sections describing South Africa's production, consumption and the effects of growth and income distribution on these. In the concluding chapter, I review and synthesise the key findings, then proceed to complete the dissertation with a short review of my related work and recommendations for future research in this area as well as to a limited extent for policy makers.

2. Literature Review

The literature review begins with a broad overview in terms of a global perspective, and narrows to a focus on the relation between individual affluence and Greenhouse gas (GHG) emission. GHG emission from the global to the individual level constitutes a vast area for discussion and is beyond the scope of this review. Thus I will not attempt to undertake a complete overview.

I start by classifying South Africa's economy within the global context, outlining the general situation within which South Africa's economy operates with regard to GHG emission. In this global context some basic facts and figures of South Africa's economic structure will be presented with special reference to the role of the energy sector in the economy. Thereafter I move from the national level to focus on household energy consumption. Private consumption is, like global GHG consumption, a vast field of study. Since this study is investigating the direct causality income - consumption – GHG emission, the literature review will be limited to this area.

Environmental science, by virtue of its many facets, is multidisciplinary and thus I would argue that it should be understood and described using a systemic and broad approach. Given the multidisciplinary nature of the discipline, I will attempt to include aspects and results from different research areas.

Opportunities for decreasing negative environmental impacts need to be weighed in terms of gained values and lost opportunities. Thus, while this thesis focuses on, and is informed by, environmental integrity, it does not ignore other economic and ethical values and realities.

2.1. Greenhouse gas Intensity of Economics

The series of conferences held by the United Nations Framework Convention on Climate Change (UNFCCC), with the outcome of the Kyoto Protocol and additional protocols, focused the attention of environmental and economic research on the issue of the energy and resource requirements of different countries (Aldy, 2005; Gabriel, 2003). Studies done in the last decade have shown that industrialized countries tend to stabilize or decrease their energy use, while developing countries increase their energy use. Both developing and industrialized countries seem to exhibit common patterns of energy use (Duro et al., 2010; Goldemberg and Siqueira Prado, 2011; Mielnik and Goldemberg, 2000).

In 2004 the Intergovernmental Panel on Climate Change (IPCC) estimated world total emissions to be at 49 gigatonnes of carbon dioxide equivalents (GtCO2eq) (IPCC, 2007a) of which 30 GtCO2 arise from combusting fossil fuels (cement manufacture is included, but not emissions from land use, land-use change and forestry, GHGs other than carbon dioxide emerging from combusting fossil fuels such as methane are also not included). South Africa contributes between 0.4 to 0.5 GtCO2, or about 1.5%, to the world's total GHG emission, ranking between 22 to 13 in the list of largest contributors to the world's GHG emission, depending on source and inclusion/exclusion of emissions (EIA, 2012; Subramoney et al., 2010; World Resources Institute, 2012). More relevant than absolute figures per country are relative figures. South Africa emits about nine tCO2eq per capita per year (without land-use change) and as a result is ranked at 48 out of 186 countries starting by the highest (World Resources Institute, 2012). This is a moderate figure in overall terms. USA and Australia emit about double the amount of GHG, with approximately 18 tCO2eq per capita and year. In Organisation for Economic Cooperation and Development (OECD) countries 10.6 tCO2eq were emitted per capita on average in 2008 (OECD, 2011). Compared to 4.9 tonnes in China, 1.9 tonnes in Brazil and 1.2 tonnes in India, South Africa appears to be very heavy in GHG emission taking the size of South Africa's economy and the living condition of the majority of the population into account. In fact, South Africa turns out to be among the most carbon intensive countries in the world based on the ratio of GDP to GHG emission (The World Bank, 2012a; World Energy Council, 2007). Figure 1 plots energy use per capita against the human development index for the year 2002. It can be seen that South Africa used considerably more energy than other countries with a similar human development index (Sagar et al., 2006).

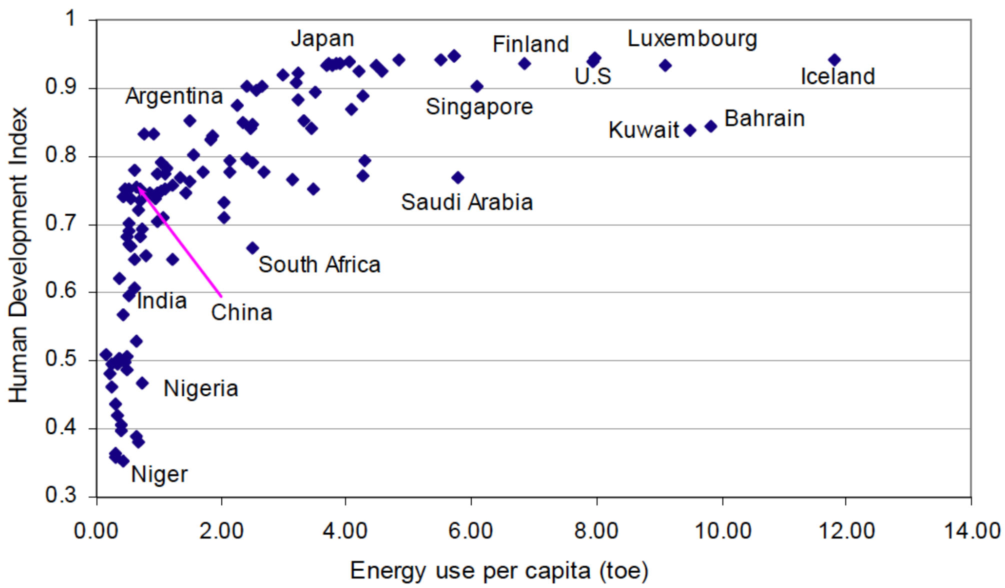

Figure 1: Energy consumption per capita vs. Human Development Index (2002) (Sagar et al., 2006)

In a globalised world environmental impacts from manufacturing and industry often do not take place in the same geographic area where final consumption happens. It is necessary to distinguish between spatial allocations of impacts, as the concept is used for the figures mentioned above, and a more systemic approach which takes into account cause and effect in terms of where impacts are allocated. In this case, impacts are allocated to the country causing it directly or indirectly irrespectively where impacts occur. The two principal allocation methods are also known as the production and consumption approach. The production or spatial approach is easy to account for and few questions arise about delimitation. The consumption, or cause root approach is much more complex, and many accounting problems arise. Usually it is done by distinguishing production according to the final consumption categories (domestic use vs. export and future splitting). Many other models exist but all are combinations of the two principal ones. When on takes global trade of embodied GHG emission into account, country rankings of GHG emission intensity look completely different (Munksgaard and Pedersen, 2001; Lenzen et al., 2007; Rodrigues and Domingos, 2008).

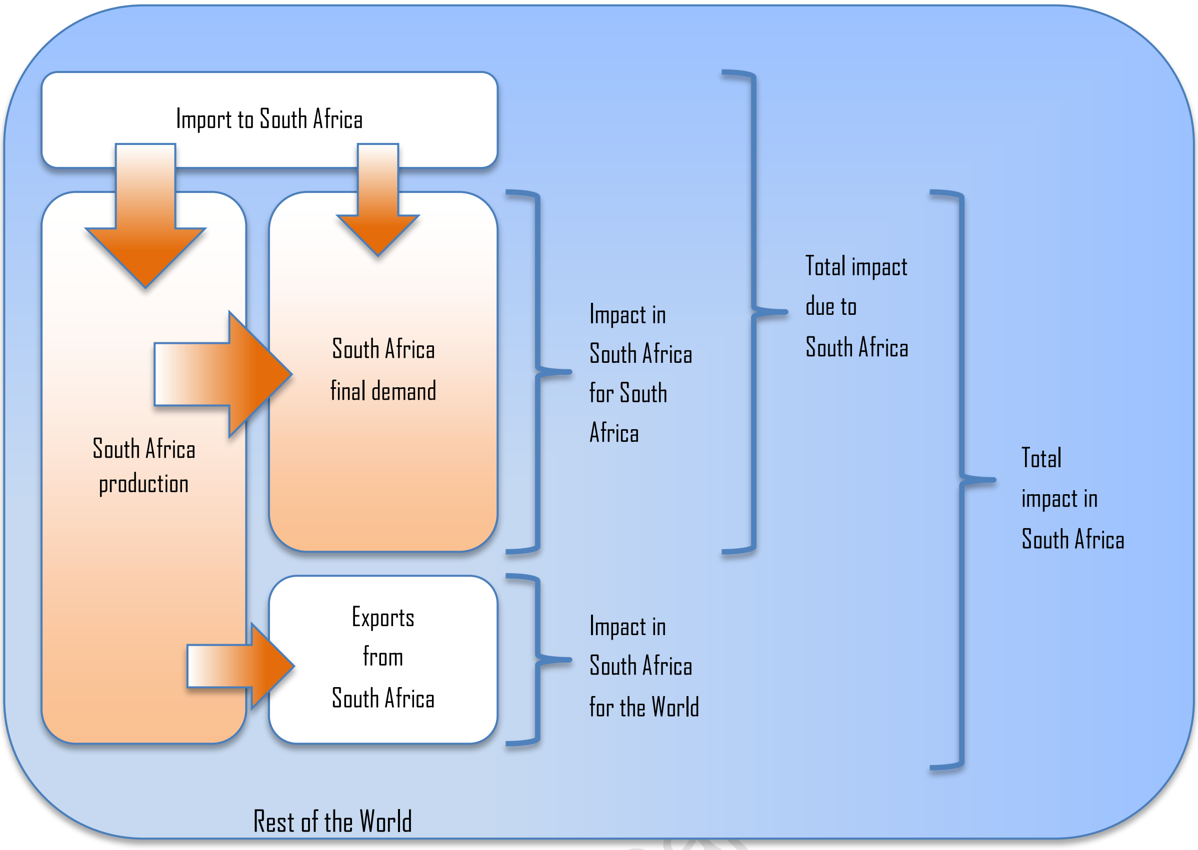

Figure 2: Spatial environmental impact induced. One needs to be clear about system boundaries and environmental impacts taken into account (figure according Jungbluth et al., (2011) modified)

Determining caused environmental impacts presents a substantial challenge. Global trade is highly complex and reliable data are rare. The country of production sources raw material in different countries. Cost and profit is not necessarily entered in the books where the product is physically produced. This kind of problem, among others, makes it difficult to gain a consistent global emission account applying a production approach. Regardless of the kind of complexities involved, multinational EEIO analysis, together with hybrid methods of EEIO and Life Cycle Assessment (LCA), were used to estimate global trade of embodied emissions (e.g. Nansai et al., 2012; Tang et al., 2012; Wiebe et al., 2011; Wiebe et al. 2012).

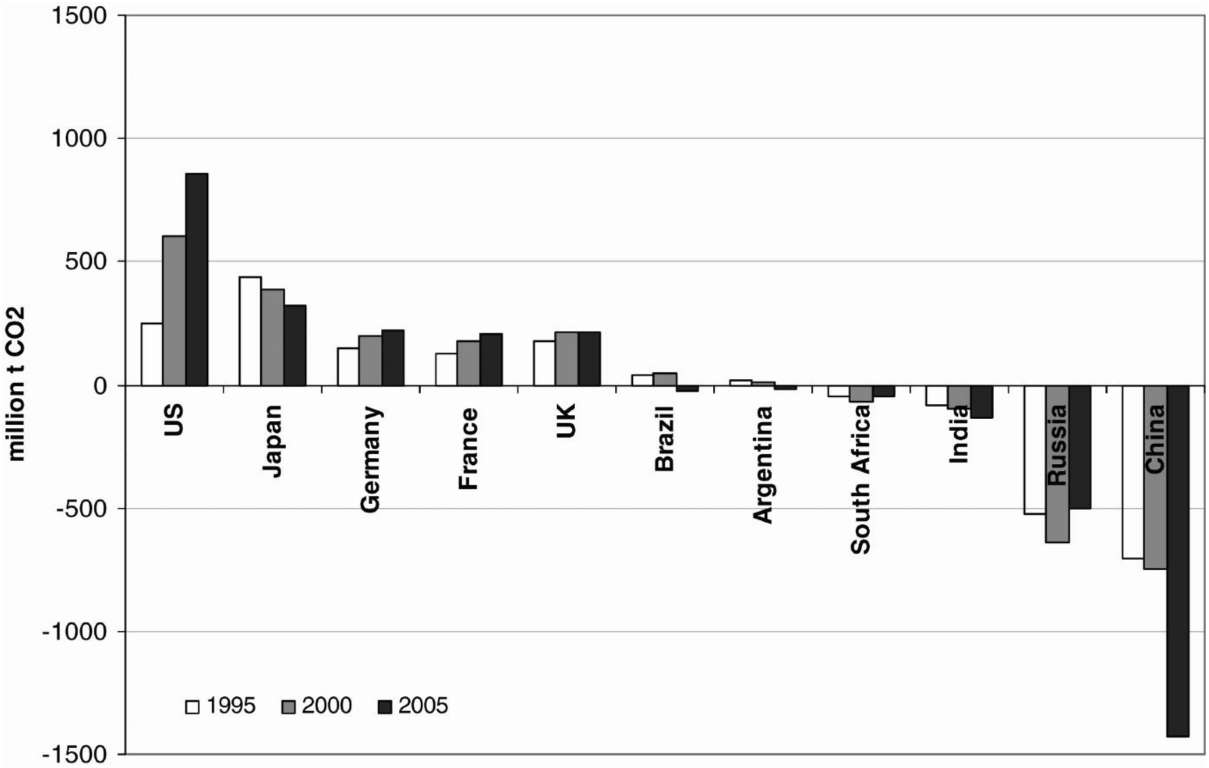

Figure 3: Carbon net imports and net exports embodied CO2 included (Wiebe et al., 2011)

An international division of work involved regions of high energy demand (chimneys of the world) and others with less, depending on the particular economic structure. Figure 3 shows the net import and export of carbon for several countries. Countries notorious for their resource hunger appear in a different light if embodied carbon trade is considered. Others appear to be even worse. In terms of the total of all goods and services, South Africa exports slightly more CO_2 in comparison to its import according to Wiebe et al. (2011; 2012), although the balance of trade in monetary units is slightly negative. A case in point of the mitigation of domestic GHG emission by outsourcing emission to foreign countries is Switzerland. One study estimates that at least 50% of GHG emission caused by Swiss consumption is emitted abroad (Jungbluth et al., 2011).

However, most figures in the literature on country comparison are based on a spatial approach. UNFCCC also accounts emissions and achieved reduction solely on a spatial approach.

2.1.1. Global Trends in GHG emissions

Until the late 20th century industrialized countries were the countries which contributed most to the global GHG emission on an absolute as well as on a per capita basis. Since 1975, OCED countries have not been contributing more than 50% of the GHG emission in absolute terms, although they have continued to maintain a far higher GHG intensity per capita (with 10.6 tCO_2/capita in 2008 representing about double the world average). Most recent trends have varied considerably between countries. The emissions of developing countries (non-Annex I countries[1]) have continued to grow by 3%, a trend led by China and India, while emissions from developed countries have fallen sharply by 6.5%. The extent to which economic slowdown is accountable for the significant drop and in comparison to other mitigation measurements showing the effects of emissions is not yet known (OECD, 2011). For developing countries, the rise in population figures is mentioned as a relevant factor for GHG emission growth alongside economic growth (Fischer-Kowalski et al., 2011). No generally accepted analysis has been established thus far. Nevertheless, there is empirical evidence that, at the very least, a relative decoupling of economic growth and environmental impact can be achieved (Biswanger et al., 2005; Fischer-Kowalski et al., 2011). However empirical evidence cannot exclude the possibility that the environmental benefits may be due to the outsourcing of environmentally harmful industries to other, especially poorer, countries (Biswanger et al., 2005).

[1] South Africa is part of Non-Annex I countries. For a complete list of Non-Annex I countries, see http://unfccc.int/parties_and_observers/parties/non_annex_i/items/2833.php

There is little doubt that world total GHG emission will increase into the future. OECD's base line model (assuming nothing changes) predicts a doubling of energy related GHG emission by 2050. There exists a wealth of literature presenting detailed GHG emission scenarios for countries, regions and the world, as well as the predicted consequences thereof and suggested mitigation strategies (IPCC, 2007b; OECD, 2011; The World Bank, 2012c).

2.1.2. The case of South Africa

As the figures in the previous section show, South Africa has a high carbon intensity compared to the world and is exceptionally carbon intense compared with countries in similar circumstances, regardless of the allocation method. What accounts for South Africa's high carbon intensity is its heavy use of coal, coupled to inefficient use of energy and its large, export-oriented mining and metallurgical industries.

2.1.2.1. South Africa's Energy Sector

Ninety two percent of South Africa's electricity comes from coal. It is the country which, in global terms, is most dependent on coal for electricity production. In addition, 25 to 30% of South Africa's liquid fuel are obtained by conversion from coal. Taken together, these figures show that coal accounts for about 70% of the country's primary energy supply, and indicate that South Africa is likely to be the country with the highest dependence on coal in the world. While it was the imperative of the past to have cheap energy available to promote mining activities, and whilst written energy policy today is about mitigation of CO2 emissions, the need for price competitiveness and availability was recently reemphasised (Eberhard, 2011; Subramoney et al., 2010; Tyler, 2009; World Coal Association, 2012).

Table 1 shows a comparison of CO2 emissions per kWh for different modes of electricity generation. Coal plants emit about twice as much CO2 per kWh as gas plants, and multiple times more than all other ways of generating electricity. South Africa is not the only country with carbon intense electricity (0.85 kgCO2/kWh)[2]; India's (0.93 kgCO2/kWh) and Australia's (0.91 kgCO2/kWh) electricity generation rate, for example, is even higher in carbon, while China generates its electricity with not much less carbon emission (0.76 kgCO2/kWh). However South Africa's electricity contains almost twice as much carbon as the world average (0.51 kgCO2/kWh), or almost triple of Europe's average (0.31 kgCO2/kWh) (all figures according to U.S. Energy Information Administration (eia) for the year 2007 (IEA, 2009)).

[2] South Africa's electricity producer ESKOM reports 0.95 kgCO2/kWh (ESKOM, 2012a), and a study by the University of Cape Town found 1.0 kgCO2/kWh for South Africa's electricity (Letete et al., n.d.). This makes South Africa's electricity the most carbon intense in the world.

Table 1: Greenhouse gas intensity per electricity generation technology (combined values of (Honorio et al., 2003; Lenzen et al., 2008; POST, 2011))

Electricity generation technology	Greenhouse gas intensity (kgCO2/kWh)
Coal	0.8 -1.2
Natural gas	0.4 – 0.6
Photovoltaic	0.05 – 0.1
Nuclear	0.06
Hydro / Wind / Geothermal / Marine	< 0.05

Producing 92% of its electricity from coal, the remaining portion of South Africa's electricity is produced by nuclear (4.2%), hydropower (2.4%), and pumped storage accounts for 1.7% (Subramoney et al., 2010).

Not only is South Africa's electricity exceptionally heavy in CO2 but also its liquid fuel. Aboyade and von Blottnitz (2012) found that syn-diesel is about four times more GHG intense than conventional diesel refined at coast. With a share of 25 to 30% syn-fuel South Africa's liquid is about twice more carbon intense than conventional fuels (Dick, 2012). Sasol is a now privatised but was originally a government-funded company[3]. Sasol owns the only commercial coal-to-liquids (CTL) fuel production facilities in the world. About one fifth of domestic coal usage is for the CTL process. Annually 44 Mt of high ash (35%) and low calorific value (less than 21 MJ/kg) coal is needed to produce about 58 million barrels petroleum products. Secunda, home to the two larger of three CTL production sites, is one of the largest single sources of carbon emissions in the world (Eberhard, 2011).

While about 30% of liquid fuel is produced from CTL processes, 70% of the liquid fuel is imported, mainly as crude oil, but an increasing amount as refined products. Additionally, small amounts of indigenous natural gas and imported gas are used too.

In the renewable energies sector solid biomass (wood) is dominant, followed by solar (mainly heat), wind and waste. The Department of Energy of South Africa estimates that in 2006 7.6% of total primary energy supply was by renewables (Subramoney et al., 2010).

2.1.2.2. South Africa's industry structure

The economy of South Africa[4] is rooted in the agricultural traditions of all its early inhabitants. From the 17th century the European settlers began generating and came to dominate a market-orientated agriculture. In the late 19th century diamonds and gold were discovered and South Africa rapidly developed a resource based industrial economy. The contemporary economy of South Africa is quite well diversified. For 2011 it was estimated that about 65% of GDP was being generated by the tertiary sector. Current state strategy is directed at the country's economy becoming a more knowledge-based economy. South Africa is considered to be an upper-middle income economy by the World Bank (Blankley and Booyens, 2010; Department Trade and Industry Republic of South Africa, 2011; The World Bank, 2012c).

Regardless of South Africa's well-developed service sector providing, for example, sophisticated banking services for the domestic market and for many other African countries, fuels and mining products, and semi-manufactured forms of goods share a large portion of the export market. Such goods typically embody more energy per gained GDP unit than more highly processed goods.

South Africa's export commodities are high in energy intensity but they contribute relatively little to the national GDP. Thus exports make for high energy use per capita. While one could argue that environmental impacts should be allocated according to a consumption based approach (described in section 2.1 Greenhouse gas Intensity of Economics as consumption based approach), the current common understanding is that responsibility for production be shared between consumer and producer (Fink, 2008; Gallego and Lenzen, 2005; Lenzen et al., 2007).

Table 2: Top ten export goods for January to December 2011 (South African Revenue Services, 2012)

No	Description	Million ZAR

[3] Sasol was founded by the South African state in 1950 with the object of commercialising coal-to-liquids technology. Its first plant was commissioned in Sasolburg in 1955. After the oil price shocks in the 1970s, and sanctions against the Apartheid government, two much larger plants were built at Secunda, in the Mpumalanga Province, in 1980 and 1982 (Eberhard, 2011).

[4] South Africa is here referred as a geographical area not as state

1	Gold, non-monetary: other semi-manufactured forms	74’835
2	Iron ores and concentrates, agglomerated	41’373
3	Bituminous coal	38’955
4	Platinum, unwrought or in semi-manufactured forms	29’748
5	Platinum, unwrought or in powder form	27’569
6	Ferro-chromium: containing by mass more than 4 per cent of carbon	21’365
7	Chromium ores and concentrates	18’665
8	Other vehicles of a cylinder capacity exceeding 1500 cm³ but not exceeding 3000 cm³	13’518
9	Iron ores and concentrates, non-agglomerated	12’499
10	Filtering or purifying machinery and apparatus for gases: other	9’725

In addition to the high level of energy required for producing export goods, there are a variety of other issues associated with resource based export structure. The economic issues can be succinctly summed up as: ‘countries become what they export’. An extensive literature dealing with the so called ‘natural resource curse’ provides empirical evidence for a high possibility of poor progress being made by countries in all sectors if one sector (natural resource extraction) dominates the economy. Among others, Hausman and Klinger (2006) discuss some aspect of this in South Africa. While I would argue that this literature needs urgently to be fully incorporated into the discussion about the cost of greening economies, South Africa’s economy in particular, the limited scope of this study does not permit further in depth exploration of this highly complex issue, particularly as it is of limited relevance to the outcome of the study.

2.1.2.3. South Africa: GHG emission mitigation strategy

South Africa’s official climate change mitigation strategy is described in the so called ‘National climate change response – White Paper’ (Government of the Republic South Africa, 2011), a high level principal paper with many other subordinate associated papers. The document unequivocally acknowledges that climate change is already a measurable reality, and calls for action. South Africa, along with other developing countries, is seen as especially vulnerable to climate change impacts and likely to face high adaption costs if the average temperature rises more than two degrees. The White Paper can be divided into three main sections: managing the risks, emission mitigation, and emission monitoring. Apart from the fact that managing the risks is mentioned consequently first, the accentuation of other targets and the necessity for contributions of first world countries casts doubt on the unconditional will of government to decrease GHG emissions. However, South Africa has committed itself to an emissions trajectory that peaks at 34% below a “Business as Usual” trajectory in 2020, and 40% in 2025, then remains stable for around a decade, and declines thereafter in absolute terms. Policymaking and regulation are planned to build an important part into emission mitigation, while market mechanisms, such as emission trade, are also mentioned but appear to be complementary.

Tyler (2010), in exploring the possibility of South African energy and climate change mitigation policies aligning concludes: ‘Whilst written and stated energy policy is to some extent aligned with a low-carbon future, both the dominant energy policy paradigm and the orientation and capacity of the country’s energy institutions are fundamentally misaligned’. Further, it is argued that South Africa is in the early stages of developing climate change mitigation policy, with only policy intentions and directions existing at this stage, which, while appropriate in terms of mitigating GHG emission, are some way from the implementation of substantial measures.

Apart from the global GHG emission situation, in South Africa the entire economy uses energy from a very carbon intense energy sector. Many of the major export goods have a high ratio of embodied energy to value. But beside paper work and a voluntary commitment to reduce its GHG emissions below a business-as-usual scenario, the country has not done much so far to mitigate further emissions. In international negotiations, South Africa’s climate change allies are the so called ‘Group 77’, a group that represents 133 developing countries and China. The Group 77 countries emphasise the responsibility of the developed and more industrialised countries in terms of GHG emissions and the need of developing countries for financial and technological aid. Terms such as ‘international financial assistance’ are common in the relevant government papers. Even though this attitude would appear logical and would seem to reflect an equitable solution to the GHG problem, I would argue that it is unrealistic in terms of ‘real politics’. To take more responsibility together with a genuine belief in the opportunities of the green economy would represent an exhilarant and a future oriented approach, ultimately to the benefit of developing countries.

2.2. Households and Environmental impacts

After the short overview how South Africa as a country is classified globally in terms of GHG emissions, and the discussion of some of the concepts and debates around the issue, I will proceed to a review of literature on the topic of household consumption and how this influences and affects the environment.

The relationships and interactions between individuals and the environment are complex and constantly evolving over time, with the specific dynamics depending on the place and section of the population. From amongst these dynamics, the literature review focuses predominantly on the effects of individual affluence on the environment.

The first section looks at the general relationship between income and environmental impact. In the second section, examples are reviewed from studies similar to the current study. The third and last part of this section presents a review of the methodologies applied to allocate national environmental impacts to final demand categories. Due to the fact that these studies are complex and yield heterogeneous results, I interpret and comment in the process of describing them in order to avoid the necessity of re-describing the studies in the discussion.

2.2.1. Income and resource disparity

"The richest 20% of the world's population were responsible for 86% of consumption expenditure in 1998, while the poorest 20% had to settle for just 1.3% of such expenditure"

(Fischer-Kowalski et al., 2011).

The effects of individual affluence on the environment can be seen in terms of two levels. The "direct" level describes direct effects of human behaviour on the environment, based on daily consumption decisions and other directly environmentally related behaviour, such as recycling and littering. The "indirect" level can be understood as the way in which individuals try to influence their environment (environment can be understood to include countries, cities, communities, companies, or fields of particular interest). The environment in which someone lives provides the infrastructure as the background for individual actions, and determines the base level of the environmental impact of the individual's living.

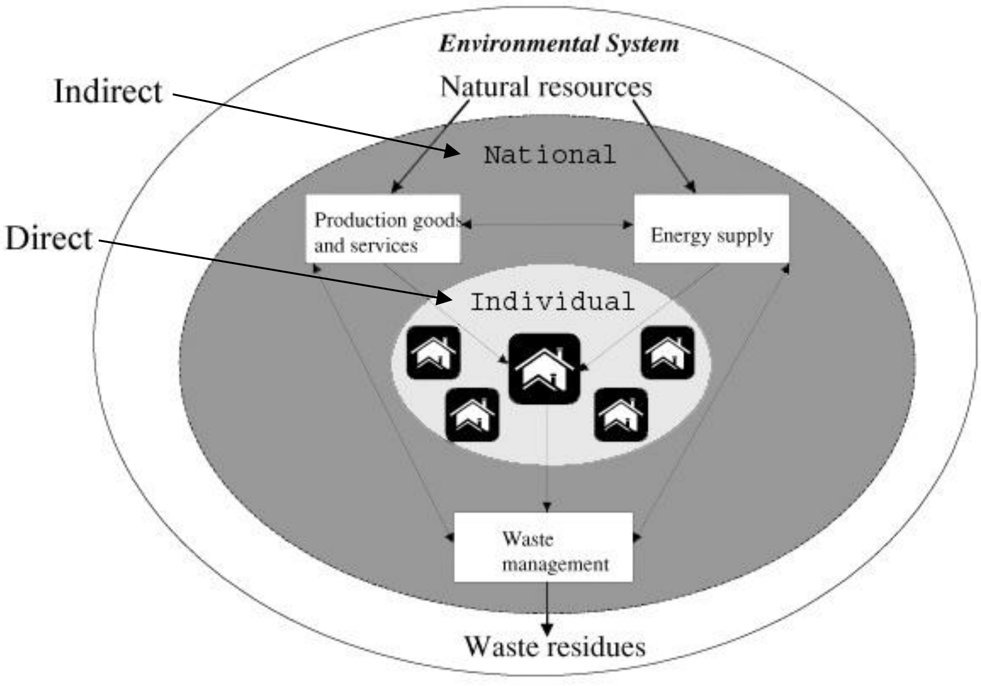

Figure 4: System description of the direct and indirect effects of individual affluence (Moll 2005) modified.

Studies related to indirect effects seem mainly to be undertaken as part of social science, social psychology and the special areas of economic game theory and management of communally owned goods. I have a very limited survey of inferences that can be drawn from the results of these studies. From a few examples from the scientific field of the 'commons' it became apparent that studies are complex, often showing complex and conflicting findings. Ostrom et al. (2007) in a review article argues that, in the context of governance of human–environment interactions, there is no simple model of systems to generate general solutions to the overuse of resources. They advocate that one detach oneself from the idea that all problems of resource governance can be represented by a small set of simple models[5]. A more abstract approach is to apply game theoretical methods to environmental issues. In addition to many other game theoretical experiments in relation to environmental issues, it has been shown that more than one equilibrium (stable game situation) can be reached for a situation in which players

[5] The high relevance of the subject for this day and age was recently be emphasised by the Nobel prize committee awarding 2009 the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel to Elinor Ostrom for her work in the scientific field of 'study of the commons'

working together can achieve a high score, but players lose if a few do not cooperate. But equilibria, we would call environmental friendly or sustainable, are labile and tend to degrade to a game situation in which each player acts in a strongly egoistical manner. To reach a "higher" equilibrium is especially difficult when the group of players is not constant and no vengeance can be taken. Studies from the field of the 'commons' have shown a complete depletion of resources occurring much less frequently than game theory is able to predict. Humans seem to be able to organise themselves in a way that enables them to overcome many of their own socio-psychological failings (Hirsch, 2009; Kuismin, 1998; Lee, 2012; Pitsoulis, 2007). However, it has been demonstrated that income has a positive and significant effect on people's willingness to pay for environmental protection, and on their willingness to accept strict environmental regulations, and that income correlates generally with environmental concerns (Meyer and Liebe, 2010).

As complex, confusing and interesting as the indirect effects are, an attempt should nevertheless be made to incorporate them into the technical and economic discourse about sustainability.

The direct environmental impact as a function of affluence has been described with the simple equation:

Impact = Population x Affluence x Technology (Ehlrich and Holdren, 1971)

Generally, in this equation population and affluence are understood as factors that lead to a higher environmental impact, while technology is needed to limit the impacts. This so called I-PAT equation attained relatively high popularity and was used in a report to the Club of Rome in 1995 by Ernst Ulrich von Weizsäcker, Amory Lovins and Hunter Lovins promoting increases in resource productivity, later known as "Factor Four" (von Weizsaecker et al., 1995).

In the I-PAT equation, increasing affluence leads ultimately to a higher environmental impact. However, there is reasonable doubt whether this is really a linear function. The counter hypothesis, that environmental impact grows with increasing income, but that, after a turning point, the environmental impact decreases with further increasing income – is under discussion and is generally known as the Environmental Kuznets Curve (EKC). Originally, this hypothesis was used to describe the possible economic evolution and development of countries, starting from an agriculture-based economy, through industrialisation and finally to a services-based economy and welfare state. However, in recent years the EKC has been used predominantly to discuss the behaviour of individuals. The theory describes in a reduced form the effects of income on environmental impacts, but without explaining the underlying reasons (Lenzen et al., 2006). The existence of an EKC for individual behaviour has been proven many times in the case of direct pollutants (List and Gallet, 1999; Millimet et al., 2003; Plassmann and Khanna, 2006). However, most EKC studies using CO2 data have not found evidence of a non-monotonic emission-to-income relationship (Tucker, 1995). For a global pollutant such as CO2, whose abatement is likely to require a significant shift in lifestyle patterns, and that has a high private abatement cost and a low private abatement benefit, it is unlikely that emission will decrease significantly solely as the result of economic growth (Plassmann and Khanna, 2006).

It is apparent however, that the impact is dependent on the nature and amount of the consumed goods. A dollar spent for transport services has a different environmental impact to that of a dollar spent for food (Huppes et al., 2008). Different income groups consume different basket of goods (goods to be understood as products and services). Therefore, the overall direct impact caused by low-income when compared to high-income households is not the same, and no general statement can be made about the effect of private affluence on a particular impact factor.

2.2.2. Household Income and its direct effect on Green House Gas emissions

Energy and resource requirements within different countries have been relatively well researched. Less attention has been given to the distribution of resource consumption within countries, even though many countries have income disparities at least as large as those between nations (Siddiqi, 1995).

For industrialized countries, a growing literature provides information about households' resource requirements (predominantly related to the total household energy demand), investigating in particular whether household income, demographic or socio-cultural variables and living environment have significant effects on resource requirements. This kind of research is usually described as the household metabolism approach. For developing countries only a few studies of this kind can be found in the literature.

Table 3: Correlation between household segregation variables for different countries (Lenzen et al., 2006)

	Size	House type	Employ-ment	Education	Urbanity	Age
Australia						
Expenditure	**-0.472**	-0.165	0.392	0.215	0.056	0.133
Size		0.212	-0.031	-0.108	-0.056	-0.274
House type			-0.087	**-0.659**	**-0.674**	0.236
Employment				0.121	0.01	-0.070
Education					**0.663**	0.068
Urbanity						0.042
Denmark						
Expenditure	**-0.573**	0.141	0.066	0.150	0.040	0.269
Size		0.112	0.181	-0.063	-0.048	-0.201
House type			0.072	0.01	-0.242	0.174
Employment				0.076	-0.073	-0.212
Education					0.083	0.077
Urbanity						-0.05
Japan						
Expenditure	-0.133	0.084	-0.046	**0.438**	0.394	0.293
Size		**0.687**	0.487	0.179	-0.393	**0.475**
House type			0.741	0.113	**-0.549**	0.514
Employment				-0.195	-0.47	0.480
Education					0.034	0.278
Urbanity						-0.132
Brazil						
Expenditure	0.198	**0.887**	0.089	**0.929**	-0.01	0.362
Size		0.411	-0.039	0.267	-0.053	0.116
House type			0.033	**0.895**	0.039	0.348
Employment				0.022	-0.172	-0.336
Education					-0.073	**0.434**
Urbanity						0.318
India						
Expenditure	-0.232	0.089	-0.053	0.312	0.123	0.009
Size		0.129	0.185	-0.109	-0.047	0.269
House type			0.071	0.144	-0.02	0.147
Employment				-0.112	-0.033	0.082
Education					0.108	-0.093
Urbanity						0.014

Note: Pairs of variables with a correlation coefficient larger than 0.4 are highlighted in bold.

Table 3 shows tested household segregation variables for four countries. Only a few variables are correlated without causality. Obviously many not only correlate but also are causally dependent on each other. The magnitude of correlation between variables differs from country to country. No general doctrine is established concerning the importance of segregation variables regarding resource requirements of households. With the exception of household expenditure, expenditure is found to be the most significant variable in all studies. Population density (urbanity), number of members per household, and size and type of dwelling are often also mentioned to be of significance.

Table 4: Summary of Literature about household income/expenditure and Energy/GHG intensity

Description *Author, (Date), Title*	Findings	Method	Comment
Vringer and Blok, (1995), The direct and indirect energy requirements of households in the Netherlands	Almost linear relationship of expenditure and energy requirements. The elasticity* was found to be about 0.8.	Hybrid energy analysis, EEIO and process analysis combined with expenditure surveys	Classical well know study.
Pachauri, (2004), An analysis of cross-sectional variations in total household energy requirements in India using micro survey data	Decreasing energy intensity with income growth. Elasticity of about 0.67.	EEIO combined with expenditure survey	Highest elasticity found in Literature. Same data likely to be used for study of Lenzen et al. (2006) In which less elasticity is reported (0.86), probably due to the exclusion of non-commercial fuels which are taken into consideration in this study. But no statement about this in the paper.
Cohen et al., (2005), Energy requirements of households in Brazil	Constant (with a tendency for increasing) energy intensity throughout all expenditure groups. About 61% accounts for indirect energy requirement	EEIO combined with expenditure survey	Only Household in urban areas considered. Same data used for Lenzen et al. study (2006).
Wier et al., (2005), Evaluating Sustainability of Household Consumption - Using DEA to Assess Environmental Performance	Higher income household tend to be slightly less GHG intense per monetary unite. Other factors, such family size, age and urbanity, are also important.	EEIO combined with expenditure survey	Study done on Denmark. Only three income groups (low, middle, high) Same result found for the single point indicator eco-efficiency. Study related to that of Wier et al., (2001).
Moll et al., (2005), Pursuing More Sustainable Consumption by Analysing Household Metabolism in European Countries and Cities	Netherlands: 15% decrease in total energy intensity from the first to the fourth quintile. UK: 23% decrease in total energy intensity from the first to the fifth quintile. Share of direct energy is 40% to 51%.	Hybrid energy analysis, EEIO and process analysis combined with expenditure surveys	The general practise of assuming the same technologies are used for production abroad as domestically makes it likely in reality the indirect energy is higher.
Lenzen et al., (2006), A comparative multivariate analysis of household energy requirements in Australia, Brazil, Denmark, India and Japan	Japan, Denmark, India and Australia all decreasing energy intensity with income growth (diminishing in this order), while Brazil was found to have constant energy	EEIO combined with expenditure survey	In all countries expenditure level is the most significant variable among others.

	intensity.		
Girod and De Haan, 2010), More or Better? A Model for Changes in Household Greenhouse Gas Emissions due to Higher Income	With 1.06 a slightly incising GHG intensity with income by spending based model decreasing by functional unite** based mode.	Expenditure survey and pure LCA based CO2eq data for goods.	Study for Switzerland. The almost CO2 free Swiss electricity was replaced by EU mix.
Baiocchi et al., (2010), The Impact of Social Factors and Consumer Behaviour on Carbon Dioxide Emissions in the United Kingdom	For low and high income CO2 emission grows proportionally more in relation to income, while in the middle-income range CO2 emission grows at a proportionally lower rate with income (U-shaped function for elasticity).	EEIO combined with expenditure survey	
Reinders et al., (2003), The direct and indirect energy requirement of households in the European Union	Much of the variation for indirect energy requirement between countries can be explained with the variation of average expenditure level of households. But direct energy requirement varies without a correlation to the average expenditure level.	Hybrid energy analysis, EEIO and process analysis combined with expenditure surveys	A study to be viewed with caution as it compares countries in terms of their different average expenditure level (corrected for purchase parity) and not individual households within a country. The results can be seen as a combined expenditure-spatial segregation of households. The share of direct energy to the total energy requirement in different countries varies from 34% up to 64%.

* Elasticity of 0.8 can be read as one per cent increase in expenditure results in a 0.8% higher energy requirement.

** Count of items, kg or square meters instant of expenditure per good.

Although the majority of the studies summarised in Table 4 found a decreasing energy and/or GHG intensity as function of income/expenditure, three out of eight found a different function. Girod and De Haan (2010) (see also section 2.3.2.1 Accounting for Differing Goods Quality) and Cohen et al. (2005) found a slightly higher energy intensity for high income groups. Assuming that all studies are correct, we can conclude that there is no general relationship between energy and GHG intensity to income/expenditure. It can range from slightly increasing to relative sharply decreasing.

A comprehensive study conducted by the Centre for Energy and Environmental Studies (IVEM) under the aegis of the University of Groningen concludes and summarizes many of the energy issues using the example of four European countries. Their conclusion reads as follows:

> "The average annual energy requirement of households varies considerably between the Netherlands, the United Kingdom, Norway, and Sweden, as well as within these countries. The average expenditure level per household explains a large part of the observed variations. Differences between these countries are also related to the efficiency of the production sectors and to the energy supply system. The consumption categories of food, transport, and recreation show the largest contributions to the environmental load. A comparison of consumer groups with different household characteristics shows remarkable differences in the division of spending over the consumption categories." (Moll et al., 2005)

Only two studies of this kind have been found for developing countries. In addition to the two studies for Brazil and India mentioned in Table 4, Siddiqi (1995)[6] reviews three studies of energy requirements in developing countries which contain figures about income of households. But all figures suffer from a rough aggregation of income groups into only three groups, and an incomplete set of energy sources is considered. However, it is noted that electricity use increases at similar rates in both the urban and rural areas of Pakistan within the three income groups. The review of three Indian cities reveals decreasing demand for dung, wood, kerosene, coal and agro waste, and increasing demand for gas and electricity, with increasing income within the three income groups.

The studies for Brazil (Cohen et al., 2005) and India (Pachauri, 2004) yielded conflicting results. While elasticity for total energy requirement to income was found to be constant in Brazil, elasticity was found to be 0.67 in India, which is the lowest value found in the literature. The constant energy intensity in Brazil is mainly explained in terms of a higher proportion of expenditure on mobility and shelter in the higher income range. Mobility and shelter have in the case of Brazil relative high energy intensities (note, Brazil is unique in that its trend towards wealthier families is generally larger and this may lead to some other specialities regarding consumption pattern). For India it is argued that, contrary to all other studies (which in 2004 were only done on developed countries), non-commercial energy, such as collected wood, is taken into account. The poor efficiency of such energy carriers was assumed to lead to a relatively high primary energy demand in low-income households.

However, irrespective of the energy intensity, there is no doubt in any study that the total energy requirement and/or GHG emissions grow as income/expenditure grows. Not one study has found something like an EKC for total GHG emission at the household level. A number of empirical studies within the perspective of environmental justice research confirm from another point of view that wealthier people suffer less from environmental burdens, yet leave behind a greater ecological footprint than poorer people (Evans and Kantrowitz, 2002; York et al., 2003).

[6] Original paper could not be accessed.

2.3. Methodology review

2.3.1. Environmental Extension of Input-Output table

The most commonly used method to allocate national environmental impacts to goods is the EEIO analysis. EEIO analysis is a well-known and established methodology and is a top down method of environmental analysis. For many industrialised countries, EEIO analyses are available, usually with a resolution of around 60 sectors, and up to 10 environmental extensions. For the European Union (EU25) a very comprehensive EEIO analysis was conducted with a resolution of nearly 500 sectors, while specifying a large number of environmental extensions and with 250 products distinguishing the total consummation (Huppes et al., 2008). The results consist of about half a million data points, which are difficult to handle and interpret. In order to have interpretable figures, and to allow them to communicate, it was necessary after all to aggregate the sectors. So it is not necessarily of much advantage to have high-resolution data.

Hand books, guidelines and a journal article describe all aspects and common conventions of the methodology (Suh and Huppes, 2002; Tukker et al., 2006; UN et al., 2003). I review here two aspects with direct implication for the current study.

The principal disadvantages of EEIO analyses are the aggregation of dissimilar products and the equalisation of monetary with physical units. The aggregation of dissimilar products cannot be overcome unless in product-by-product IO-Tables, with fine distinction of sub-types of a good. The equalisation of monetary with physical units is not compelling. Principally it is possible to make a purely physical flow account for the resource of interest to avoid using monetary units. Due to lack of data this is hardly ever done for larger systems such as countries. Hybrid flow accounts[7] constitute an option to improve accuracy. According to this model, different market actors pay different prices for the same commodity and therefore one market actor gets more physical units per monetary unit than do other market actors. In order to correct this imbalance, monetary transactions can be made to reflect exchange of physical units between trade partners more precisely (UN et al., 2003). This method has been seen to be applied for general EEIO analyses, but not for studies with reference to household consumption pattern as a function of income. Such studies use hybrid analysis to gain accuracy. Hybrid analysis attempts to incorporate LCA (in this context often referred to as "process analysis") and EEIO analysis. Readily available data are used for a process analysis. These are usually the direct energy inputs into the final product and the materials acquisition stage immediately upstream of that final stage. Where the acquisition of data for continuing the process analysis further upstream presents a rapidly escalating effort, the process analysis is shortened and a figure from an input-output analysis substituted. It is believed that hybrid methods deliver the most accurate results (Kok et al., 2006). A precondition is the availability of LCA data for basic material on frequently used goods and services. This is not given in the case of South Africa.

The treatment of imports is also a classical methodology problem. Approaches often assume imports are produced with the same technology as their domestic equivalent (e.g. Moll et al., 2005). Such an assumption appears to be a bit simplistic, and it introduces considerable errors into the analysis by aiming for a global system boundary. The best way would be to build up a multi-regional EEIO model in which imports from each country are treated separately. Apart from being extremely labour intensive, methodological problems remains in practise due to a lack of data and the reconciliation of many different data sources (Lenzen et al., 2004).

There are more methodological issues with EEIO analysis, in particular if EEIO is combined with LCA or multi environmental impact categories are applied. Neither of these is relevant for the purpose of this study. Therefore I refer at this point to further readings. The work of Suh and colleagues is often mentioned in this regard (e.g. Huppes et al., 2008; Suh and Huppes, 2002; Suh et al., 2004).

2.3.2. Household Metabolism Approach

Calculating the energy requirements and CO2 emission associated with household consumption was first developed and published in 1995 by Biesiot and Moll (1995) and Vringer and Blok (1995), and can be seen as a new chapter in the field of energy analysis and lifecycle analysis (Biesiot and Noorman, 1999). Subsequent to this, the methodology and variations thereof have been well described in the literature.

A general comparison of the applied methodologies for the household metabolism approach using mainly EEIO analysis was made by Kok et al. (2006). Giro and De Haan (2009) recently introduced a fourth method that uses EEIO analysis but pure LCA data in combination with household expenditure data.

Four methods can be distinguished:

[7] Note: the term 'hybrid flow account' is used for two different accounting purposes. Firstly it is used to compare monetary unit flow with physical unit flow in order to analyse and account for gains, losses compared to transferred goods used in ordinary accounting in micro and macroeconomics. Secondly, in the way that it is used in this thesis, regarding environmental concerns. The main purpose in both cases is to align monetary flow with physical flow of a certain material.

- Input–output analysis, with all data based on national accounts (EEIO-basic)
- Input–output analysis combined with household expenditure data (EEIO-expenditure)
- Hybrid energy analysis, input–output analysis combined with LCA data (EEIO-LCA-expenditure).
- LCA data combined with household expenditure data (LCA-expenditure)

Kok et al. tested the first three methods on data from the Netherlands and found a difference of less than 4%. The result of the bottom-up method of Girod and De Haan (2009) compared with the mainly top-down methods of the other studies shows that results are within the range of other studies on GHG emission. Also, the relative share of GHG emissions from shelter, food and mobility (the most important categories regarding GHG emissions) are within the range of other studies, although variations do occur.

These are important findings for the current study. I used the second method with EEIO analysis for impact allocation to sectors and goods in combination with detailed expenditure data from a consumption survey. Although there are no detailed LCA data available for most of South Africa's sectors and goods, it was shown for other countries that EEIO analysis can deliver fairly accurate results.

2.3.2.1. Accounting for Differing Goods Quality

While much thought is given to errors arising from equalisation of monetary and physical units in EEIO analysis, surprisingly little effort has been made to quantify physical flow by final household consumption, even though it is apparent that different income groups not only consume different amounts but also consume completely different kinds of goods. Judging from marketing orientated research, the consumption behaviour for different income groups seems to have been comprehensively investigated (e.g. Bils and Klenow, 2001). The so called 'Engel-curve' can be used to describe how household expenditure on a particular good or service varies according to household income. Girod and De Haan (2010) are the only authors who address this problem in conjunction with environmental impact by using functional units such as kg, hours (services) and square meters (living) instead of expenditures. The effects of this are massive, according their study for Swiss households; elasticity of GHG emissions to expenditure is reduced from 1.06 to 0.53. The related key question is: does higher price per functional unit lead to higher GHG emissions per functional unit as assumed by the method that assigns GHG emissions to monetary units? This question, also posed by Girod and De Haan (2010), was answered by Giro and De Haan (2010) citing the two studies done by Vringer and Blok (1996, 1997)[8] in which it was found that energy requirements increase with quality but less than linearly with price. They acknowledge that this can be true for many commodities but emphase that this is not universal. They further argue that higher prices also can lead to less environmental impact. In their case, local (Swiss) and/or organic food is more expensive but has less environmental impact as shown by several studies. For non-food products, the environmental performance of regional products is often better in OECD countries because of more efficient production processes and stricter environment standards than those applied to cheaper East Asian imports. They also argue that more expensive goods are likely to have longer lifetimes, which can help to reduce environmental impact.

The question seems to me not only a technical but also a philosophical one: How do we account for different prices of similar goods? For example, meat from the same animal can easily differ in price per kg more than ten times. Is it still reasonable to use kg when we know that production volume is set according to demand for prime pieces? For example, chicken in the EU is produced and sold for breast and legs and the rest is given away "under price" (Lovell, 2012). There is also the question of how the accounting should be done for second-hand goods such as used cars – according to the proportion of km driven, the number of years used, or according market prices?

However, Girod and De Haan admit that the reduction in elasticity from 1.06 to 0.53 is probably somewhat optimistic, and that future research needs to be done involving "quality" and impact.

2.4. Interpretation and comments

Although the above review of completed studies shows a clear correlation between household income and total GHG emission, no general relationship can be observed about the elasticity. Both total elasticity and its evolution along the income group differ considerably between countries. The findings also vary depending on the factors other than income, and they vary in their interrelationship. It will be interesting to see how South Africa fits into the picture, particularly regarding the two studies for developing countries. It is questionable whether the study from Brazil is directly comparable because of its selection of households in an urban environment only and the special case of the increase of the number of household members with income growth. However the study from India, with the inclusion of non-commercial energy carriers, in addition to the large income range covered, will be a useful benchmark.

[8] The original studies could not be accessed.

Reviews from the field of EKC conclude that these kinds of studies are very sensitive to assumptions made, boundaries set, and data sets used (Harbaugh et al., 2002; List and Gallet, 1999). Little to no concerns were found to be expressed in journal articles about the quality of, and possibility of bias and errors in, the underlying data such as those from income and expenditure surveys, as well as for the results. However, the mentioned data sets are generally deemed as reliable and appropriate for the purpose of this kind of study. Generally I share the opinion. However, more reflection critical analysis, such as attempts to verify results from other points of view rather than by using a narrow comparison with the work of others doing exactly the same could improve construction of theory and reliability and validity of results.

Despite the dominant academic discussion about relative decoupling of energy use and income growth at a country as well as at a household level, it is important to keep in mind that if incomes rise additional money is spent, resulting in an increased environmental burden. It requires an incredible shift in behaviour and major efforts in applied technology to compensate for the additional expenditure required. As mentioned at the beginning of the dissertation, general observation renders it obvious that environmental sustainability cannot be reached without eradicating poverty. However the question remains as to how this awareness and concern correlates with the general observation of the increasing environmental impact of increasing income. An optimistic view would link this to the fact that many of the studies in this review measure only the direct impact. The available data sets, and the methodology applied, are insufficient to describe the totality of human activities. Improvements on a structural level, together with the will of government and policy makers to continue on a more sustainable path seem, in very recent studies, to be showing results, as indicated by the achieved relative decoupling of economic growth and environmental impact (Fischer-Kowalski et al., 2011; OECD, 2011). The current trend to increasing global energy demand will hopefully come to be seen as insufficient on its own to assess the overall progress towards a more sustainable society.

3. Methodology

3.1. Hypothesis and Overview

The literature review indicates that the GHG intensity of an economy is determined by its energy production, economic structure, and the consumption behaviours of the population. According to the literature, South Africa clearly faces challenges posed by its energy production and in all probability by its economic structure, particularly with regard to export. The consumption behaviour of the population is heterogeneous due, in all likelihood, to the high income disparity between different population groups. It will be interesting to establish whether the average household consumption is more GHG intense than other final demand categories. Whether the heterogeneous consumption pattern results in significantly different GHG intensities per income group is also not clear at this point. The following hypothesis was formulated during the planning of this research and prior to the completion of the final version of the literature review (Piaget, 2012).

Hypothesis:

The total environmental impact depends marginally on income distribution.

Drawing from the literature review it is possible to state that, in order to confirm the posed hypothesis, a relative constant GHG intensity throughout the whole income range is required.

Even though the literature review makes it appear less likely that a constant GHG intensity throughout the whole income range will be found, it is possible that the income distribution in South Africa affects GHG emission only marginally, not least because it has been shown that Brazil, a country similar to South Africa in some aspects, has a constant GHG intensity (Cohen et al., 2005). Hence, I will retain the original hypothesis and use it to challenge my own research. Firstly, the hypothesis clearly addresses the core of this research. I would argue that any modification would not contribute to a more comprehensive understanding of poverty alleviation on GHG emission in South Africa. Secondly, a comprehensive analysis of South Africa's economy and household consumption is required to test the hypothesis, in the course of which many key related questions will be addressed. Therefore the existing hypothesis appears to perform a useful function in in structuring and guiding this chapter on methodology, as well as those presenting the results and the discussion.

Many analyses of the economy and household consumption in regard to environmental impacts within a country have been done to date. In this process an EEIO analysis is usually conducted. The method is well established and generally believed to be suitable for environmental impact accounting on a national level. The method is sensitive to the underlying datasets and assumptions, but it has been proven that the EEIO analysis model is of a potentially high accuracy (see section 2.3 Methodology review). The following chapter describes how the EEIO analysis for South Africa has been conducted and the results obtained.

Three datasets, viz. South Africa's Final Supply and Use Table 2005/2006 (Stats SA, 2005); Income and Expenditure of Households 2005/2006 (Stats SA, 2008a); and Energy Balance 2006 (Subramoney et al., 2010) were compiled to build the final research database. Derivation of an Input-Output table (IO-Table) from a Supply and Use Table (SUT) according to the United Nations' System of National Accounts (UN et al., 2009) and its extension with environmental information by applying conventions and methods given in "Environmentally extended Input-Output tables and models for Europe" (Tukker et al., 2006), are the principal steps to allocate South Africa's greenhouse gas (GHG) emissions arising from energy consumption to industry sectors. By merging the thus obtained dataset with information on household consumption patterns given in the Income and Expenditure Survey (IES), GHG emissions from consumption and production were allocated to different income groups. By assuming that today's poor will have similar consumption patterns once migrated to a higher income group as those who are already in that particular income group, effects of economic growth and income distribution were studied.

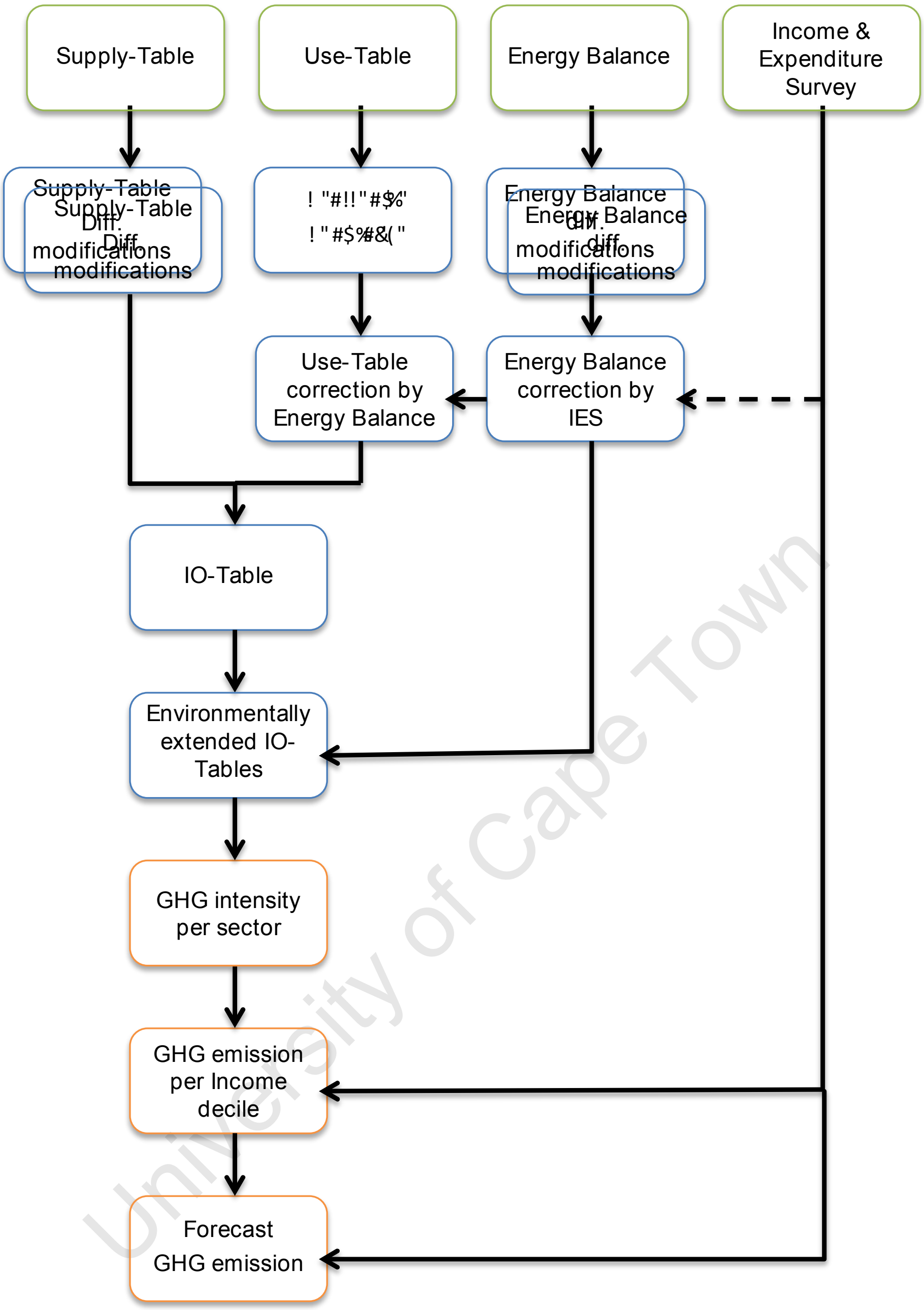

Figure 5: Principal data flow; green are original data sets, blue principal merging and derivation steps, orange main results

In the following sections, all research methodology steps are described in detail. Special attention is given to all assumptions made. Assumptions are always debatable and some of those made are heroic. I will explain the way the assumptions are made and how they influence the results.

3.2. Derivation of Input-Output Table from Supply and Use Table

3.2.1. Introduction to Input-Output Tables

Input-Output analysis is a method used to describe and analyse national economies. In the 1960s Leontief developed the method and received the Nobel Prize in economics for it in 1973. The SUT and resulting IO-Tables are often regarded as the cornerstone of a System of National

Accounts (SNA). They have both statistical and analytical functions. As a statistical tool they serve as a co-ordinating framework for economic statistics, both conceptually for ensuring the consistency of accounting frameworks and for ensuring the numerical consistency of data obtained. As an analytical tool, SUTs serve as a basis for calculating the economic data contained in the national accounts, and they are conveniently integrated into macro-economic models in order to analyse, among others, final demand and industrial output levels. As IO-Tables they can show the interrelationships between industries in an economy with respect to production and need of products. With satellite account matrices, IO-Tables can be used in many specific fields of interest (UN, 2000; UN et al., 2009).

SUTs are always the basis of IO-Tables. In their basic form, Supply tables show the supply of goods and services per sector, and as whole show the product mix of a certain system (country) in monetary units. The Use Tables contain information about the use of goods and services as intermediates by other sectors and as final demand. Added value and import figures are usually integrated as well.

Supply table

	Industries			Total		
Products	Agriculture	Industry	Service	**Domestic production**	**Imports**	**Total supply**
Agricultural products	270	30	50	350	20	370
Industrial products	10	430	100	540	50	590
Services	20	40	550	610	30	640
Total	**300**	**500**	**700**	**1 500**	**100**	**3 100**

Use table

	Industries			Final demand			
Products	Agriculture	Industry	Service	Final consumption	Capital formation	Exports	**Total use**
Agricultural products	30	50	140	80	20	30	350
Industrial products	90	100	70	120	100	60	540
Services	60	100	70	290	60	30	610
Imports	30	40	15	5	5	5	100
Value added	90	210	405	0	0	0	705
Output	**300**	**500**	**700**	**495**	**185**	**125**	2305
Imports							
Agricultural products	**4**	**9**	**3**	**1**	**1**	**2**	20
Industrial products	**16**	**19**	**7**	**3**	**3**	**2**	50
Services	**10**	**12**	**5**	**1**	**1**	**1**	30
Total	**30**	**40**	**15**	**5**	**5**	**5**	100

Figure 6: A simple Supply and Use table (UN, 1999)

In the above SUT example, three products are produced by three sectors, e.g. the sector "Agriculture" produces agricultural products to the value of "270", industrial products to the value of "10" and services to the value of "20". From the Use-Table we know that the "Agricultural" sector requires agricultural products to the value of "30", industrial products to the value of "90" and services to the value of "60" to produce their goods. The example illustrates that one sector produces a wide range of products of which many are not associated with this particular sector. The average input necessary for a good differs considerably between the sectors, which produce this particular good.

The information in such an SUT is derived from a wide range of sources. For the compilation of South Africa's SUT 2005, industrial surveys, household surveys, investment surveys and foreign trade statistics are mentioned to be the most important sources. It is apparent the quality of information in SUT and IO-Tables depends very much on the underlying data and the assumptions made.

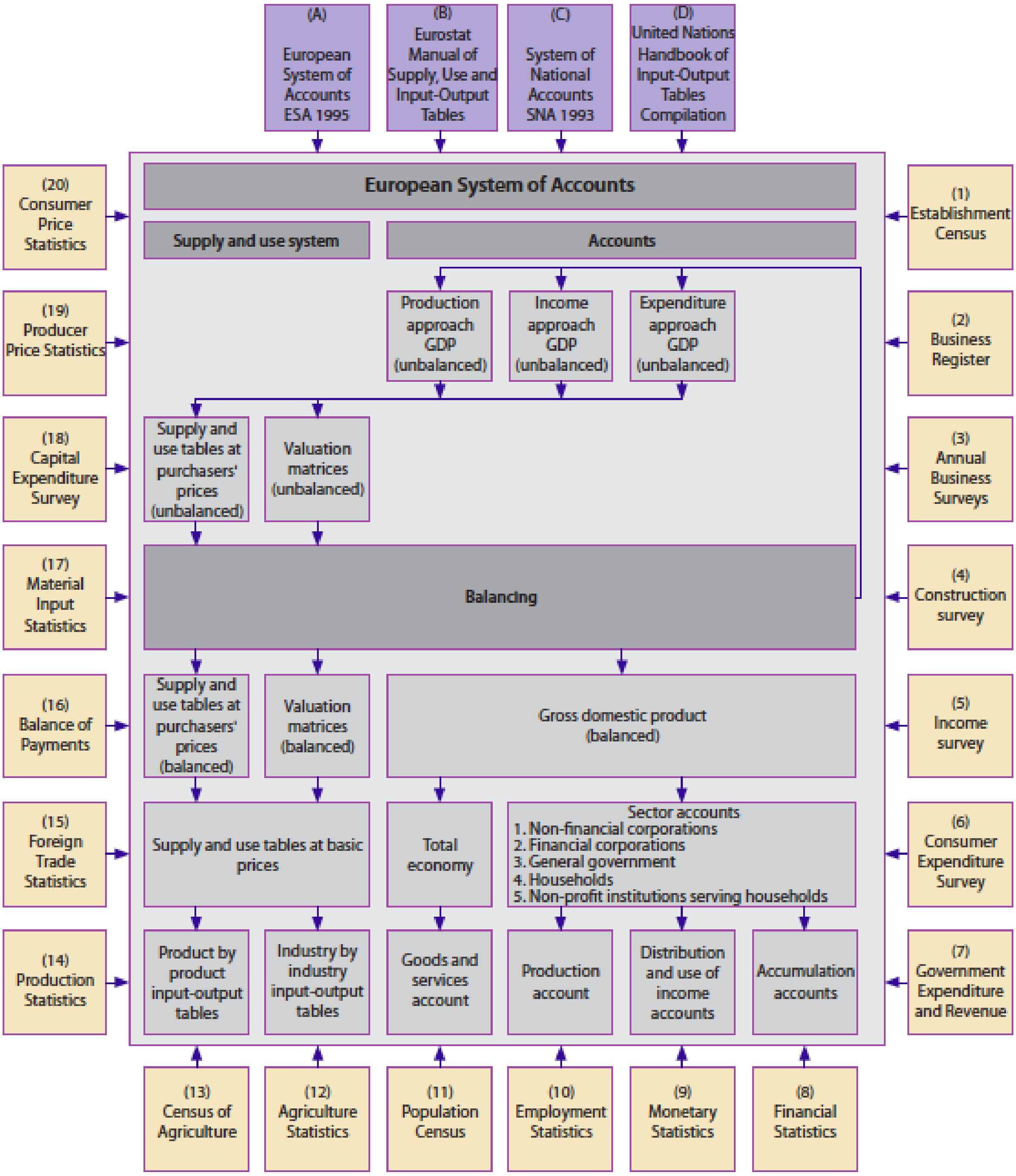

Figure 7: System of information to compile SUT and IO-Tables and possible outcomes thereof (Eurostat, 2008)

Currently, many countries publish IO-Tables with a typical resolution of 50 to 150 sectors and goods. However, no appropriate IO-Table was found for South Africa. South Africa has published an SUT for the year 2005/2006 (Stats SA, 2005) and is currently compiling IO-Tables based on the SUT data of the year 2009. The current timeframe suggests that an experimental IO-Table will be published in 2013 (Lehohla, 2012).

There are many different ways to derive IO-Tables. The main transformation systems distinguish between product-by-product and industry-by-industry IO-Tables. For both there exist several sub-methods and hybrids thereof. In regard to using the IO-Tables for environmental extensions, an industry-by-industry approach is strongly recommended (Tukker et al., 2006). Since this dissertation is not about compiling IO-Tables, only the chosen path is described.

3.2.2. Compiling Input-Output table from Supply and Use table

The methodology used strictly follows the instructions given by Eurostat (Eurostat, 2008). The database was the SUT at purchaser prices derived by Mason-Jones (2011) from the original published SUT (Stats SA, 2005). It was necessary to convert the original SUT to a comparable price basis. Given supply at basic prices was corrected by taxes less subsidies and transport and trade margins to obtain supply at purchaser prices.

The following steps were undertaken to compile an industry-by-industry IO-Table.

In order to derive the IO-Table from the SUT it is necessary to have the SUT in quadratic form. Therefore the SUT had to be transformed from a 104 x 171 (products x sectors) into a quadratic 104 x 104 table. The given industry sector distinction in the SUT is similar to the International Standard Industrial Classification (ISIC) third level code. To reduce the number of sectors, they were principally aggregated to groups according to ISIC second level. ISIC second level contains only 66 sectors. Therefore some of the sectors remained split, aiming for the best possible resolution of 104 x 104 sectors. The criteria to aggregate a sector or not was the share of total supply at third level. All sectors with a share more than 0.2% of total supply remained disaggregated, except ISIC "Government" (O84), "Manufacture of textiles" (C13), "Manufacture of rubber and plastics products" (C22) and "Specialized construction activities" (F43). These sectors have been aggregated in regard of the further use of the IO-Table in combination with IES when these sectors are of less interest compared to the remaining disaggregated "Manufacture of food products" (C10).

Assuming that the Energy Balance (Subramoney et al., 2010) reflects usage of energy more accurately than the general SUT, the Use-Table was corrected for the four major energy products: "coal and lignite" (P5); "electricity and gas" (P8); "petroleum products" (P38); and "electricity distribution" (P88). To do so, the total amount spent on each of the four energy products was redistributed to the 23 industry groups named in the energy balance, and then further distributed to the related sectors according to their share within the industry group stated in the original Use Table. With this modification, the flow of physical energy within the economy is more accurately described than cash flow than in the SUT (Ukidwe and Bakshi, 2005). More details are given in section 3.3.2.2 Correction of Use-Table by Energy Balance.

The so gained quadratic and corrected SUT were then transformed into an industry-by-industry IO-Table (104×104) based on fixed product sales structure assumption (each product has its own specific sales structure, irrespective of the industry where it is produced) as described in Eurostat Manual of Supply, Use and Input-Output Tables (Eurostat, 2008) as Model-D. The details of this are outlined below.

Supply table

Products	Industries			Total Domestic production	Imports	Total supply
	Agriculture	Industry	Service			
Agricultural products						
Industrial products		V^T		q-m	m	q
Services						
Total		g^T				

Use table

Products	Industries			Final demand			Total use
	Agriculture	Industry	Service	Final consumption	Capital formation	Exports	
Agricultural products							
Industrial products		U_d			Y_d		q
Services							
Imports		U_m			Y_m		
Value added		W					w
Output		g^T			y		

Input-Output table - industry-by-industry

Indusries	Industries			Final demand			Total use
	Agriculture	Industry	Service	Final consumption	Capital formation	Exports	
Agricultural							
Industry		B_d			F_d		q
Service							
Imports		B_m			F_m		m
Value added		W					w
Output		g^T			y		

Figure 8: SUT and IO-Table in matrix notation and nomenclature of Eurostat (Eurostat, 2008).

Notes: V = Supply matrix (product by industry), V = Make matrix - transpose of supply matrix (industry by product), U = Use matrix for intermediates (product by industry), Y = Final demand matrix (product by category), F = Final demand matrix (industry by category), B = Matrix for intermediates (industry by industry), W = Value added matrix (components by industry), y = Vector of final demand, w = Vector of value added, q = Column vector of product output, g^T = Column vector of industry output.

The SUT on the one hand and the four principal IO-Tables on the other hand, together with their related transformation matrix "T", build a consistent matrix system which allows the conversion from one into the other. Figure 8 shows an SUT as a set of matrices and the resulting IO-Table in its set of matrices. While Supply matrix "V^T" and Use matrix "U" are constrained to be square, all other matrices are of rectangular shape with different row-to-column ratios. The notation uses capital letters for matrices and lower cases for vectors.

The mathematical compilation of the IO-Table from the SUT has been made with a fixed product sales structure assumption regarding the further use in environmentally extended Input-Output analysis. The few necessary matrix manipulations are stated in Equation 1 and Equation 2 (nomenclature of Eurostat).

Equation 1 $$\boldsymbol{B} = \boldsymbol{T} \times \boldsymbol{U}$$

with B = matrix for intermediates

T = transformation matrix (T = V x (diag(q)-1)

V = make matrix (V = V^T)^T)

and

Equation 2 $$\boldsymbol{F} = \boldsymbol{T} \times \boldsymbol{Y}$$

with F = final demand matrix (industry by industry)
T = transformation matrix (T = V x (diag(q)$^{-1}$)
Y = final demand matrix (product by industry)

The result of this is the IO-Table with fixed product sales structure assumption (for the complete IO-Table see Appendix 7.1 IO-Table).

The so gained IO-Table is of the most basic form. It should not be seen as a discrete result due to modifications of the Use-Table (see section 3.3.2.2 Correction of Use-Table by Energy Balance) and lack of appropriate treatment of import, export and added value. It serves only for the environmentally extended input-output analysis for domestic GHG emission, which is described in the next section.

3.3. Environmental Extension of Input-Output table

Environmental extension is one of many possible satellite systems of Input-Output tables. With satellite matrices, areas of interest can be analysed by adding information of special concern without interrupting the central system.

The central IO-Table provides the economic structure of a system by describing monetary transactions between market actors. If such a system is conclusively extended with information such as sectorial emissions or resource use then systems can be analysed to this regard. This top down method is a tool capable to analyse effects of changes in the economic structure but also in the area of interest e.g. environmental policy analysis (Eurostat, 2009, 2008; Tukker et al., 2006).

3.3.1. The general Equation for Environmental Extension

The following description of environmental extension flows closely the Eurostat manual "Environmentally extended input-output tables and models for Europe" (2006). The matrix for intermediates in the IO-Table (see Figure 8 - matrix-B) shows for each sector the consumption of goods and services of various other sectors that is necessary to produce its own output. A matrix "A" (r×r) can be defined by dividing the elements of matrix-B by total output q^T such that each column of "A" shows the necessary intermediate inputs of each other sector to produce one unit (in monetary terms) of output of that particular sector. Matrix-A is usually referred to as the technology matrix.

Equation 3

$$a_{ij} = \frac{b_{ij}}{q_j}$$

$$with\ A = a_{i,j}\ _{i=1,\dots,m;\ j=1,\dots,m}$$

$$B = b_{i,j}\ _{i=1,\dots,m;j=1,\dots,m}$$

Having final demand (vector y) and total supply equal to total use (market balance $q \triangleq g^T$) then the amount produced (q) is exactly equal to the amount consumed by sectors (Axq) plus the amount of final consumption (y). Hence, general matrix equation can be written:

Equation 4

$$A\,q + y = q$$

Thus, total Supply needed to satisfying final demand is calculable by:

Equation 5

$$q = I - A^{-1}\,y$$

with I = r×r identity matrix

Equation 5 donates the economic structure of the system. It is also used to analyse effects of change in final demand (Δy) onto total industry output (Δq) (see section 3.5.2 Determining sectors with significant contribution to future GHG emission).

Adding an environmental description to each sector by defining a matrix "E" provides the environmental extension. Matrix-E shows the amount of resources consumed and pollutants emitted per unit monetary output of that sector. The underlying assumption is that all goods produced by a certain sector require the same inputs of resources and input is proportional to the amount of output. This necessary simplification does not always reflect reality. For example, agricultural products vary in GHG intensity (e.g. meat compared to wheat) but all products are sold with the average GHG per monetary unit. Matrix-E has the dimension k×r (k environmental factors by r sectors) and is usually called the environmental intervention matrix. In our case the environmental intervention matrix has the dimension 1x104, being the GHG emissions in tCO2e per mZAR by 104 sectors.

Equation 6 $$\boldsymbol{m} = \boldsymbol{E}\ \ \boldsymbol{I} - \boldsymbol{A}\ ^{-1} \boldsymbol{f}$$

with m = total direct and indirect environmental impact
E = environmental intervention matrix (e×r)
I = identity matrix (r×r)
A = technology matrix (r×r)
f = final demand vector (r×1)

Direct and indirect environmental impact (m), caused by a certain final demand, result from matrix multiplication of matrix E with final demand vector f. Or, if one is interested in the contribution of different final demand categories, a final demand matrix F (r×n) (consumption from r sectors by n final demand categories) is used and to get M (k×n) k environmental factors by n final demand categories.

It is possible to allocate impacts made by final consumption of a product to the supplying sector. I believe that for this work the allocation of direct emissions to final consumption categories delivers better results (see Equation 8 and section 3.3.2 Utilisation of Energy Balance). Regardless of allocation, the method implies that all impacts are made due to final consumption. Behind this is the view that only consumption drives production. Therefore indirect impacts caused by production are added to direct impact of consumption. If there is only one final consumption category, this accounts for 100% of the countrywide impacts (or according other boundaries).

It is very important to note that with Equation 6 the resulting figures contain only impacts made by (or assigned to) the industry sectors to enable final consumption. Final consumption groups can also contribute to a certain environmental impact. This direct impact has to be added in order to get total direct and indirect impact. For example if someone purchases in South Africa in the year 2012 petrol for one Rand, 0.3 kg GHG was already emitted in order to produce this petrol according to the results in this study. This is the indirect share. If this person now combust the petrol, about 0.2 kg GHG will be emitted additionally. This contributes the direct emissions by final consumption. Altogether about 0.5 kg GHG will be emitted[9].

Leaving final demand in Equation 6 results in environmental impact per sector and monetary unit output of that sector (matrix "Z").

Equation 7 $$\boldsymbol{Z} = \boldsymbol{E}\ (\boldsymbol{I} - \boldsymbol{A})^{-1}$$

with Z = total direct and indirect environmental impact per sector and monetary unit (k×r)

The Z-matrix here simplifies to the vector of GHG intensity per sector (tCO2e/mZAR) and is one of the central outcomes of this work.

Besides knowing the GHG intensity, it can be also of interest to know total direct and indirect environmental impact caused by the activity of certain sectors (in absolute values). In order to do so, intermediate use per sector was equalised with consumption of this sector. This results in the matrix Equation 8:

Equation 8 $$\boldsymbol{M_U} = (\boldsymbol{E}\ \ \boldsymbol{I} - \boldsymbol{A}\ ^{-1} + \boldsymbol{S})\ \ \boldsymbol{T} \times \boldsymbol{U}$$

with M_U = matrix of total direct and indirect environmental impacts

[9] Note that in this particular example of petrol (gasoline) in South Africa, the ratio of indirect to direct emissions is unusually high, owing to the significant proportion of gasoline made via the carbon-intensive 'coal-to-liquids' technology route.

E = environmental intervention matrix of total impact (k×r)
I = identity matrix (r×r)
A = technology matrix (r×r)
S = Direct Energy Matrix Sik=1 if i=r=Sector with direct emission; Sik=0 otherwise
T= transformation matrix (T=V×(diag(q))-1)
U = Use matrix for intermediates (r×r)

Or more simply in conventional notation:

Equation 9

$$m_{ij} = q_j * Z_{i,j}$$

with mi,j = total direct and indirect environmental impacts for sectors

To derive the environmental intervention matrix, data need to be introduced describing the environmental impact per sector. In our case of GHG, the Energy Balance for South Africa 2005 together with emission factors for major fuels was the primary source of information. Further, if SUT and IO-Table are applied solely, the exchange of goods is strictly set equal to the cash flow (each sector and final demand category receives exactly the same amount of a good per monetary unit). In reality this is not the case. For environmental analysis it would be of great benefit if data could be corrected in a way to represent the flow of goods in natural units (e.g. tons) rather than describing the economic relationship (Ukidwe and Bakshi, 2005). For the primary distribution of fossil fuels and electricity, the Use-Table was corrected by the information given in the Energy Balance.

The following section describes the compilation of the environmental intervention vector for GHG emissions and the correction of Use-Tables with the information given in the Energy Balance.

3.3.2. Utilisation of Energy Balance

The analysis focuses on the GHG emissions originating from energy consumption. GHG emissions from other sources, such as methane arising from agricultural activities or methane fluctuation by coal mining, are not taken into account. The primary source of data is South Africa's Energy Balance 2005/2006 (Subramoney et al., 2010). In addition, I took advantage of the work done by Mason-Jones and Notten (2011) reworking of the Energy Balance. Corrections for higher calorific value of exported coal, usage of crude oil and biomass for auto-producer of electricity were made. Including methane and nitrous oxide arising from fuel combustion, a total of 467 $MtCO_2eq/a$ was calculated. This is comparable to other published estimations for South Africa's total GHG emissions. U.S. Energy Information Administration (EIA) estimates 445 $MtCO_2/a$ emissions (excluding other GHG than carbon dioxide) from combustion of fossil fuels for the year 2006 (EIA, 2012) and South Africa's Millennium development Goals Country Report 2010 reports 434 $MtCO_2/a$ emissions (also excluding other GHG than carbon dioxide) for the year 2007 (Republic of South Africa, 2010).

Two slightly different ways to allocate the GHG emissions were used. Theoretically, the two allocation methods should deliver the same results. Because of the aggregation of dissimilar products and because the cash-flow in the IO-Table does not necessarily represent the flow of goods, the results are different for certain sectors. A principal disadvantage of Input-output analyses, and all similar methods, is the aggregation of dissimilar products. The aggregation of dissimilar products in our case means that GHG intense products of an industry are equally treated as less intense products. In a situation where a product mix other than the average is purchased, too much or too little GHG are assigned to the buyer. A typical example is the agricultural sector, which produces, among others, live cattle, wheat and accommodation services. But different customers receive the goods. Regardless of which product they really get, the same amount of GHG per Rand is assigned to the buyer. This bias results randomly. Assuming the Energy Balance is correct, direct GHG emissions can be fed into the economic system at different points in the production chain (allocation method one). I believe this delivers better results than allocation of GHG solely to the sectors sourcing fossil energy at the very beginning of the production chain (allocation method two).

3.3.2.1. Correction of Energy Balance by Household Expenditure

Additionally to the above-mentioned modifications by Mason-Jones & Notten, further corrections were made for the final consumption of combustible fuels using figures given in the 2005 IES, assuming total energy consumption by residential location is correct in the Energy Balance but that IES reflects the split of energy products better.

Keeping the figures in the Energy Balance for Coal, Petroleum Products and Solid Biomass and assigning the related GHG emissions to income groups according to percentage in IES would lead to the result that the poorer half of the population emit more than half of total direct GHG from combusting fuels, while spending only about 9% of total expenditure for combustible fuels. The corrections are of high relevance because of wide influence to GHG intensity per decile and all affiliated results. The corrections for residential usage of Coal, Petroleum Products and Solid Biomass are therefore outlined in detail.

Coal

The original Energy Balance states 9,993,044 tons or about 19% of South Africa's total final consumption (excludes energy sector) is by residential usage. This made expenditures of about 2 billion Rand for coal assuming a very low price of 200 ZAR/t (Eberhard, 2011). IES only reports expenditure for coal of about 1 billion Rand. However, for consistent GHG intensity per income decile it is necessary to keep the level and mix of energy usage according to IES levels. A correction of residential coal usage by a factor of 0.5 was therefore made. Having the residential sector accountable for 1.5% of total domestic usage of coal is in line with the reworked Energy Balance for the year 1998 of Blignaut et al (2005).

Petroleum products

While the total amount of petroleum products (almost solely fuels) in the Energy Balance agrees very well with the sales figures of SAPIA (2008), it is questionable if the split between industrial and residential usage is correct.

The original Energy Balance reports 1,191,347 kl of petroleum products for final usage by the residential sector. By the known price of 5.23 ZAR/l (January 2006) this results in total expenditure of 6.2 billion Rand for petroleum products according to the Energy Balance. But IES contains the figure of 26.2 billion Rand for petroleum products and the original Use-Table states 40.4 billion Rand. Correcting the Energy Balance with the figure given in IES leads to a total usage of petroleum products by the residential sector of about 20%. Considering that 68% of all vehicles registered in 2006 were private owned (Merven et al., 2012) this seems more realistic than the 5% share in usage of petroleum products as stated in the original Energy Balance. The reworked Energy Balance for the year 1998 of Blignaut et al. (2005) also finds that only 3.7% of petroleum is direct combusted by the residential sector, but 60% of fuel is unspecific assigned to the trade sector. However, the Energy Balance was corrected according to the IES, which means an up-scaling of residential usage of petroleum products by 4.2 times.

Solid Biomass

The Energy Balance estimates usage of Solid Biomass (predominantly wood) by the residential sector to be 190400 TJ or about 39% of Households total primary energy supply (inclusive of electricity). Assuming a low caloric value of 15 MJ/kg and a price of 0.45 ZAR/kg wood results in annual expenditure of 5.8 billion Rand or an average of 470 ZAR/a per household for solid biomass. IES reports 0.8 billion Rand (estimated value for free collected wood taken into account). Literature values for wood usage in the Northern Cape are closer to the value given in the Energy Balance (Wise et al., n.d.).

In this case the Energy Balance is rather realistic. But the Energy Balance was corrected to meet the values of the IES. To avoid bias in the GHG emissions per income decile, the reported mix of energy products per income decile overrides the summarised use of energy products in the Energy Balance. Without correction, solid biomass accounts for 57% of the direct emissions by residents. Since only the poorer half of the population uses a relevant amount of solid biomass, these emissions would be exclusively assigned to them in addition to the also mainly used coal. Non-commercial fuels such as wood are often used with poor efficiency leading to a relative high primary energy demand in low-income households. However, having a scenario in which the poorer half of the population emit much more GHG then the richer half of the population while only contributing 9% of the expenditures seems not to describe the reality.

The usage of wood was reduced by factor 7.1 in the Energy Balance.

Total Scaling

The share of residential usage of combustible fuels was assumed to be best estimated by Energy Balance. In order to meet the total amount direct combusted fuels by residential in TJ, the above mentioned energy products were up-scaled by a factor of 1.38 above and additional to already made individual corrections. Therewith direct GHG emission by the residential sector is 7% of South Africa's total emissions. This figure was also found by Blignaut (2005).

3.3.2.2. Correction of Use-Table by Energy Balance

The Use-table was corrected for the sale of the energy products "Coal and lignite", "Petroleum products" "Electricity and Gas" and "Electricity distribution" according the figures in the modified Energy Balance. But no correction was made for agricultural and forestry products which are the source of energy products "solid biomass". The agricultural sector supplies its product to many sectors. A modification of the sales structure of the agricultural sector would be inappropriate. For the other mentioned energy products, the total supply in Rand was kept constant but redistributed according to the usage in the Energy Balance. This leads to significantly higher expenditure for energy products by energy intense sectors. For example, after correction the sector "Electricity and gas" purchases slightly more than the half of all "Coal and lignite", while it was less than a quarter in the original Use-Table.

This adjustment is important to reflect the attribution of indirect GHG emissions in South Africa's economic system more accurately than the purely economic-based original Use-Table does. This modification affects only the Use-Table. It changes the required input by sector in order to produce its output. The output of each sector in the Supply-Table has not changed. In order to keep the Supply and Use-Table balanced, the difference must be compensated in the added value. Therefore the resulting IO-Table is not suitable for further economic analysis.

3.3.2.3. Compiling GHG intervention vector (sector allocation)

Finally, the following steps were undertaken to compile the environmental intervention vector for GHG emissions.

The given energy consumption per industry sector and energy carrier in TeraJoule (TJ) was transformed into Carbon dioxide equivalent (tCO_2e) by using emissions factors published by the IPCC (IPCC, 2006a).

The 54 energy carriers used in the Energy Balance were aggregated to the four distinguishable energy carriers in the SUT (coal and lignite, electricity and gas, petroleum products and solid biomass).

The 104 distinguished sectors in the SUT were allocated to their 23 main groups used in the Energy Balance (both SUT and Energy Balance using ISIC).

The known GHG emissions for the 23 main groups were redistributed to their sub-sectors according to the share of consumption in the Use-Table. This was done for the four energy carriers mentioned above.

By summation of GHG emissions arising from the four principal energy carriers per sector, and dividing by the total output of that sector, the environmental intervention vector for GHG emissions was compiled.

EEIO analysis on a country level often assumes that imported goods are produced with the same GHG intensity as locally. As discussed in section 2.3.1 "Environmental Extension of Input-Output table" this can introduce considerably large errors. I decided in favour of accuracy and limited the system boundary to the geographical boundary of South Africa for the current study. To exclude embodied GHG emission of imported goods has the additional advantage to be in line with the GHG accounting system of UNFCCC which also use on a spatial approach and excludes induced GHG emission abort as discussed in section 2.1 "Greenhouse gas Intensity of Economics". Accepting that UNFCCC is currently the relevant panel in the matter of GHG emission, a pure spatial approach by GHG accounting can be seen as more suitable to deduce policy implications. However, the model accounts for all physically made GHG emissions on South Africa's territory. GHG emissions made outside of South Africa are not taken into account. Therewith the utilisation of most imports by South Africans is emission free. It is important to note that, imported energy products such as crude oil count towards South Africa's emission if these goods are combusted in South Africa. Imported petroleum products can be utilised with less GHG emission than locally refined petroleum products because GHG emission arising from refining does not count towards South Africa's emission. If imported embodied GHG emission were taken into account the total GHG emission as well the average GHG intensity would be higher. Imports make up for about 12% of the supplied goods in South Africa (Stats SA, 2005). According Arndt et al. (2011) are less GHG intense goods dominant by imports (e.g. machinery and vehicles). Therefore it can be assumed that the GHG intensity and total GHG emissions of domestic consumption would be less than 10% higher if imported embodied GHG were taken into account.

3.4. Integration of the Income and Expenditure Survey

The next major step in the methodology was to expand the SUT's final demand category "Households consumption expenditure" by expenditure pattern per income group contained in the Income and Expenditure Survey 2005/2006 (IES) (Stats SA, 2008a), so as to allocate GHG emissions to different income groups. First, background information about the IES is given and secondly, the data handling is described.

3.4.1. Background to the Income and Expenditure Survey

The IES is, together with the more recognised Census, the main source of information about the living conditions of South Africa's population. The IES 2005/2006 survey period was from September 2005 to August 2006. During this time, 24,000 households were polled about their income and expenditures. All sample households were visited a minimum six times, during which five interviews were carried out. In addition, the households were requested to write diaries about their income and expenditures over a period of four weeks. This generated a data set with over 100 million data points containing information about the sample households possessions, income and expenditure. With such a high number of samples a good mean of households can be assumed, but it doesn't avoid biases.

Among others the following biases are mentioned:

- Households failed to report on non-consumption items such as savings, debts and capital losses.
- Biases arose on the income side whenever respondents under-reported their earnings, either through forgetfulness or out of a misplaced concern that their reported data could fall into the hands of the taxation authority.
- On the expenditure side it is unlikely to have 100% reported. Statistics South Africa observations and international experience show that high-frequency items appear to be under-reported.
- Information about financial expenditures, including various forms of saving, investment and the repayment of principle and interest on various forms of borrowing, are very likely to be misrepresented, as the concepts involved are complex and not easy for households to report reliably.
- The ratio of household income as recorded in the national accounts to that estimated by the different IESs differs significantly from one survey to another. This raises questions about the accuracy of absolute values[10].
- The totals for tax paid reported in the IES recovers only 51% from what is registered by the South African Revenue Service.
- These biases have opposite signs but do not necessarily cancel each other. However, the confidence interval for mean expenditures is 4%[11] (Stats SA, 2008a, 2008b).
- It is also important to note that IES includes "in-kind-income" and "in-kind-expenditure". "In-kind" is defined as all items acquired by households without paying for them, e.g. bursaries, subsidies from an employer, free medical services, private use of a company car or similar vehicle, value of discounted fares for educational purposes, grants from schools and other educational institutions, but excluding gifts and maintenance from other households members (Stats SA, 2008a, 2008c).

For low-income groups, expenditures are higher than income, but above the fifth decile income is higher than expenditure. The IES is clear about the reason for higher income than expenditures but it remains unclear to the reader how low income households can have up to 100% higher expenditures than income. For low-income groups it is assumed that they do not know about their real income and overestimate expenditures, but no clear explanations are given. Investments such as added value to a dwelling or any kind of capital investment do not count towards expenditure. This can explain the large difference for income and expenditure in the higher income tranche. Having such a big difference between income and expenditure, the results for GHG emissions intensity and all related outcomes obviously depend on whether the income or expenditures are considered. Tendencies for GHG intensity as a function of income or expenditure are the same but enhanced in the case of income. Having half of the population with part of their income not spent in the way defined by the IES does not make much sense in regard of this research, which intends to estimate the resulting GHG emissions of all activities by households. Therefore, the division of the population is by income but all results are based on related expenditure patterns for a particular income group. For example, GHG intensity is per Rand spent and not per Rand earned. Higher income groups, who have significant capital formation activity, therefore also have GHG emissions associated with capital formation additional to those resulting from their expenditure as quantified here.

3.4.2. Data handling and integration

Income and expenditure data per household decile (one tenth of all households) were taken from the statistical release of Stats SA (2008a). Additionally, the tenth income decile was split into five equal sub-groups using the original data set[12]. With this, fourteen distinguishable income groups were formed, with the top five constituting the tenth income decile. For each income group, the annual expenditure for 111 goods is listed in the statistical release. For the top decile, the much more detailed expenditure information in the original data set was aggregated to the same 111 product groups. Average income of the richest ten per cent (tenth decile) is 405,617 ZAR/a and 893,761 ZAR/a for the richest two per cent respectively. With division of the tenth income decile, the covered income range for which expenditure patterns are known could be more than doubled. To gain insight into the consumption patterns of the very affluent is important for modelling future GHG emissions as a function of income and income distribution (see section 3.5 Effects of growth and income distribution on GHG emission).

[10] IES 2005/2006 captures 72% of the estimated household income in the national account.

[11] Confidence interval itself is not specified.

[12] Hosted by Data First, University of Cape Town.

Mathematically it is problematic to have unevenly distributed groups. For regression purposes the groups must be weighted. For charts the sub-groups of the tenth decile were named 9.5, 9.75, 10.0, 10.25 and 10.5 decile, thus having a group called "10.0 income decile" but representing the income range of 94 to 96% with less income and less expenditures than mean of the true tenth decile. The true tenth decile is built by the average of the top five income groups.

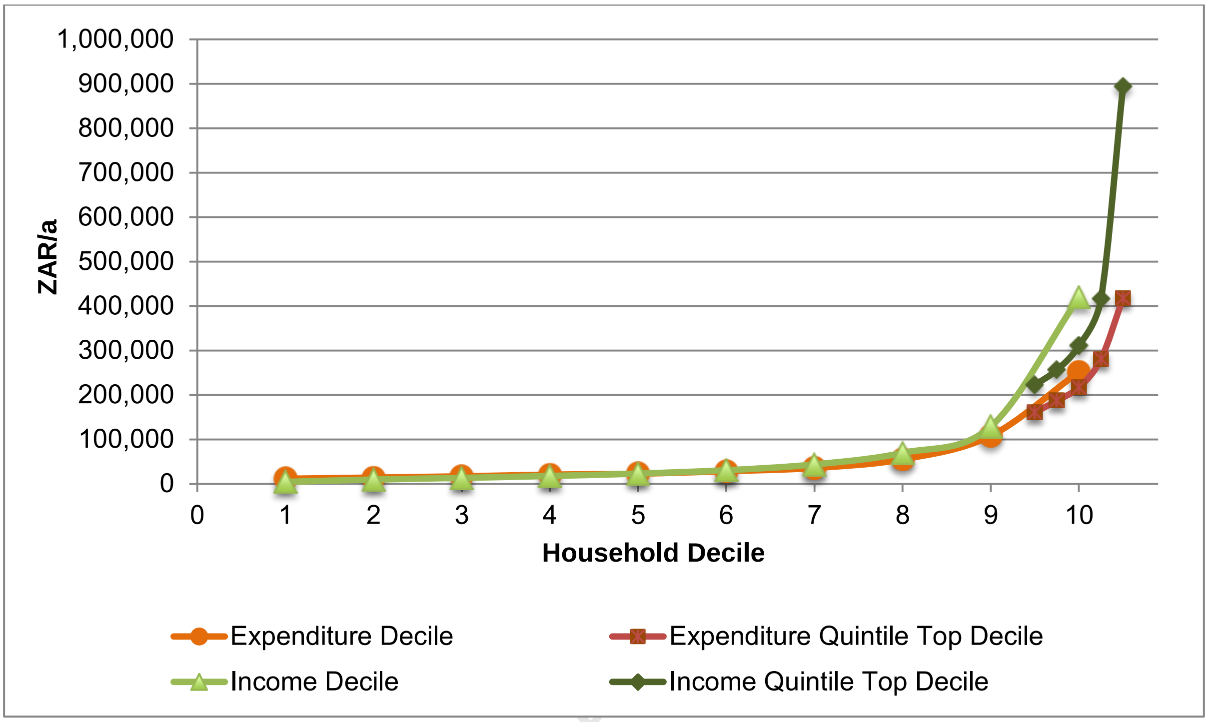

Figure 9: 2005/2006 Income and Expenditure per year and decile. Income inequality within the tenth income decile is almost as high within the whole population.

Expenditures in the IES are classified according to "Classification of Individual Consumption According to Purpose" (COICOP). The goods in the Supply-Table are classified according to the UN's "Central Product Classification" (CPC). By having two well described classification codes it is simple to transform expenditures from COICOP to CPC using a transformation matrix. Unfortunately "water" and "electricity and gas" are different aggregated in both classification systems. CIOCOP aggregates water and electricity distribution. This brings an uncertainty about the actual share of expenditure on "electricity and gas" and "water" as it is aggregated in the CPC. Further, there is a poor distinction between infrastructure costs for water, electricity and gas and the goods as such. Since the derived IO-Table is one of the form Industry-by-Industry and final demand is converted anyway from demand per good into demand per sectors, this does not have high implications. On a sector level no distinction is made between infrastructure and product cost. For those products, as well for the others which are higher aggregated in the IES than they appear in the Use-Table, total expenditure for a particular product group was divided according to the ratio given in the original Use-Table.

Thus, the final demand vector "Households consumption expenditure" in the Use-Table sized 104x1 was extended into a final demand matrix (104x14) containing annual expenditures for 104 goods for 14 income groups. After substituting final demand, the normal matrix manipulation can be performed as described in the previous section. First transformation from final demand per good into final demand per sector according to Equation 2, and then total GHG emissions per income group is calculated according to Equation 6. The total final demand of households according to the IES is only 71% of households' total final demand according to the original SUT. Nevertheless, the resulting GHG emissions from the consumption pattern in the IES are only 15% lower.

Hence the product mix consumed by households is different in the SUT and the IES. The highest relative differences are in the product group "Plaster, cement" (CPC group 374) and "Paint, related products" (CPC group 351) with a positive difference of 990% in the IES compared to the SUT. The highest absolute difference is in the product group "Motor vehicles, parts" (aggregated CPC groups 491 and 492) with higher expenditure in IES of 60'638 million Rand (plus 88%). After conversion of demand per product to demand per sector, the difference between the IES and the SUT became smaller, with highest relative difference of 790% in the sector "Paints, varnishes, printing ink, mastics" (ISIC C20-5) and highest absolute difference of 43'360 million Rand in the sector "Real estate activities" (ISIC L56). These figures are the result of scaled IES expenditures by a factor of 1.43 to have equal total expenditure in IES and SUT for comparing purposes. For a complete list of the differences between SUT and IES see Appendix 7.2. However no scaling of expenditure were done for the calculations of GHG emissions per household group.

Knowing the high impact on results I have tried to convert household expenditures into functional units such as count of items, kg or square meters (see section 2.3.2.1 Accounting for Differing Goods Quality). For example, it was assumed that energy intake per capita is constant (kJ/capita) for the food category or the total numbers of registered cars were distributed among the income groups. All assumptions lead to increasing GHG emission intensity by poorer household and to less GHG emission intensity by affluent. However, this was more or less a rough estimate for which no database exists, and methodological issues remain. Therefore no such conversion is used for the result section of this thesis.

3.5. Effects of growth and income distribution on GHG emission

So far results are descriptive, using the SUT, Energy Balance and IES to describe GHG intensity of South Africa's economic sectors and final demand categories, for different income groups. In the last section, attempts are made to model and forecast GHG emissions. To gain some insights into the major future environmental impacts is taken as essential in this study. Insight into future impacts can help to define the right priorities in research, technology development and policy making to minimize the potential environmental impact. In addition, knowledge of future trends is highly advantageous from an economic planning point of view.

A key factor to incorporate into the modelling of environmental impact by income group is the dynamic nature of income levels at the aggregate level. In a developing country such as South Africa, the size of different income groups is relatively fast changing. With the assumption of positive economic growth there will be more households in a higher income group in the future than at present. Apart from general changes in the society, it is likely that households which move into a new income group will consume a similar basket of goods as those already in the particular income group. From the first part of this research we know the particular environmental impact of a certain basket of goods, and income group, respectively. Based on this, future GHG emissions as a function of economic growth and income distribution could be estimated.

3.5.1. Simulation of growth and income distribution

The very simple approach of redistributing households to income groups was utilised to simulate economic growth and different income distribution scenarios. In practice each income decile contains 1,247,132 households. By assigning the average income of the next decile to some (or all) of them, the average income/expenditure is increased. Those assigned higher income are also assigned the basket of goods consumed by the next decile.

It was chosen to consider economic growth in the range of 0 to 30% and income distribution with Gini-coefficients from 0.28 to 0.83 (see also section "A note on Gini-Coefficient"). To gain 30% growth requires 7.6 years of constant grow at a rate of 3.5%. This is in the range of the long-term forecast of the National Treasury (National Treasury Republic of South Africa, 2012).

It is important to note that the model does not build on GDP growth, as would be ideal. Sectors are different in employment structure and level of GDP contribution. To underlay the model with a simulation of GDP growth as a function of change in final demand and compensation structure of employees is beyond the scope of this work. In lieu of GDP growth, total private expenditure growth and total economic output growth was taken into account, regardless of necessary macro-economic preconditions to make growth happen.

Income growth is also problematic to compare with GHG emissions growth, because income exceeds expenditure by a factor of 1.33 in the IES. Limited information is given about the use of that excess for the different income groups. The assumption can be made that excess is used for tax and private capital formation (any kind). Both are separate final demand categories but more details are required to incorporate these final demand categories into the model. Ignoring excess of income would lead to a strong decoupling of GHG emissions and income growth which will not be observed in reality. Therefore it is unfavourable to compare income growth with GHG emissions growth.

In order to maintain a consistent growth scenario throughout the categories the causality income growth – consumption expenditure growth – production growth – total economical output growth - environmental impact growth is supposed. Therefore the simulation starts with income growth but deviates household's expenditure growth and thereafter output growth from it to compare with consumption and production-based GHG emissions growth. In addition income behind expenditure growth is needed to determine the Gini-Coefficient on the common income base.

3.5.2. Determining sectors with significant contribution to future GHG emissions

In order to produce one unit of a certain good, a certain amount of inter-sectoral trade is additionally required. The environmental impact caused by these inter-sectoral activities is assigned to final demand. The ratio to supply one unit of a good for final demand and the necessary total output of the economy therefore varies considerably between sectors, but has proven to be constant for all tested scenarios. The total output of South Africa's economy grows double that of final demand growth (according the specific IO-Table in this work). With other words, if final demand for an average basket of goods grows by one million Rand, the total output grows about two million Rand. Hence GHG emissions can be plotted as a function of South Africa's total economic output as the second best indicator after GDP[13].

Having the detailed final demand for each sector, total output per sector can be easily calculated according to Equation 5. Each sector has its own relationship between final demand and total output. For example, final demand from the coal sector can drop to zero while total output is still increasing. But food products depend very much on final demand. However, IO-Tables allow identifying sectors with potential high contribution to future GHG emissions by finding the ones with a combination of above average growth and a high GHG intensity.

3.5.3. A note on Gini-Coefficients

Gini-Coefficients are, among others, a statistical possibility to describe distribution of anything within a population of any kind. In economics, Gini-coefficients are often used to describe income and assets distribution within a country. The mathematics can be read elsewhere (e.g. Wikipedia). Zero indicates a totally equal distribution (all have the same) and one a complete inequality (one has all). Many aspects need to be considered using Gini-Coefficients with income distribution. Some of the keywords around the issue are income before vs. after tax, accounting for social grants and other transfers, per household vs. per capita, group median vs. group average, with vs. without income from capital, purchasing power parity, etc. In this work the most common and simple Gini-Coefficient is used, being total income of any kind per Household before tax. It is in the nature of an index that it does not describe circumstance to a full extent. Many distributions can result in the same Gini-coefficient. In order to simulate meaningful income distribution the following income distribution scenarios were applied:

Table 5: Scenarios of income distribution of future growth for modelling purpose

Name	Description
To the Rich	Additional income goes exclusively to the tenth income decile. Decile one to nine keeps their income but do not gain additionally income. This leads to more inequality with income growth from South Africa's current coefficient of 0.72 up to 0.83 after 30% income growth.
Actual Proportions	Total available income is distributed as today. Gini-coefficient is constant at actual level of 0.72.
Brazil	Total available income is distributed according the distribution in Brazil as a country with a similar structure but a somewhat more equal income distribution. Gini-coefficient about 0.64.
Equal share of growth	Each decile gets the same amount of additional income. Equality increases with growing income, from current 0.72 to 0.56 after 30% income growth.
To the poor	All additional income is assigned to the poorest. Rapid growth of equality from today's 0.72 to 0.44 after 30% income growth[14].
Sweden	Total available income is distributed according the distribution in Sweden as the country with the second most equal income distribution. Gini-coefficient about 0.32.

South Africa had, in 2005, a Gini-Coefficient of 0.72 before tax and 0.67 after tax. Therewith it is among the countries with the highest inequality. Recent data indicate a tendency towards even more income inequality for income before tax and stable for after tax (Leibbrandt et al., 2010; Republic of South Africa, 2010; Stats SA, 2008b).

[13] One may assume a constant ratio of total output to GDP within a certain growth and development of an economy. In the year 2005 it was about 2.4.

[14] By the way, if the poorest of the population is given the additional income arising from 3 years of 3.3% grow, all are lifted out of worst poverty and arrive in the today sixth income decile.

3.6. Limitations

The study has limited validity. All results should be seen as indicative only. There are many reasons for this. Firstly, all results are based on complex data sets, and need to be treated with caution. Even if much effort was put into the compilation the variability remains high. Secondly, the principal disadvantage of Input output analyses, and all similar methods, are the aggregation of dissimilar products. The aggregation of dissimilar products in the inter-sectorial trade and by final consumption tends to adjust GHG intensity to the mean. It is likely that the particular type of a specific consumed good is different among different buyers. For example, the total amount spent for food per capita increases by 73% from the South African ninth to tenth income deciles (with variation but to the same extent for all particular food items). It is not very likely that people in the tenth decile eat that much more, rather they do not consume the same type of food. Unfortunately there is no way to avoid this uncertainty as long as expenditures are not listed in a very detailed way and specific environmental data for each subtype of a good are available.

The forecast model has its own and additional limitations. IO-Tables are not sufficient to describe complex macro-economies and their response to growth. Important factors such as technology and population are set to constants. Also, marked effects e.g. rising prices for high-demand products with limited availability, such as land and new national and international regulations, are not simulated. Further, only direct effects of affluence are determined. Indirect effects, such as acceptance and willingness for structural changes in terms of environmental sustainability, cannot be determined with the method. But it is not only important which goods are consumed but also how the goods are produced. The way goods are produced depends very much on general policy, which in turn depends on the population and their willingness for structural changes. So, maybe half of the effects are left out completely.

However, the simulation as it is in this study can be used as a ceteris paribus baseline model. It determines the pure effects of increasing affluence in the South African context as accurately as possible. It could be combined with forecasts of technology and demographic developments to model the future more realistically.

4. Results and Discussion

In the process of analysing an entire economy and its population it is inevitable that a sizeable volume of data will be produced. I believe that such volumes of data are most accessible in the form of tables and graphs. In order not to overload the chapter, a digest of tables is used but the complete tables can be found in the appendix. The chapter starts with the analysis of South Africa's production regarding GHG emission intensity and total direct and indirect emission per sector. In the second part, the consumption section, firstly the findings for the different final consumption categories as given in the SUT are presented and then an in-depth analysis of final consumption by households is conducted. Finally, I forecast GHG emission arising from household consumption as a function of economic growth and income distribution.

4.1. Greenhouse Gas Intensity of South Africa's Production

The analysis of production in this thesis is made from a domestic perspective. It looks at GHG emissions resulting from domestic activities. The analysis includes impacts from production of goods for export but excludes induced impacts abroad by consumption of South Africans.

4.1.1. GHG intensity; emission per ZAR output and Sector

The first result of EEIO analysis is the direct and indirect environmental impact per monetary unit and sector. In the case of South Africa, this is the GHG emission per Rand of each of the 104 of South Africa's economic sectors as distinguished in the SUT. According to the way GHG emissions are allocated and the method used, sector GHG intensity is defined as kg carbon dioxide equivalent per Rand gross domestic output (kgCO2eq/ZAR). It includes cumulative embodied GHG and all direct emissions produced by the sector necessary to produce its average goods to the value of one Rand.

The 'Electricity and gas' sector, with its enormous consumption of coal, has, with its 4.2 kgCO_2eq/ZAR, by far the highest GHG intensity. Each Rand spent to buy electricity causes GHG emission of 4.2 kgCO_2eq. This is 3.3 times more than the next less intense sector, 'Petroleum products'. Petroleum products have an average GHG intensity of 1.3 kgCO_2eq/ZAR, followed by the 'Air transport' and 'Land transport' sectors, which are also carbon intense, with 1.1 kgCO2eq/ZAR and 1.0 kgCO2eq/ZAR respectively. On the low intensity side are the typical service sectors, such as financial, insurance, wholesale and the large governmental sector (Central, provincial and local government, in terms of their combined deliveries, account for about 9% of all goods). All these sectors have a GHG intensity of about 0.1 kgCO2eq/ZAR..

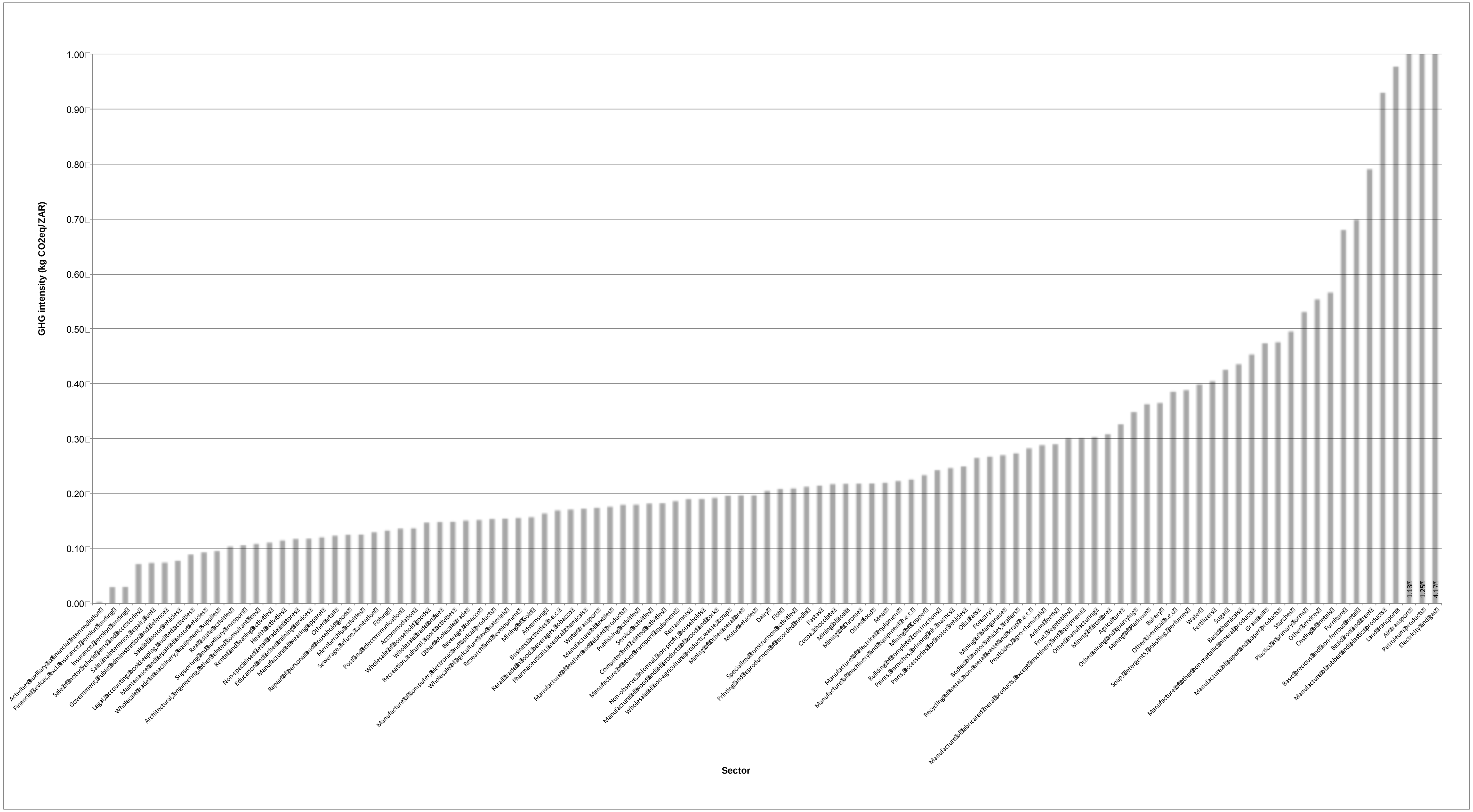

Figure 10: GHG emission per Rand gross domestic output and sector

A general hierarchical order in terms of GHG emission intensity per sector can be observed (decreasing): energy, transport, heavy industries, manufacturing and service sectors, although the groups overlap and the order is not strict or fixed.

The ratio of lowest to highest intensity is 841[15]; leaving the lowest and highest five sectors, GHG intensity is ranging from 0.08 to 0.79 kgCO2eq/ZAR, with a ratio of 9.9. Without the extremes, a rand spent can thus cause about ten times more GHG emission depending on the sector within which the expenditure is made. Figure 10 shows the GHG intensity per sector. For a complete list of GHG intensity per sector see Appendix 7.3.

The above comparison applies to discrete economic sectors. Although one sector typically produces more than one product, it is not misleading to represent a sector in terms of its main product and the embodied GHG emission of the sector at the gate of its place of manufacture. For combustible fuels, considerations of after sales emission may be important in terms of a comparison between the potential direct and indirect GHG emission of a product. There are only three principal types of combustible fuels: coal, petroleum products and solid biomass (mainly wood). Coal is of special interest in terms of GHG emission. Its production sector, 'Mining of Coal', with 0.2 kgCO2eq/ZAR, actually produces relatively low levels and volumes of carbon emission if it is producing coal and lignite, which makes up over 95% of the sector's sales (methane and other VOC fluctuation by coal mining are not included). However, since it is very likely that the coal is combusted after purchasing, coal is the product with the potentially highest GHG emission per Rand. To quantify its exact emission per Rand is a delicate process because of the wide price range of coal. In 2009 the domestic coal price was 187 ZAR/t on a mass basis and export sales were 512 ZAR/t ex-mine (Stats SA, 2012). Washing, land and sea transport, port charges, etc. are major cost factors in the international coal trade but market effects can be dominant. At the beginning of 2006 the API-index, which should reflect the real physical prices, was about 50 USD/t (318 ZAR/t) at Richards Bay port (Incoterm: FOB). However, according to Eberhard (2011) Sasol financial reports indicate that internal coal prices for its syn-fuel process operations are less than 150 ZAR/t. Assuming that domestic small-scale customers pay prices close to international market prices, and Sasol and Eskom pay about 150 ZAR/t, between 4.2 to 14.7 kgCO2eq are emitted by burning coal[16] for the value of one Rand. According the EEIO analysis of this thesis, an average GHG intensity of about 9.9 kgCO2eq/ZAR results if all emission arising from combusting coal are allocated to the sector 'Mining od coal'. Deducting the 0.2 kgCO2eq/ZAR GHG emission arising from mining of coal, 9.7 kgCO2eq/ZAR (hence 226 ZAR/t) remains for combusting coal in the value of one Rand.

The main products of the sector 'Petroleum products' are petrol and diesel. Combusting petrol for the value of one Rand (about 0.19 litre by January 2006) resulted in an additional 0.5 kgCO2/ZAR (IPCC, 2006b). In total, purchasing and burning petroleum products for one Rand will in the end result in about 1.8 kgCO2eq/ZAR.

Wood is a product of the two sectors 'Agriculture' and 'Forestry'. However, firewood probably makes up only a small share of the sector's total supply of goods. It would probably be misleading to add the average embodied GHG emission of 0.3 kgCO2eq/ZAR (both sectors) to the potentially direct emission of wood. However, wood causes about 1.6 kgCO2eq/kg direct emissions (IPCC, 2006a) or 0.7 kgCO2eq/ZAR at an average price of 0.45 ZAR/kg (Wise et al., n.d.).

4.1.2. Sector total GHG emission

It can also be of interest to know the total GHG emission of the various sectors. While the energy balance gives information about the direct use of energy per sector, and related GHG emission of this can be easily calculated, the EEIO analysis can include indirect emissions. Including embodied GHG results in double accounting. Therefore the sum of direct and indirect GHG emissions of all sectors is 2.6 more than South Africa's total GHG emissions are in reality. Obviously the total GHG emission depends strongly on the economic size of each sector. A sector's GHG intensity can simply be multiplied by the sectors' total output to estimate total direct and indirect GHG emission induced by this sector. The top five sectors in terms of GHG emission are 'Electricity and gas', 'Land transport', 'Petroleum products', 'Basic iron and steel' and 'Non-observed, informal, non-profit, households' (in this order). The first four sectors are not only extensive, but also GHG intense sectors. The 'Non-observe, informal, non-profit, households' sector is of average GHG intensity (0.2 kgCO2eq/ZAR, Rank 57) although it is the third largest sector in South Africa's economy, and therefore this sector ends up as the fifth largest contributor to South Africa's GHG emission[17]. Figure 11 shows 'direct' and 'direct and indirect' emission per sector. Many sectors do not produce any direct emissions since they do not combust a relevant amount of fuels, instead covering their energy requirements by using electricity. One can argue that GHG emission caused by electricity should be included under direct emission because of its nature as energy carrier. If one goes this route, it becomes arguable why

[15] Not considering sector 'Activities auxiliary to financial intermediation' with its very low GHG intensity of 0.005 kgCO2eq/ZAR result in a ratio of 130 from the second lowest to the highest intensity.

[16] Corrections for differentials in calorific value are not made due to lack of data.

[17] SNA recognises household activities as well non-observe, informal and non-profit as part of the general economy. It is distinct to household final consumption. However delineation and accounting for this sector is a challenge (UN, 2000).

other (basic) inputs are not included. This shows the advantage of EEIO analysis with its accounting for direct and indirect emissions. An EEIO analysis does not stop after a certain bunch of inputs, but instead takes all inputs that are required by a sector and their embodied impacts into account. However, in order to calculate the figures, the sectors' demand for intermediates was set equal to something like "final demand by sectors". This is critical since in economic terms nothing meaningful can be associated with sectors' intermediates demand being equalised with final consumption. Nevertheless, required intermediates per sector can be used as approximation of sectors goods turnover and therewith associated GHG can be calculated.

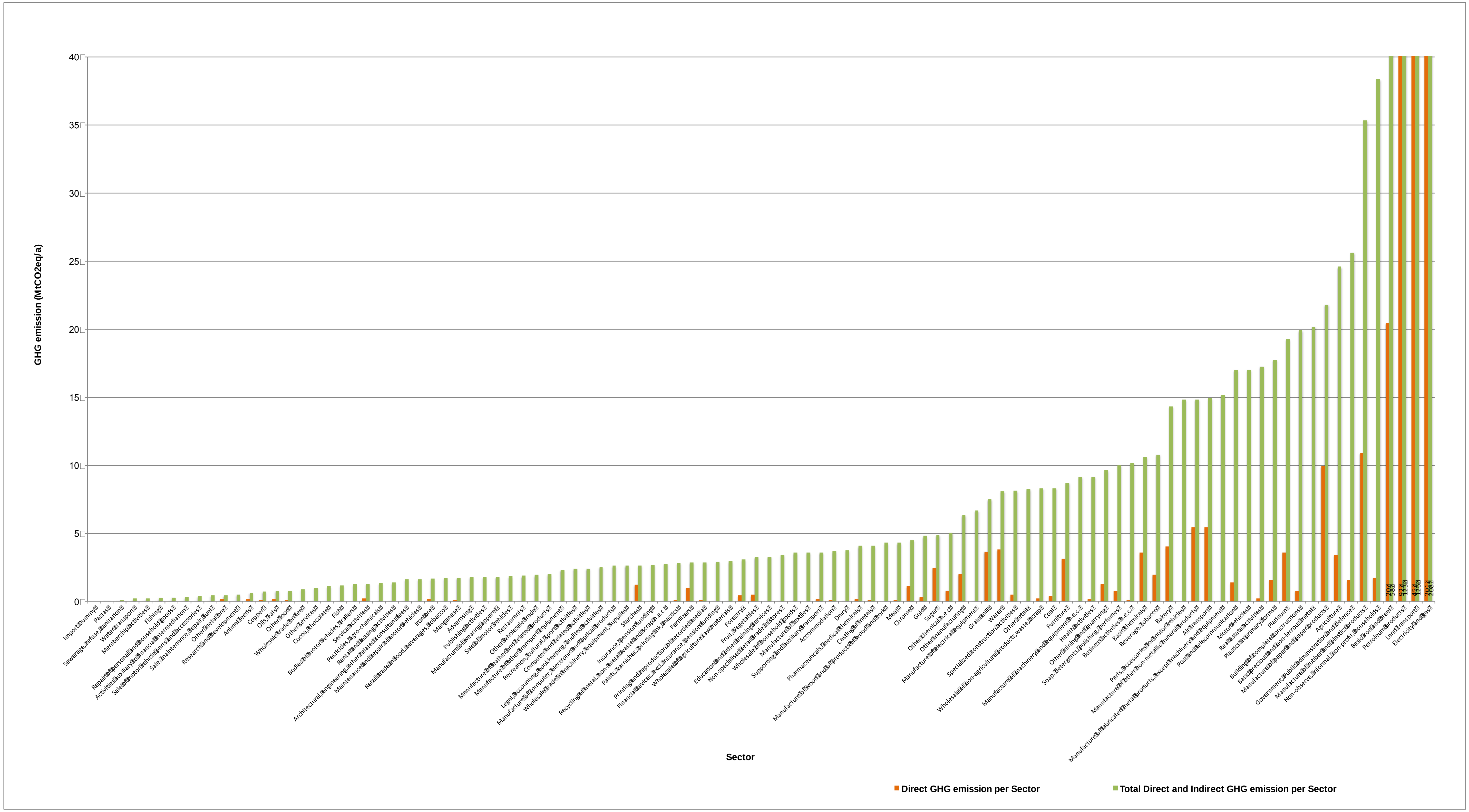

Figure 11: Direct GHG emission and total direct and indirect GHG emission from energy consumption per sector

4.1.3. Data Validation

GHG intensity data are not easily accessible and comparable because of the unusual unit per ZAR. For example, 'Meat', with 0.22 kgCO2eq/ZAR, accounts for less GHG per ZAR than 'Fruit and vegetables' with 0.30 kgCO2eq/ZAR. At first glance this does not seem appropriate. Converting the figures from kgCO2eq per Rand into the more commonly used kgCO2eq per kilogram unit shows that meat, with 6.0 kgCO2eq/kg, has a GHG emission five times higher than fruit and vegetables, with 1.2 kgCO2eq/kg[18]. Although it remains questionable whether the absolute figures are correct, at least the relative rank seems to be reasonable in this case.

The first source of comparison are the figures calculated by Arndt et al. (2011). These figures were calculated in order to investigate the potential effects of a carbon tax in South Africa. They use a similar method and the same database as that used in this thesis except that the some mathematical differences by calculating the IO-Table and the environmental intervention matrix appear. No in-depth analysis was done to quantify the direction and nature of these differences. Variations for GHG intensity per sector occur to a degree of 83% in relative terms ('Land transport' 0.2 kgCO2eq/ZAR by Arndt et al. to 1.0 kgCO2eq/ZAR according to this calculation), and to 1 kgCO2eq/ZAR in absolute terms ('Electricity and gas' 3.1 CO2/ZAR by Arndt et al. to 4.2 kgCO2eq/ZAR according to this calculation). However, in general the results are similar with a mean difference of 7.4%, and a standard deviation of 35.6%[19]. Having two studies independently carried out with similar results lowers the chance of results containing fundamental errors. However, by using the same database, the results are biased in the same way and no statement can be made about direction and magnitude.

In the following section I compare the results of a few sectors with figures from the literature.

4.1.3.1. Electricity and gas

The 'Electricity and gas' sector is by far the most carbon intense sector, with 4.2 kgCO2eq/ZAR, and by far the biggest direct emitter, emitting 43.1% of South Africa's total GHG. This is about 2.1 times more than the next largest emitting sector, 'Petroleum products'. The 'Electricity and gas' sector remains the biggest emitter if indirect emissions are taken into account, although indirect emission produced by electricity generation contributes only a small share, with about 0.14 kgCO2eq/ZAR. However, 'Electricity and gas' is responsible for 1.6 times more direct and indirect GHG emission than the next largest emitting sector, The 'Land transport' sector ('Land transport' with 45.2 MtCO2eq/a direct emission for a total output of 129 billion rand hence 0.35 kgCO2eq/ZAR direct emission, plus 43% of sector's 'petroleum product' emission as indirect emission). In terms of the future, the 'Electricity and gas' sector is the sector which will grow at the fastest rate in terms of GHG emission in all economic growth and income distribution scenarios (see 4.3.1 Sectors with a potentially high growth in Greenhouse gas emission). Therefore this sector is of particular relevance. Although the sector is made up of electricity and gas, electricity dominates significantly, contributing 97.3% of the sector's energy supply (in TJ). Therefore in the following sections of this study, the electricity and gas sector, in terms of GHG emissions, will be treated as electricity only.

A number of publications present figures for GHG emission of South Africa's electricity per kWh. These figures range from 0.85 kgCO2/kWh (direct emission only) (IEA, 2009) to 1.02 kgCO2eq/kWh (direct and indirect emissions) (Letete et al., n.d.). South African electricity producer ESKOM itself reports 0.95 kgCO2/kWh direct emission (ESKOM, 2012a). This study found a GHG intensity of 4.2 kgCO2eq/ZAR converted with the average price of 17.05 c/kWh in the period 2005/2006 (ESKOM, 2012b) resulting in 0.71 kgCO2eq/kWh direct and indirect emission. If one takes the 1.02 kgCO2eq/kWh, the recovery is 70%. Considering the broad approach of this study this is reasonable. However, given that electricity plays such an important role regarding GHG emission, a correction of its GHG intensity was considered. It was shown that a correction has limited impact on the GHG intensity and total emission ranking of sectors (86% of the sector move two or less positions in the GHG intensity ranking). Using a higher GHG intensity for electricity without correction by other sectors leads to significant higher total GHG emission. To avoid an overestimation of total GHG emission and because of the relative little impact on rankings, correction of GHG intensity for electricity was not used.

4.1.3.2. Petroleum products

The 'Petroleum products' sector is also heavy in GHG emissions, and therefore important to this study, and, with the unique synthetic fuel sold in South Africa, it is even more interesting to compare it to conventional fuels in terms of GHG emissions.

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[18] Weighted average meat mix retail price: 24.1 ZAR/kg (Producer prices and consumption 2005/2006: Beef 16.5 ZAR/kg, 17.2 kg/capita; Pig 10.0 ZAR/kg, 4.1 Kg/capita; Sheep 23.4 ZAR/kg, 3.4 kg/capita; Chicken 12.5 ZAR/kg (2008), 29.5 kg/capita (DAFF, 2012; Lovell, 2012). Differences between the producer price and the retail price range between 64 and 73% (DAFF, 2002). Fruits average 3.6 ZAR/kg (DAFF, 2006)

[19] Difference may occur due to different aggregation levels. Arndt et al. was somehow able to keep the 171 sectors as in the SUT, I had to aggregate them to 104 sectors.

A recently conducted LCA of Sasol Synfuels petrol in Secunda found 15.5 kgCO2eq/l Synfuels (Methane, other VOC, SO_2 and NO_X taken into account), and that synthetic petrol meets approximately 26.5% of South Africa's demand (Dick, 2012). Aboyade and von Blottnitz (2012) state that synthetic diesel is about four times more GHG intense than conventional diesel refined at coast. Assuming synthetic diesel and synthetic petrol are similar, an average direct and indirect GHG intensity of 6.9 kgCO2eq/l can be calculated for the South African petrol mix on the production side. Converting the 1.3 kgCO2eq/ZAR of this study with the average price of 5.23 ZAR/l in January 2006 (SAPIA, 2008), a GHG intensity per litre of 6.5 kgCO2eq/l results. Hence a satisfactory recovery rate of 95% could be achieved for this particular sector.

4.1.3.3. Meat

The 'Meat' sector ISIC C10-1 includes: operation of slaughterhouses, production of fresh, chilled or frozen meat, production of meat products such as sausages, salami, pâtés, etc., but excludes animal production, which is part of the agricultural sector (UN, 2008). The environmental impact of beef has been relatively well researched. Detailed studies usually consider, not only GHG emission from energy consumption, but include the usually dominant enteric fermentation (beef) and wastes etc.[20]. However, figures published by Subak (1999) facilitate recalculation for energy related GHG emission of traditional African pastoral, and a specific intensive, US feedlot system. This comparative study found that, for African pastoral and US feedlot systems, 8.4 and 14.8 kgCO2eq/kg beef meat respectively, the energy related to these was low - 0.1 kgCO2eq/kg beef meat - for Africa pastoral, and 5.5 kgCO2eq/kg beef meat for US feedlots. My study reports 6.0 kgCO2eq/kg energy related GHG emission for all kinds of meat. It is likely that, due to various husbandry systems, and the different growth and feed metabolising rates for different animals, energy related GHG emission rates vary considerably but not to the same extent if enteric fermentation is taken into account. Bearing in mind the generally high carbon intensity of the South African economy, 6.0 kgCO2eq/kg seems possible for a meat mix as described in footnote 18.

4.1.3.4. General effects and biases

However, the principal disadvantage of an EEIO analysis is the aggregation of dissimilar products. Sectors usually produce more than one good, but not all goods of a sector contain the same amount of resources. Buyers do not purchase the average product mix of a sector. Since this is not reflected in the EEIO method it is likely that an equalisation across the sectors takes place. For instance, as we know from many LCAs, livestock farming is more resource intense than crop growing. This is not reflected in an EEIO analysis if the agriculture sector is not disaggregated. Regardless of the particular good purchased by adjacent food industries, for example, meat processing plants and grain mills, all receive the same amount of indirect GHG emission assigned per Rand spent on agricultural products. Because of this, and because the underlying data are also not free of error, a large variance for individual sectors results and therefore must be assumed and taken into account, even though the above mentioned examples have been found to be fairly accurate.

4.2. Greenhouse Gas Intensity of South Africa's Consumption

In this section the different final demand categories regarding GHG emission are analysed, followed by an in-depth analysis of final demand by households using detailed expenditure data provided by the IES.

4.2.1. Greenhouse Gas Intensity of Final Demand Categories

South Africa's SUT contains the five final demand categories: export, household consumption expenditure, general government consumption expenditure, fixed capital formation, and changes in inventories. In order to conceive of the importance of the two categories 'Private Households' and 'Government' in South Africa's economy, one needs to keep in mind that, in addition to their final consumption, they are also part of the production side with the corresponding production sectors, 'Non-observe, informal, non-profit, households' and 'Government, Public administration and defence' (see Footnote 17). Their share of total final consumption expenditure can be taken from Table 6. Their economic share of total output is about 30.6% for Households and 16.6% for Government.

In terms of an EEIO analysis all environmental impacts are assigned to final consumption. Total direct and indirect GHG emission of the five final consumption categories of the SUT is the exact total GHG emission of South Africa. This is shown in Table 6, where GHG intensities are also reflected in two ways: firstly by the ratio of total GHG emission to total expenditure per final demand category ($kgCO2eq/ZAR_{(exp)}$) this indicates the proportion of caused GHG emission to the total economical size of a final demand category (similar to the GHG intensity per

[20] Globally, about 9% of emissions in the entire agricultural sector consisting of energy related CO2, 27% are related to enteric fermentation (Schwarzer et al., 2012).

industry sector) and secondly by the ratio of total GHG emission to total GDP contribution per final demand category (kgCO2eq/$ZAR_{(GDP)}$) this indicates caused emission per gained GDP which can be interesting from a macro economic point of view.

Table 6: GHG emission and Expenditures per Final Demand Category

Final Demand Category	Total direct and indirect GHG emission		Final demand expenditure		GDP contribution		GHG Intensity	
	MtCO2eq/a	%	bnZAR/a	%	bnZAR/a	%	kgCO2eq/ $ZAR_{(exp)}$	kgCO2eq/ $ZAR_{(GDP)}$
Export	110	23.6	430	18.4	307	21.9	0.26	0.36
Households	285	61.0	991	51.3	764	54.5	0.29	0.37
Government	23	5.0	306	15.8	203	14.5	0.08	0.12
Fixed capital formation	44	9.4	264	13.6	115	8.2	0.17	0.38
Changes in inventories	4	1.0	18	0.8	11	0.8	0.24	0.39
Total Final Demand	467	100.0	2009	100.0	140	100.0	0.23	0.33

The comparative analysis of the five final demand categories is somewhat difficult because of the result for government consumption. The production sector 'Government, Public administration and defence' uses supplies from many sectors but produces only one product called 'Public administration'. The sector has a very low carbon intensity of 0.07 kgCO2eq/ZAR (sixth lowest) and is hardly required by any sector and final demand category except 'Government consumption' according to the SUT. Because the final demand category 'Government consumption' consists of 99% of its own low carbon product, this final demand category also has a very low GHG intensity of 0.08 kgCO2eq/ZAR. Whatever the meaning of this structure in economic terms in the SUT, and subsequently in the IO-Table, the other final demand categories need to be analysed by relative comparison to each other, but excluding government consumption.

The results are surprising for export. Based on the knowledge of South Africa's main export goods, and the finding of an above average GHG intensity for those goods, 'Export' would be expected to have the highest GHG intensity (kgCO2eq per Rand final demand and/or GDP contribution). As Table 6 shows, this is not the case. An in-depth analysis has shown that this apparent contradiction is due to the direct usage of energy products by final demand categories other then 'Export'. If the direct use of energy products is excluded by household consumption, a total expenditure intensity of 0.21 kgCO2eq/$ZAR_{(exp)}$ is the result. Moreover, according SUT no electricity is exported[21]. If one includes the 13.4 TWh electricity (Subramoney et al., 2010), with its 12.8 MtCO2eq/a emission and 1.3 bn Rand revenue (ESKOM, 2012b) this results in an average export intensity of 0.38 kgCO2eq/$ZAR_{(exp)}$ which is then by far the highest intensity. Additionally, it can be assumed that export prices per unit are typically lower than those in the domestic market because of its wholesale and bulk product structure. This leads to an underestimation of caused GHG emission per Rand revenue in the export market. Quantifying South Africa's exported (and imported) embodied energy and GHG emission by using foreign trade statistics and the results of this study, although labour intensive, would be well worth considering in future discussions about South Africa's GHG emission per capita and its source.

'Fixed capital formation' has a low GHG intensity if final demand expenditures are considered although it is fairly heavy in carbon if only the GDP equivalent is considered. This is because imported goods have with 28% a large share in 'Fixed capital formation'. Imports count towards final consumption expenditure but cause zero emission in South Africa. If GDP is considered, imports do not contribute at all, and become zero while the same amount of GHG remains. 'Fixed capital formation', obviously, is mainly made of physical goods, which have an above average GHG intensity.

The role of 'Changes in inventories' is negligible.

4.2.2. Greenhouse Gas emission of private Households

The following section provides an in-depth analysis for the final consumption category 'Households consumption expenditure'. Final consumption by households as given in the SUT is replaced with the more detailed consumption expenditure figures of the IES. Using IES data

[21] South Africa exports about 2'207'230 TJ/a of energy as different energy products, with an equivalent of about 213 MtCO2eq/a.

allows for distinguishing the consumption patterns of different income groups. Total household consumption differs considerably between SUT and IES. If IES data are used household expenditure are 28.4% less, resulting total direct and indirect GHG emission is 14.6% lower (for more detail see section 3.4.2 'Data handling and integration' and Appendix 7.2).

4.2.2.1. GHG Intensity as a function of Household expenditure

GHG intensity as a function of household expenditure is shown in Figure 12. The figure shows that total GHG intensity decreases with expenditure apart from an exception in the very low expenditure area. It is interesting to see that expenditures of up to 55'000 ZAR/a (seventh decile) decrease the total GHG intensity due to a decreasing direct GHG intensity with a fairly constant indirect GHG intensity. Above 55'000 ZAR/a direct GHG intensity is relatively constant while indirect GHG intensity is decreasing.

The overall elasticity of total expenditure to total GHG emission is 0.68 (first to tenth decile). The elasticity is almost constant throughout the whole expenditure range. An exception is seen from the first to second decile with an elasticity greater than one (1.29), and a kind of volatility occurs in the expenditure range 160'000 to 220'000 ZAR/a. Therewith South Africa has a similar elasticity as reported for India with 0.67 (Pachauri, 2004). For Brazil a constant GHG intensity was found throughout the whole expenditure range (Cohen et al., 2005). A high income and expenditure disparity as it is usually the case in developing countries leads to differences in the living condition. Theoretically it is possible that completely different living conditions are similar in GHG intensity. But it does not seem to be very likely. From this perspective, a variance in GHG intensity of any kind is expected. Why the result for Brazil is different cannot be explained at this stage. The authors of the study mention a couple of factors. All could be associated with the fact that families in Brazil are generally larger in high-income households. This contrary to India and South Africa where after a certain turning point the number of people per household are negatively correlated with income. A comparison on an income per capita base rather than income per household could be used to asses the differences.

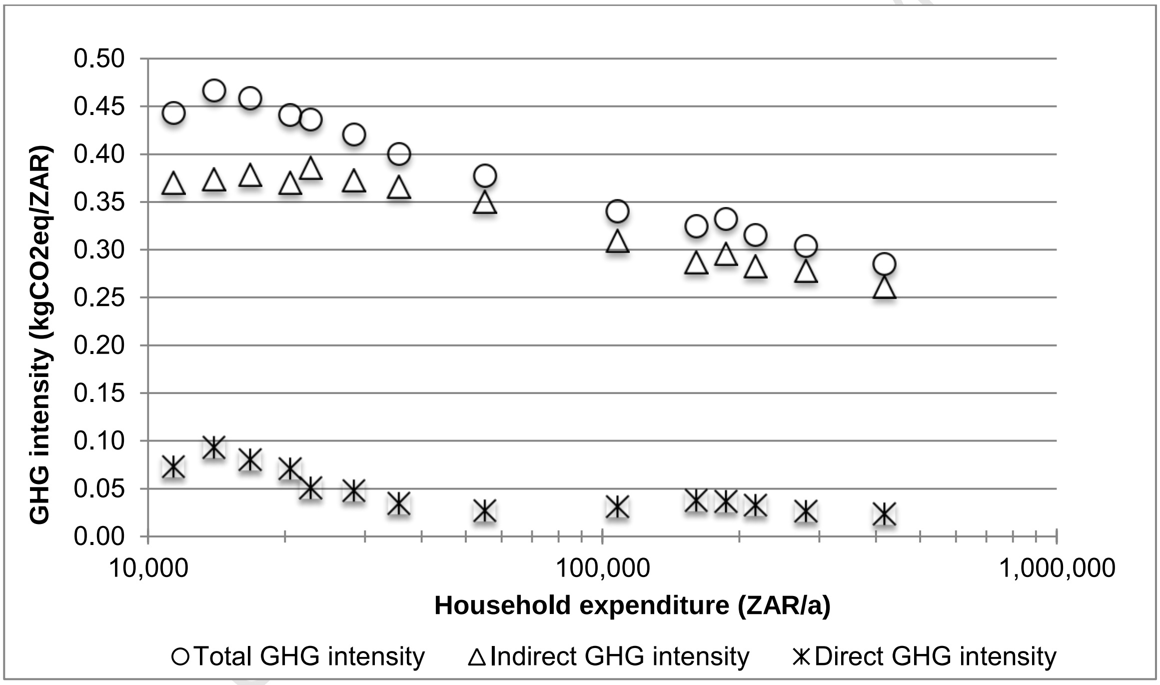

Figure 12: Direct, indirect and total GHG intensity as function of household expenditure. The data points also represent the decile, the average of the top five constituting the tenth income decile (note the log scale of the x-axis).

It is important to keep in mind that in the chosen model approach higher expenditures of the affluent lead ultimately to more physical consumption even it can be reasonably assumed that higher expenditures are partly used to purchase better quality rather than more. For the relevant discussion of this limitation refer to section 2.3.2.1 Accounting for Differing Goods Quality.

The share of direct energy use (including electricity) in relation to total energy requirements of households is unusually small, with an average of 15% if compared to the literature, which shows the share on direct energy to be between 34% to 64% for European countries, 39% for Brazil, and 53% for India (Cohen et al., 2005; Moll et al., 2005; Pachauri & Spreng, 2002; Reinders et al., 2003). The resulting share of direct GHG emission is on average 20% if electricity is included. If electricity is excluded from direct emission (as it is usually done in this thesis) the share on direct emission is on average 11% with a high of 20% by the second decile and a low of 7% by the eighth decile. The low average is a direct consequence of the figures coming from the energy balance. According to the SUT, households spend about 5.7% of their total expenditure on energy products, and according to the IES, 6.8%. After a conversion of the average expenditure in the IES with average prices of energy carriers into energy units, a comparison of energy requirements of households in the IES and the energy balance was made to verify the figures. Usage of coal and solid biomass were four and seven times higher in the energy balance than in the IES. Petrol Products were about four times less in the energy balance than in the IES, while Electricity usage is about the same in both sources. In total, IES figures indicate 40% less direct energy usage than the energy balance. There is no reason to assume that the IES systematically underestimates the purchase of energy products. Thus it could be argued that the IES generally confirms the energy balance with its low share of energy usage by the 'Residential' sector. The reasons private households have such a low share in South Africa's energy requirements remains unclear. It maybe partly explained by the observation that South Africans do not extensively heat or cool their houses. By comparison, warming of private households in Switzerland needs about 20% of the Swiss total energy demand (Kemmler, 2011; Swiss Federal Office of Energy, 2011). However, this remains at the level of speculation, a more detailed analysis being required, especially since India and Brazil also have significant higher direct energy requirements, and it being reasonable to assume that many households in those countries also do not extensively heat or cool their houses.

The utilisation of different energy carriers changes considerably in relation to expenditure level. Figure 13 shows how liquid fuels are continuously substituted for solid fuels as individual households' total expenditure grows.

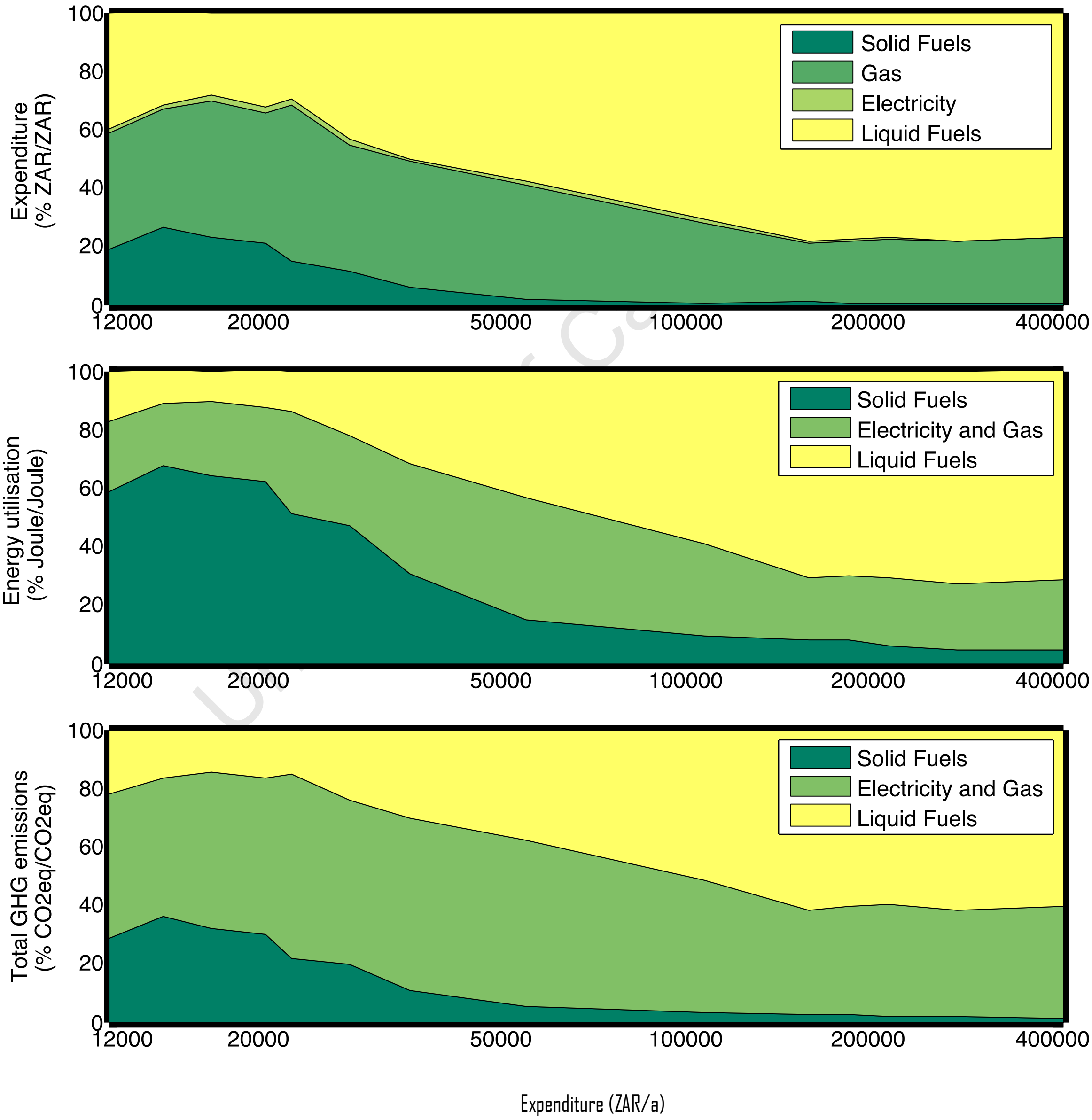

Figure 13: Share of expenditure, utilised energy and total GHG emission per energy carrier as function of total household expenditure. Solid Fuels are important to cover the energy demand of less affluent households. However solid fuels contribute

relative little to GHG emission. Free basic electricity is included as in-kind expenditure and covers almost the entire electricity consumption of less affluent households.

Not only is direct energy consumption changing with household's expenditure level. The decreasing GHG intensity as function of total household expenditure can be explained by the different baskets of goods consumed by different income groups. Income above a certain level is mainly spent on less carbon intense goods, such as housing services and insurance. As Figure 14 shows, with increasing income, the share of expenditure on less carbon intense goods is increasing.

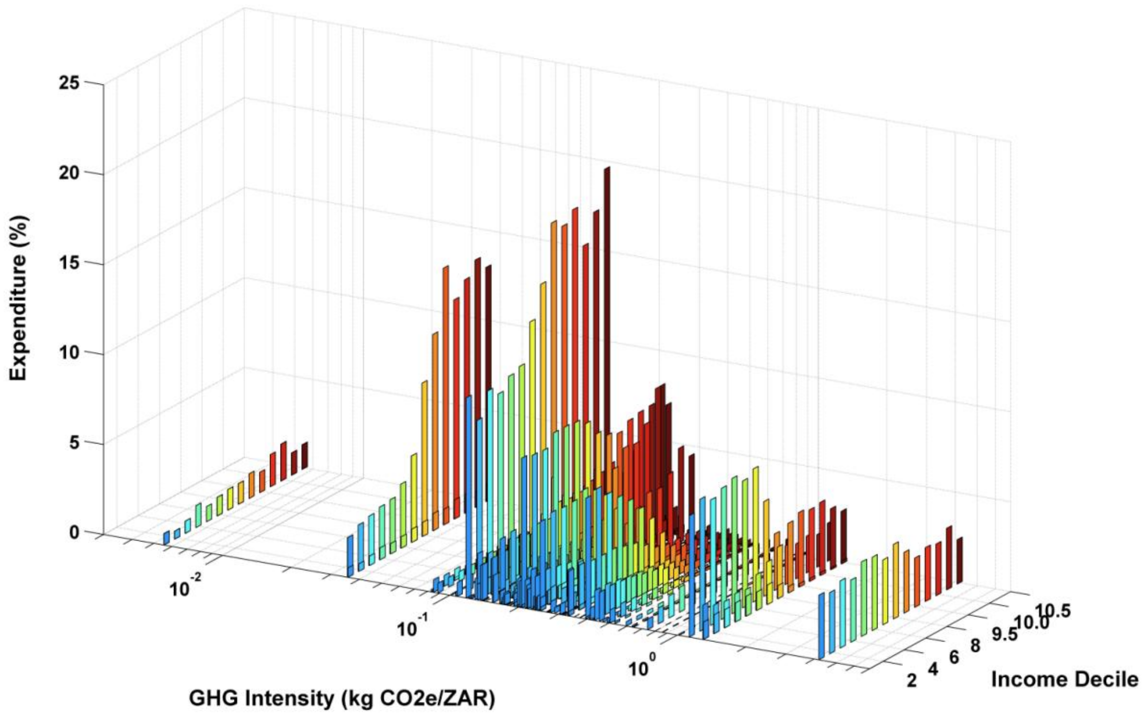

Figure 14: Share of expenditure on goods as a function of GHG intensity of goods and income groups. The share of expenditure of high-income groups on less GHG intense goods is increasing.

4.2.2.2. Total GHG Emission per Income Decile

The total direct and indirect GHG emissions ascribed to household consumption increase by income decile. In the range of the first to the sixth income decile the increase is about 20% per decile. Thereafter GHG emission starts to increase sharply, almost a doubling from the eighth to the ninth decile, and more than a doubling from the ninth to the tenth income decile. Even though the average GHG emission per Rand spent decreases significantly from low to high income/expenditure households, the much higher expenditures of the affluent more than counter this. In fact, the tenth income decile alone cause about 23% of South Africa's total energy GHG emissions (including export, government, capital formation and changes in inventories), while the same number of households in the first income decile cause only 1.5% of the same emissions.

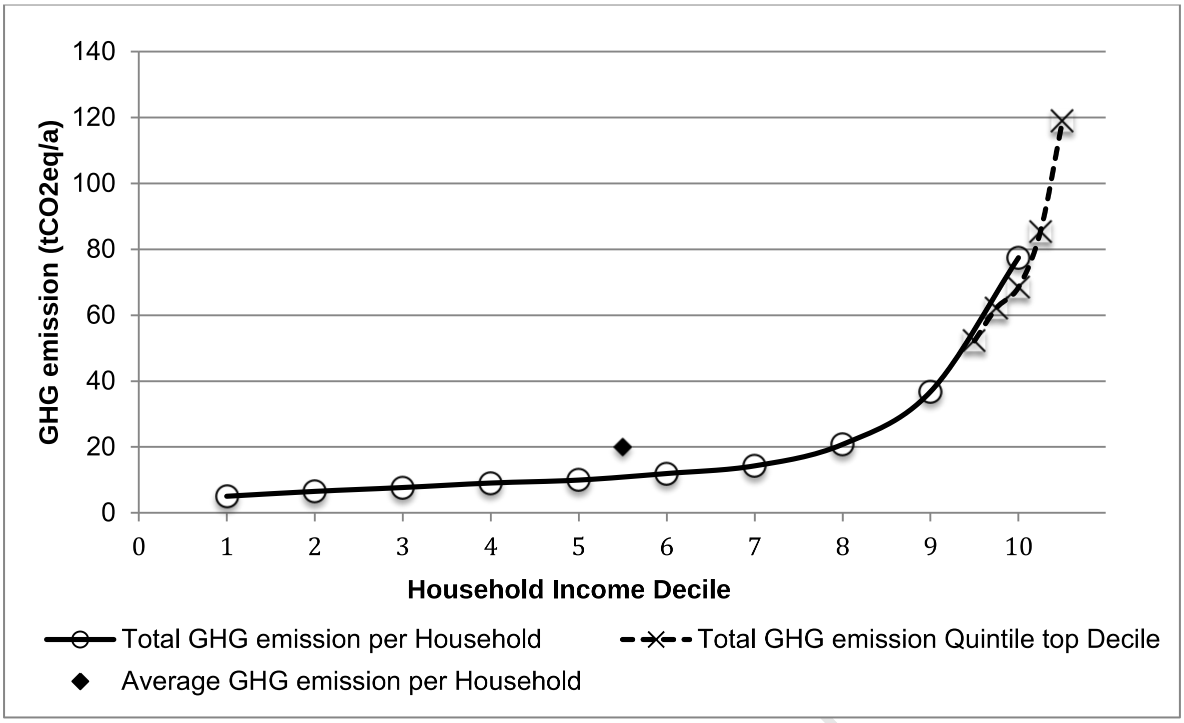

Figure 15: Total direct and indirect GHG emission per household and income decile[22].

The total GHG emission of South Africa arising from combusting fuels was calculated with 467 MtCO2eq/a (see 3.3.2 Utilisation of Energy Balance). With a population of 47'391'000 people in the period 2005 - 2006 (Stats SA, 2008a) this results in 9.86 tCO2eq/capita and year on average. This is slightly above the nine tCO2eq/capita and year estimated by the World Resources Institute (2012). However, of this amount, private household consumption and related production cause 5.1 to 6.0 tCO2eq/capita and year, depending on considered household consumption data IES or SUT respectively.

4.3. Effects of income distribution and economic growth

Based on the assumption that today's less affluent will have similar consumption patterns, once they have migrated to a higher income group, as those who are already in that particular income group, the effects of economic growth and income distribution were estimated.

As a result of the fact that higher expenditure lead to less GHG emission per Rand spent, a relative decoupling of household expenditures and related GHG emission growth will likely be observed on a long-term basis. However, if today's income/expenditure were to be more equally distributed, more money would be spent by low and middle income households, which have a higher GHG intensity than high income households. Hence total GHG emissions can be expected to be higher by the same total economic output.

Simulations indicate that a lower Gini-coefficient might result in higher GHG emissions from consumption: household expenditure growth of about 20% in the next few years would cause an increase in GHG emission from domestic consumption and related production of about 19.8% if the additional expenditure is generated by the poorest sector of the population, but only about 14.4% if the additional expenditures were generated exclusively by the tenth income decile. Enabling the poorest to gain the necessary additional income for such expenditure growth would result in a Gini-coefficient of 0.48, with todays first to sixth income decile having a minimum income slightly above today's seventh income decile. If we assume a constant Gini-coefficient, the decoupling effect is about 3.0% in the case of additional expenditure generated by the poor. Current income distributed to a Gini-coefficient of 0.48 causes about 2.8% more GHG emission than is the actual case. Figure 16 shows GHG emission growth as a function of total household expenditure growth[23], and income distribution expressed as Gini-coefficient.

[22] Note the difference between per capita and per household. On average 3.8 people living in a household according IES.

[23] The percentage of household expenditure growth is equal to the percentage of induced total economic output growth because of the almost constant ratio of total final demand to total output for all tested scenarios.

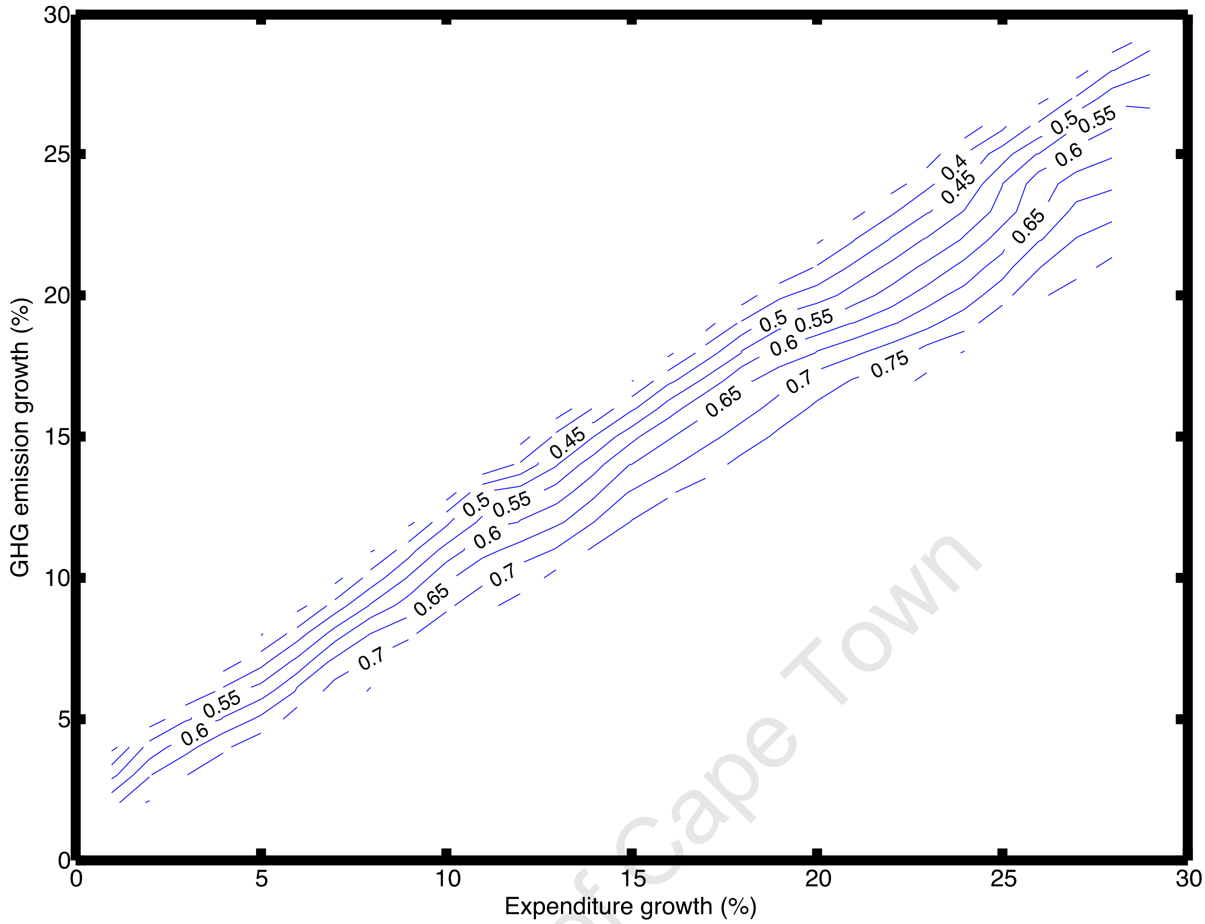

Figure 16: GHG emission growth as a function of total output growth and income distribution expressed as Gini-Coefficient. Less income disparity leads to higher GHG emission.

Theoretically, in a very long-term scenario, high income/expenditure equality will cause less GHG emission since the average GHG intensity is lower if all people are affluent than if some remain poor with a high GHG intensity.

4.3.1. Sectors with a potentially high growth in Greenhouse gas emission

GHG emissions growth of different economic sectors depends on the goods consumed. Different baskets of goods are consumed by low and high income groups. Depending on the income distribution and subsequently total final consumption per sector, GHG emissions growth per sector would vary considerably. However, the top five sectors are the same in all tested income distribution scenarios due either to a high GHG intensity or because of their large share in final demand. Table 7 shows the ten sectors that are expected to generate the most additional GHG emissions for two different income distribution scenarios, relative to household expenditure growth of 20%.

Table 7: Sectors with highest GHG emission growth rate for a two income distribution scenario

Scenario 1: 20% expenditure growth, income distributed in actual proportion (constant Gini-coefficient)					
Rank	**Sector**	**Sector's GHG intensity (tCO2eq/mZAR)**	**Output growth (mZAR)**	**GHG emission growth (MtCO2eq)**	**Output and GHG emission Growth (%)**
1	Electricity and gas	4166	5676	23.6	18
2	Petroleum products	1248	9437	11.8	19

3	Land transport	980	7228	7.1	15
4	Non-observe, informal, non-profit, households	193	19178	3.7	21
5	Real estate activities	106	28477	3	23
6	Basic iron and steel	793	3425	2.7	24
7	Motor vehicles	199	13331	2.7	29
8	Parts, accessories for motor vehicles	252	8801	2.2	28
9	Manufacture of rubber and plastics products	932	2365	2.2	19
10	Post and telecommunication	138	10657	1.5	21

Scenario 2: 20% expenditure growth; additional income went exclusively to the poorest

Rank	Sector	Sector's GHG intensity ($tCO_2eq/mZAR$)	Output growth (mZAR)	GHG emission growth ($MtCO_2eq$)	Output and GHG emission Growth (%)
1	Electricity and gas	4166	6934	28.9	22
2	Petroleum products	1248	11158	13.9	23
3	Land transport	980	13454	13.2	28
4	Non-observe, informal, non-profit, households	193	18875	3.6	20
5	Real estate activities	106	25274	2.7	21
6	Manufacture of rubber and plastics products	932	2463	2.3	20
7	Basic iron and steel	793	2463	2.0	17
8	Air transport	1130	1664	1.9	34
9	Furniture	682	2372	1.6	36
10	Post and telecommunication	138	11228	1.6	22

The 'Electricity and gas' and 'Petroleum products' sectors will contribute most to future additional GHG emission, having an unfavourable combination of a relatively high share of South Africa's economy and a high carbon intensity. The two energy sectors together are responsible for about 63% of current direct GHG emissions. If an income distribution scenario is applied, in which high income disparity is maintained, energy sectors will grow at a below average rate, and therefore a decoupling of consumption based economic growth and GHG emission growth will be observed. In fact a total economic output growth of 30% by a Gini-coefficient of 0.83 will cause energy sector growth of only 22%. In a scenario in which income is more evenly distributed, as in Sweden (Gini-coefficient of 0.32), the two energy sectors grow about 34%. The difference in growth of the energy sectors is in part due to household direct consumption, but mainly induced by the increased final demand of sectors with high energy requirements, as shown in Table 7.

The simulation indicates that 'Real estate activities' will grow most in absolute economic terms in many income distribution scenarios. Even with its low GHG intensity, the 'Real estate activities' become a major source of GHG emissions. For a complete list of sector and related GHG emission growth, see Appendix 7.6.

The forecasts of economic and associated GHG emission growth have limited validity for many reasons (see section 3.6 Limitations). However it indicates notable changes only as a result of alteration in household income and income distribution.

5. Conclusion

This dissertation set out to contribute to the description and the understanding of what causes South Africa's economy to be as GHG intense as it presently is, and to predict the impact which increased affluence of South Africa's population could have on GHG emissions. In this final chapter I will present a discussion on what conclusions can be reasonably drawn from the results, in terms of the present and future impacts of GHG emission in South Africa. Firstly, the methodology's potential to contribute to the field of research and the understanding of the causes and sources of GHG emissions is very briefly reviewed. Secondly, conclusions are drawn from a production and consumption perspective, as well the implications of growth and income distribution in terms of GHG emission. Thirdly, the hypothesis is reviewed and discussed. Fourthly, I speak briefly about the possible implications the results of this study and gained knowledge could have on my own related work. Finally, some recommendations are offered for further research and for policy making.

5.1. Methodological issues and insights

The heterogeneous nature of direct GHG emission per sector indicates the need for a more systemic approach towards determining the effective contribution of a sector to GHG emissions than the ordinary energy balance can deliver. Many sectors have direct GHG emission close to zero due to using mainly electricity, which, once produced, can be utilised emission free to cover energy demands. GHG emission caused by electricity usage could easily be included in direct emissions per sector but there is no rationale provided by a comprehensive GHG accounting to include GHG caused by electricity production and exclude GHG produced by other sectors. EEIO analysis enables a systemic approach. Even though the level of uncertainty of the results of an EEIO analysis is high, I and many others, viz. the proponents of EEIO methods (see section 3.3 Environmental Extension of Input-Output table), believe that it delivers a more accurate and comprehensive picture of the true source of GHG emissions than the most precise energy balance, with its limitation to direct emission will ever do.

Based on the description of production and consumption as a reinforcing economic cycle, it is of considerable importance to establish which particular goods are causing high environmental impacts throughout the entire production line. Analysing the system, identifying and mitigating high impact consumption patterns in order to develop strategies to change such consumption patterns is a complementary (although not new) approach to reducing environmental impacts. EEIO analysis is a suitable method to extract the information needed to prioritise further investigation, research and policy making in terms of a less environmentally damaging impact from production and consumption.

5.2. Production perspective

From a production perspective this study has confirmed the dominant role of electricity and petroleum production in South Africa regarding GHG emission. These energy sources are not only the biggest emitters of GHG but also by far the most GHG intensive sectors, together emitting more than 60% of all GHG. From a production perspective the key question is, is there a decarbonisation of South Africa's industry, in particular that of energy production taking place? There is little hope that we will observe an absolute reduction in GHG emission in the immediate future, not only in general, but in the energy sector. Even if a very optimistic reduction of GHG intensity were to occur from today, from 0.96 to 0.68 kgCO2/kWh, as it is outlined in ESKOMs environmental vision, it would be nullified by rising electricity demand, resulting in additional GHG emissions per year in absolute terms (ESKOM, 2011). Moreover, this vision has not yet been realized; GHG intensity has increased steadily. No binding commitment to lowering GHG intensity has been made either by ESKOM or by Government (ESKOM, 2012a, 2011). One of the associated problems for the production sector is that ESKOM is a para-statal organisation, and each and every (large-scale) producer and all households in South Africa rely on ESKOM. No market signal can be given by choosing electricity supplies from an alternative source. The question that arises here is one concerning the role of the other sectors in such a situation. Although one may assume that, because electricity and petroleum production dominate GHG emissions, the other sectors are of less importance, the contrary is the case. Energy saving measures become even more important if energy production is GHG intense. Assuming that the technological and political battle for clean and affordable energy production will be fought on an international level, energy saving measurements could become the primary responsibility and task of national institutes and industry. According to this study, the sectors 'Land transport', 'Basic iron and steel', 'Manufacture of rubber and plastics products', and 'Agriculture' would be the first choice for enhanced efforts in this regard. 'Land transport' and 'Agriculture' in particular often have national and local specialties which need to be considered and/or can be used for improvements.

However, sustainable production creates the base for sustainable consumption. Even the most committed environmentalist will use carbon intense products if no alternatives are available. For instance, South Africa's electricity and petrol is used and will be continue to be used regardless of its carbon footprint. It is thus essential to have clean products available to make changes in consumption patterns effective and sustainable, as discussed in the next sections.

5.3. Consumption perspective

Total GHG emission is strongly correlated with expenditure. In the case of South Africa, where income and therefore expenditure disparity is amongst the highest in the world, this manifests in a 15-fold difference in levels of GHG emissions between the lowest and the highest income decile. This is only marginally mitigated by the finding that GHG emission to expenditure elasticity is stronger in South Africa than in all OECD countries but about the same as that in India. The high elasticity can be explained in terms of the divergence in living conditions of South Africa's population, which in return is based on income disparity. It can be generally expected that the higher income disparity, the higher the elasticity. However, it was shown that in the range of 10'000 to 45'000 ZAR expenditure per year and household, covering 60% of the households, indirect GHG intensities resulting from consumption remain largely constant. The utilisation of energy products in this income/expenditure range changes in way which lowers direct GHG intensity and therewith total GHG intensity. The literature around the topic of household metabolism approaches and the literature reviewed in this thesis, focus to some extent on energy and/or GHG intensity as function of income, as an explanatory note for the relationship of income and total resource consumption. This should not fail to take account of the fact that after all the caused GHG emission in absolute terms is the relevant factor, if one is evaluating this from an environmental perspective. Although GHG intensity is lower amongst high-income groups, each Rand spent contributes towards GHG emissions.

5.4. Income Inequality and Future GHG emission

The magnitudes of the effects of economic growth on GHG emission will depend to some extent on income distribution. A relative decoupling of consumption based GHG emission and economic growth may be observed due to the fact that additional income is usually less GHG-intensely spent. The simulations indicate that a lower Gini-coefficient might result in higher GHG emissions from private household consumption and related production. However, in terms of GHG mitigation aims, it is hard to imagine a future in which the majority of South Africa's population, still living in relative poverty, have the same consumer behaviour as today's affluent, without significant reductions in the use of fossil fuels, both for consumption and production.

From a consumption perspective, the key question would be the specific nature of sustainable consumption patterns. Compared with production, whose general principles to reduce impacts are prevention, reduction and recycling, it appears that reducing impacts from consumption is more complex. The most effective principles for reducing GHG impacts, prevention and reduction, seem to be feasible only to a limited extent, particularly in developing countries, in which convenience goods continue to dominate consumption. From the literature we know that households with identical expenditure levels can vary by a factor of three and more in the caused GHG emissions (e.g. Girod and De Haan, 2009). However, even if we assume that additional income is spent exclusively in the most sustainable way, a dramatic increase in consumption based GHG emission would still be highly likely, since the richer half of the population spend about six times more than the poorer half. Thus we can conclude reduction of GHG impact will require both progress in cleaner production and changes in consumption patterns.

However, unlike production, consumption is closely related to human behaviour. Attempts to change human behaviour are very critical in many respects. First and foremost such attempts and strategies constantly threaten personal freedom. Therefore and to ensure efficiency, I would argue for bottom up rather than top down approaches, that machinery of the market should be employed rather than imposing legal restrictions.

As mentioned at the beginning of the thesis, accelerating environmental depletion, and a large share of the world's population still living in poverty, are two of the biggest problems facing the world today (UN, 2012). It is assumed that these two problems are highly interdependent and cannot in any sustainable way be pursued independently (Lusigi, 2008; Mueller, 2006; UN, 2012). Recognizing the increasing GHG emissions of increasing income, the hope lies in the poitive indirect effects affluence may have in regard to the environmental concerns. I aggree, common sense dictates that long-term environmental sustainability cannot be reached without eradicating poverty, but economic wealth will not secure environmental sustainability.

5.5. Hypothesis review

The following hypothesis was formulated prior to the study (Piaget, 2012) and reinforced in section 3.1 'Hypothesis and Overview' of the dissertation. The literature review yielded conflicting results in this regard. Even though it seemed less likely that hypothesis can be confirmed, it was chosen to retain its original wording because the hypothesis as posed appeared to be a useful aid to guide research.

Hypothesis:

The total environmental impact depends marginally on income distribution.

The hypothesis is proven to be wrong in the case South Africa. Regarding GHG emissions, the effects of income distribution are not negligible, neither for current income, nor for additional generated income in the future. In the light of the data collected for this study, this has become apparent, but at the time of developing the hypothesis I subscribed to the somewhat simplistic notion that people living in deprivation would be frugal in the use of natural resources. While this may be true in absolute terms, I failed at this point to convert total usage into any sort of intensity and therefore had not concluded correctly that expenditure by low-income households would lead to generally higher resource intensity per rand spent. After the literature review, in which energy and GHG intensity as function of income and/or expenditure is prominently discussed, the specific condition under which the hypothesis can be found confirmed became apparent. However, it is important at this point to remember that according to the findings of this study, a high Gini-coefficient will lead to less GHG emission, but this may not reflect reality. As already mentioned, this study only demonstrated the causality of income, consumption, production and related GHG emission. Apart from consumption patterns, many other factors have been mentioned in the literature to be positively correlated with income, such as general awareness of environmental issues, willingness to pay for and to accept stricter environmental regulations (e.g. Meyer and Liebe, 2010). Another factor is the number of children in a household. According the I-PAT equation (see page 13), this is probably one of the most relevant factors. Affluent families in South Africa generally have fewer children (South African Human Rights Commission and UNICEF, 2011; Stats SA, 2008a). Fighting poverty through distributing income more equally would slow population growth and its predicted stabilisation would be ensured. If birth rate were taken into account as a factor, a more equal income distribution could be to the advantage of any reduction of environmental impacts. Thus we can assume the likelihood of income distribution having measureable effects on environmental impacts. The direct effect of income equality is negatively correlated with GHG emission on a short to medium term. The magnitude and direction of combined effects of wealth on GHG emission and other impact factors remains unclear.

5.6. Personal reflections

Encouraged by my supervisor, I will briefly outline the implications of the findings of this study for a more sustainable society in my home country Switzerland.

If we ask why we still depend so heavily on fossil fuels we may conclude that it is because of the price. They are simply the cheapest energy source. If we ask why energy is used so inefficiently we may also conclude that it is because of the cost. In economic terms often energy efficiency does not matter. This was the bottom line of thinking which finally motivated my colleagues and me by proposing a change in the tax system of Switzerland about which a national referendum will be held soon[24]. Basically we propose to replace Value Added Tax with a tax on primary energy use (The Federal Chancellery, 2013, 2011). The proposed tax system would initially induce additional taxes of roughly 1 USD per litre of petrol and 0.1 to 0.2 USD per kWh of electricity, according my calculations. My colleagues and I invested much thought and time in estimating the effects such an energy tax could have. Although the limited scope of this thesis does not permit going into the details, the findings of this study, as well the literature, indicate that an unintentional shifting of the tax burden from rich to poor households could take place. This is due to the fact that low-income households may have higher energy intensity per monetary unit than wealthier households; the relative tax load may be higher for low-income households than for affluent households. This is in addition to concerns about the unequal opportunities of low and high income groups to adapt consumption and lifestyle patterns. However, I am now convinced that to adapt consumption patterns is the key to a more sustainable society in Switzerland, not only because of direct caused environmental impacts, but also because of the enhanced effects through induced changes in production. The effects of an energy tax on consumption is at least as important as those of the energy tax on production, which has to date been generally more considered.

5.7. Recommendations

5.7.1. Recommendations for further research

The following recommendations are offered regarding the need for further research:

- The figures supplied in this dissertation are indicative only. For future use the model needs to be improved, and the database reviewed and extended. Most importantly, the data for residential energy usage should be reviewed. A general improvement could be achieved by applying a hybrid method to incorporate figures from additional sources, such as LCA studies. In addition, an evaluation of the transport structures and the wholesale and resale structure needs to be done in such a way as to avoid bias through different sales structures, as well as a review of export and import regarding alignment of economic and physical unit flow. Including GHG emissions from sources other than fuel combustion would increase relevance. And disaggregation of sectors such as 'Land transport', 'Petroleum products',

[24] I am a founder and former board member oft the Green Liberal Party of Switzerland. One out of seven parties currently with a national parliamentary group.

'Agriculture', 'Real estate activities' and 'Non-observe, informal, non-profit, households' would also be beneficial. The up-coming IO-Table of Statistic South Africa (Lehohla, 2012) maybe support this.

- Following on from this, a detailed comparison of the study by Arndt et al., (2011) and this thesis would add value and could be used to establishing consistent figures for general use.
- Quantifying South Africa's exported (and imported) embodied energy and GHG emission by using foreign trade statistics and the results of this study, although labour intensive, would be well worth considering in future discussions about South Africa's GHG emission per capita and its source.
- If one aims to contribute to the EEIO analysis method it could be worthwhile to think about a two-stage method by which information about sectors output, as contained in the original SUT, is used in combination with results from an EEIO sector analysis to allocate and disaggregate sector impacts on their products. This could deliver better results than the traditional approach of diagonalizing SUT (sectors are limited to the production of only one product) in order to make an EEIO product analysis. However more reading and research is required to assess what has already been done in this regard.
- The analysis of caused GHG emissions through consumption as a function of household income should be repeated with disaggregated household data. South Africa's IES contains detailed consumption information from all 24'000 polled households. Using individual household data, rather than the average per income group, allows for a detailed study of the variation of GHG emission within the income ranges and potentially allows identifying sustainable consumption patterns.
- Apart from these closely related and interrelated proposals, in a broader sense I would recommend further research to explore ways of sustainable production and consumption in order to limit GHG emissions and general resource usage. Research with regard to sustainable production and consumption has to go above and beyond the optimizing of production, which is made for a long time whether for economic or environmental reasons. I envisage a form of de-materialised consumption. This study, and many others before it (e.g. Huppes et al., 2008) has demonstrated that one rand spent can cause ten times less the amount of GHG emission if services are purchased instead of commodities. On the other hand, it can be argued that freedom of choice in this regard is limited, particularly in developing countries, in which convenience goods continue to dominate consumption. I envisage a future in which incorporated production of different goods and their consumption are limited to one place. This would minimise residuals and transport in the form of urban farming (I'm speaking of urban farming as a model preferable to that of a big contributor), and I envisage completely closed cycles in material flows enabled by means of product design. Designing and engineering would not include only production, but would extend to the whole system or cycle of production and consumption and would require more rather than fewer engineering skills.
- Also it would be interesting to investigate the socio-economic dimensions of consumption in low-income areas in order to answer such questions as: Which consumption patterns are associated with prestige? What are the factors influencing consumption and are these changing? What is the situation regarding prevailing reuse and recycling: is there something like a common scheme? Which inferences can be drawn therefore regarding sustainable consumption as income grows?
- From an economic perspective, I found it interesting to investigate the economic effects of greening South Africa's (energy) production. If we assume that the necessary technology to produce substantial amounts of renewable energy is available, it becomes a question of how and who finances the transition. Which model for financing large-scale infrastructure projects could be applied? Who would win and who would lose? And how does all of this articulate with the aims of reconciliation and redress of South Africa in general and black empowerment specifically?

5.7.2. Recommendations for Policy Makers

Due to the general purpose and scope of this study, no concrete recommendations can be made for policy makers based solely on the findings of this study. However, the results of this study emphasise that any growth strategy needs to be accompanied by an environmental impact mitigation strategy. In the case of South Africa, where a defined goal is to strengthen low and middle income households, the goods and infrastructure required by those households need to be targeted by environmental policy makers. According to the results of this study, power generation, transport infrastructure and housing are important in this regard. However, since it is uncertain how the country and its different sectors will develop, I argue that policy makers must target the underlying principles causing environmental depletion rather than particular sectors. As mentioned in section 5.5 'Personal reflections', I would advocate for imposing a tax on (energy) resource usage. Those economic sectors, which need large amounts of resources, would be generally slowed down, with little to marginal impact on national employment and/or GDP. However, other researchers are able to provide more comprehensive answers to these questions, and I recommend further reading at this point (e.g. Alton et al., 2012; Devarajan et al., 2009; Goldblatt, 2010).

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7. Appendix

7.1. IO-Table

South Africa industry-by-industry Input-Output table based on SUT 2005 (Stats SA, 2005) with fixed product sales structure assumption. GDP not calculated because of modifications in Use-Table.

7.2. Comparison Household Expenditures according SUT to IES

Comparison of household expenditures according SUT to IES. Expenditures are general higher in SUT than in IES. In order to compare on the base of equal total expenditure, the expenditure in IES had been up-scaled with factor 1.43 for products and 1.40 for sectors. Household expenditures are listed for products. In order to get expenditures per sector, the expenditure vectors needs to by multiplied with the transformation matrix 'T' of the IO-Table. The ten products and sectors with the highest difference between SUT and IES are marked.

7.3. GHG intensity per Sector

GHG emission per Sector and Rand output.

7.4. Total GHG emissions per Sector

Direct GHG emissions per sector and Total direct and indirect GHG emission per sector.

7.5. Summary Effects of Growth and Income Distribution

Effects of household income growth on household consumption expenditure and industry output by different income distribution scenarios. For a description of income distribution scenarios see section 3.5.3 'A note on Gini-Coefficients'.

7.6. Forecast of Sector Growth

Forecast of sector growth as result of different income distribution scenarios. Depending on income distribution and subsequent consumed basket of goods sector growth and related GHG emission varies.

7.7. Household consumption related GHG emission per Decile

Key figures of private household consumption and related GHG emission per income decile.

That's it that's all