A SECTORAL BENCHMARK-AND-TRADE SYSTEM TO IMPROVE ELECTRICITY EFFICIENCY IN SOUTH AFRICA

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Dedication

To my dearest late grandparents – I am sure they are proud of me from heaven.

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Abstract

The continuously increasing energy intensity internationally is recognised as one of the greatest dangers the human race is facing nowadays with regards to future climate change and its detrimental consequences. Improving the intensity of energy consumption is an important step towards decreasing greenhouse gas emissions originating from fossil fuel-based electricity generation and consumption.

As a result of this, South Africa took the bold step in 2010 to commit itself to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) in taking all the necessary actions to decrease the country’s greenhouse gas emissions by 34% to below the “business-as-usual” scenario by 2020 (Republic of South Africa, 2010). In order to do so, the country has to substantially reduce its energy consumption. This should be done without affecting the economic output; however, major energy consumers might prefer to decrease their output in order to comply with the rules focusing on the reduction of energy use.

In South Africa, harmful environmental effects are created mainly from the electricity consumption’s unprecedented rise. The bulk of the country’s greenhouse gas emissions (more than 60%) originate from the electricity generation sector which is heavily dependent on coal-fired power stations. The purpose of this study is to promote a benchmark-and-trade system to improve electricity efficiency in South Africa with the ultimate objective to improve the country’s greenhouse gas emissions. The uniqueness of this study is two-fold. On the one side, South African policy-makers have rarely discussed or proposed the implementation of a cap-and-

trade system. On the other side, the same mechanism has never been proposed regarding electricity efficiency.

In order to do so, it is first required to acquire an in-depth knowledge of the electricity consumption and efficiency of the South African economy in its entirety and on a sectoral level. The key findings of the empirical analysis are as follows:

A decreasing effect of electricity prices to electricity consumption existed during the period 1980 to 2005, contrary to the increasing effect of total output to electricity consumption. Also, the results indicated that the higher the prices, the higher the price sensitivity of consumers to changes in prices (price elasticity) and vice versa.

The relationship between electricity consumption and electricity prices differ among various sectors. The findings of the exercise point towards ambiguous results and even lack of behavioural response towards price changes in all but the industrial sector, where electricity consumption increased with price decreases. On the other side, economic output affected the electricity consumption of two sectors (industrial and commercial) presenting high and statistically significant coefficients.

Based on a decomposition exercise, the change in production was the main factor that increased electricity consumption, while efficiency improvement was a driver in the decrease of electricity consumption. In the sectoral analysis, increases in production were part of the rising electricity usage for all the sectors with ‘iron and steel’, ‘transport’ and ‘non-ferrous metals’ being the main contributors to the effect. On the decreasing side of consumption, only five out of fourteen sectors were influenced by efficiency improvements.

The country’s electricity intensity more than doubled from 1990 to 2007 and the country’s weighted growth of intensity was higher than the majority of the OECD countries by a considerable margin. Also, nine of the thirteen South African sectors were substantially more intensive than their OECD counterparts.

Although the picture presented is rather dismal, there is scope for improvement. This study proposes a sectoral benchmark-and-trade system. This system aspires to steadily improve the participants' efficiency performance by awarding the successful participants with monetary incentives through trading with the less successful ones.

The benchmark is chosen to be subject to the average of OECD members for each sector. Depending on the sectors' performance compared with the standard chosen, they will be awarded credits or allowances to sell if they do better than the benchmark. If they are worse-off, they will have to buy credits in the market created. The price per credit will be determined by the interaction of demand and supply in the market.

The findings of a comparison with a carbon tax system show that the proposed system benefits the majority of the sectors and gives them better incentives to change their behaviour and production methods to more efficient ones. The system also fulfils the desired characteristics of a benchmark-and-trade system: certainty of environmental performance; business certainty; flexibility; administrative ease and transparency.

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1 GENERAL INTRODUCTION

1.1 Introduction

Electricity is defined as "... a form of energy from charged elementary particles, usually supplied as electric current through cables, wires, etc. for lighting, heating, driving machines, etc." (Oxford Advanced Learners' Dictionary, 2005).

Electricity is a low value yet necessary good within any economy and is one of the pillars of economic and social development (Blignaut, 2009). The generation, supply and distribution of electricity have the potential to unlock economic development.

Electricity consumption in South Africa has increased significantly over the past decade. The bulk of the country's greenhouse gas emissions (more than 60%) originate from the electricity generation sector which is heavily depended on coal-fired power stations (Blignaut, Mabugu, & Chitiga-Mabugu, 2005). Hence, the unprecedented rise in consumption has created serious concerns regarding the environmental effects, including higher CO_2-emissions as a result of the increased combustion of coal.

As a result, South Africa took the bold step at the beginning of 2010 to commit itself to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) in taking all the necessary actions to decrease the country's greenhouse gas emissions by 34% to below the "business-as-usual" scenario by 2020 (Republic of South Africa, 2010) .

In response to the international and local commitment for improvement of greenhouse gas emissions, global energy consumers have shown interest in switching from traditional forms of energy to renewable, cleaner ones and thereby improving the energy use and its detrimental effects on the environment.

This study will show that South Africa has the potential to follow the international trends and improve the current situation of electricity consumption taking into consideration the production capacity of the economy.

1.2 Problem statement

Over the past two decades, South Africa has undergone major political, social and economic changes. As a developing country on a path towards high and sustainable growth, it has experienced critical energy issues. The mismatch of the supply and the increasing demand resulted in the recent electricity crisis in 2008, affecting the whole economy considerably.

Since the country's democratisation, the local energy authorities have mainly focused their efforts on the increase of electricity supply by expanding the current electricity production rather than focusing on demand-side management. However, from an environmental point of view, the greater production of electricity will result in higher emissions of greenhouse gases, especially CO_2, due to the fact that electricity generation in South Africa depends mainly on coal-burning.

However, targeting the reduction of electricity consumption might prove detrimental to the economic output of the country. Major electricity consumers might prefer to decrease their output in order to comply with the rules and regulations focusing on the reduction of electricity usage.

International literature has shown that focusing on an indicator that takes into consideration both economic output and electricity usage is preferred. Hence, energy policy-makers should focus on the energy efficiency (intensity) of the economy not only on an aggregate level but also on a sectoral level.

This study proposes a solution that promotes demand-side management towards the improvement of electricity efficiency in South Africa. In order to do so, it is required to analyse the electricity consumption and efficiency of the South African economy in its entirety as well as in the various sectors. The mechanism that will finally be proposed is an electricity efficiency benchmark-and-trade system.

This system will encourage particularly the most electricity-intensive sectors to save electricity in order to avoid the cost-related and environmental consequences from the extensive use of electricity. The fundamental principles of such a benchmark-and-trade system would be based on the programmes related to air pollution, but applied to energy efficiency. According to the Environmental Protection Agency (EPA) (Environmental Protection Agency, 2008), a cap-and-trade system against the air pollution is "… a market-based policy tool for protecting human health and the environment". The idea of trading energy was first tried in the 1970s with trade of pollutants, such as sulphur dioxide and nitrous oxide, to combat acid rain. Moreover, the European Union used trading of carbon to reduce greenhouse gas emissions (BBC News, 2006).

The uniqueness of this study is two-fold. First, South African policy-makers have never proposed or discussed the implementation of a cap-and-trade system. Second, this system has never been proposed for the case of electricity efficiency.

1.3 Objectives of this study

The main objective of this study is to develop and design a market-based solution for the electricity efficiency in the South African economy. This may provide a long-term solution for the major electricity problems in the country. In order to do so, a thorough analysis of the behaviour of the economy in its entirety but also at a sectoral level is required.

The following specific objectives will guide this study:

- To conduct an extensive local and international literature review on electricity efficiency related matters
- To examine and analyse the South African electricity sector and its unique characteristics
- To estimate the sensitivity of the economy's and the different consumers' electricity demand to price changes over time
- To examine the role of electricity efficiency in the evolution of the country's electricity consumption and investigate how significant the role of the structure of the economy is

- To compare the country's total and sectoral electricity intensities with a group of developing and developed economies in order to conclude if South Africa is following international standards

- To design the proposed electricity efficiency benchmark-and-trade system, and make recommendations on how this market should be regulated and what the limits of the intervention should be in order for this market to be considered successful.

1.4 Structure of this study

The rest of this study is organised as follows:

Chapter 2 deals with the essential literature on energy efficiency matters, the specific case of South Africa and cap-and-trade systems. Section 2.1 focuses on the South African electricity sector. It presents the key players and the evolution of their roles and responsibilities during the last two decades, as well as the policies and regulations that are in place. Finally, the status quo is illustrated by presenting data and information on current electricity consumption and prices.

Section 2.2 provides information on the definition of energy (electricity) efficiency and intensity. It also evaluates the importance of the specific indicator and the different ways of measurement. Finally it concludes with discussing international and local efforts towards the improvement of efficiency.

Section 2.3 describes the fundamentals of a cap-and-trade system and discusses international applications. Subsequently, the system is assessed and its strong and weak points are presented.

Chapter 3 deals with the empirical evidence that led to the proposed model. Section 3.1 discusses the aggregate price elasticity of electricity demand in South Africa. The Kalman filter, an econometric technique, is employed in order to estimate the evolution of the sensitivity of electricity consumption to changes in price and output.

Section 3.2 analyses price elasticity in a disaggregated level. By using panel data techniques, the different behavioural responses of a number of economic sectors to changes in the sector-specific prices and output are shown.

Section 3.3 employs a decomposition analysis to examine the role of the changes in the structure of the economy, electricity efficiency and output with the increasing trend of electricity consumption of the country both at aggregate and sectoral level.

Section 3.4 provides a comparative analysis of the total and sectoral electricity intensities of South Africa to the OECD countries, taking into account dissimilar output structure of the various sectors.

Chapter 4 presents the proposed benchmark-and-trade system in order to improve the picture of electricity efficiency in South Africa. Section 4.1 explains in detail the theoretical mechanisms as well as the policy implications of the system for the country. It also discusses the economic and environmental benefits of the system and then compares it with the current basic alternative, the carbon tax.

Finally, Chapters 5 provides a general conclusion of this study. Section 5.1 synthesises the main points of the study and Section 5.2 restates the objectives, summarises the key findings and the proposed system, and provides policy implications. Section 5.3 proposes future research paths resulting this study.

2 LITERATURE REVIEW

Before proceeding to the analysis of the dissertation, it is imperative to provide information specifically on a) the South African electricity sector, its key players, policies and regulations, as well as the evolution of electricity consumption and price (Section 2.1); b) the definition of energy (electricity) efficiency and intensity, its importance and measurement, and international and local efforts towards its improvement (Section 2.2); and c) the implementation of cap-and-trade systems internationally as well as their advantages and disadvantages (Section 2.3).

2.1 Electricity profile: the South African case

The South African electricity sector has been characterised through the years by unique traits and it has passed through different phases where various key players had dissimilar responsibilities. In this section, the main phases as well as the key players and their roles in each phase are analysed. This is followed by a discussion on the evolution of policies and regulations regarding electricity through the years, as well as consumption and prices.

2.1.1 Electricity regulation and institutions

2.1.1.1 National Energy Regulator South Africa (NERSA)

Before the 1990s, regulators had limited power in the decision regarding electricity price-setting. However, the situation has changed since the establishment of the post-apartheid National Electricity Regulator (NER) and we turn to that next.

In order to establish a national regulatory framework for the electricity supply industry, the South African Government published the first Electricity Act in 1987 (RSA, 1987). With this Act the Electricity Control Board and the NER were established and the Act's main objectives were to:

a) "Achieve the efficient, effective, sustainable and orderly development and operation of electricity supply infrastructure in South Africa;

b) Ensure that the interests and needs of present and future electricity customers and end-users are safeguarded and met, having regard to the governance, efficiency, effectiveness and long-term sustainability of the electricity supply industry within the broader context of economic energy regulation in the Republic;

c) Facilitate investment in the electricity supply industry;

d) Facilitate universal access to electricity;

e) Promote the use of diverse energy sources and energy efficiency;

f) Promote competitiveness and customer and end-user choice; and

g) Facilitate a fair balance between the interests of customers and end-users, licensees, investors in the electricity supply industry and the public" (RSA, 1987)

According to the Act, the responsibilities and duties of the Regulator are now specified. The Regulator must:

a) "Consider applications for licences and may issue licences for the operation of generation, transmission and distribution facilities and for trading of electricity;

b) Regulate prices and tariffs;

c) Register persons who are required to register with the Regulator where they are not required to hold a licence;

d) Issue rules designed to implement the national government's electricity policy framework, the integrated resource plan and this Act;

e) Establish and manage monitoring and information systems and a national information system and co-ordinate the integration thereof with other relevant information systems;

f) Enforce performance and compliance, and take appropriate steps in the case of non-performance" (RSA, 1987).

In terms of the National Energy Regulator Act, 2004 (RSA, 2004), NERSA was established with the mandate to carry out the functions of the Gas Regulator, the Petroleum Pipelines Regulatory Authority as well as NERSA. NERSA's mission is "… to regulate the energy industry in accordance with government laws, policies, standards and international best practices in support of sustainable development" (RSA, 2004) and its main strategic objectives are as follows (National Energy Regulator, n.d.):

- "To implement relevant energy policy efficiently and effectively;
- To implement relevant energy law efficiently and effectively;

- To implement relevant energy regulations efficiently and effectively;
- To identify, develop and implement relevant energy rules efficiently and effectively;
- To establish the credibility, legitimacy and sustainability of NERSA as an independent and transparent energy regulator;
- To create an effective organisation that delivers on its mandate and purpose; and
- To evaluate the Energy Regulator's effectiveness” (National Energy Regulator, n.d.).

More specifically, “[u]tilities such as Eskom, Sasol, etc. cannot increase their regulated rates or alter their conditions of service until NERSA approves the new tariffs. To obtain approval, a utility must demonstrate that such a change is merited. The utility files an application with NERSA to ‘prove’ that an increase is justified. The advocacy role requires that there must be an independent body to represent the side of the consumers during the tariff determination, especially the voiceless consumers” (National Energy Regulator, n.d.).

Marquard (2006) also mentions that NER (now NERSA) played an important role in the distribution tariffs regulation and the launch of a Wholesale Electricity Tariff pricing system, as well as in the assistance and monitoring of the electrification programme.

2.1.1.2 Policies and regulations

Following the political restructuring in 1994 and the transition to democracy, the country started an initiative to eliminate inequalities and to provide electricity to the majority of the population. In 1994, the newly-elected government commenced discussions for a *White Paper on Energy Policy* which was finally released in 1998. Firstly, there was a need for a formal description of the South African energy sector both from a demand and a supply perspective.

From the demand perspective, the status quo is usually analysed in terms of energy needs and usage of households, industry, the commercial sector, mining, transport and agriculture. Regarding the supply, sub-sectors included for analysis are coal, electricity, nuclear, liquid fuels, gas and renewable forms of energy.

The *White Paper on Energy Policy* also specifies the cross-cutting issues for the future of the energy sector:

a) *Integrated energy planning:* the need for technical functions in order to achieve maximum success of energy policies.

b) *Statistics and information:* the need for a database covering numerous areas and provision of information by the government.

c) *Energy efficiency:* the need for energy efficiency consciousness in all aspects of economic activity by establishing energy efficiency standards for commercial buildings and industrial equipment. Government will promote improved appliances for wood and traditional fuels and it will set, monitor and evaluate targets for industrial and commercial energy efficiency improvements.

d) *Environment, health and safety:* the present and future energy policies need to take into account the environmental and health effects and provide solutions for the problems caused by energy use.

e) *Research and development:* appropriate research by government, the private sector and universities is essential.

f) *Human resources:* an attempt for further development of the human resources in the sector is needed.

g) *Capacity-building, education and information dissemination:* there is a need for government's support in the mentioned topics.

h) *International energy trade and co-operation:* possible reduction of trade barriers, facilitation of regional co-operation, and establishment of relationships with energy players internationally.

i) *Fiscal and pricing issues:* the need for alignment of fiscal and energy policies.

j) *Governance and institutional capacities.*

With the rapid electrification programme, the main electricity supplier (Eskom) and the new government made an effort to supply electricity to the majority of households, especially in the undeveloped rural areas. In 2001, the Free Basic Electricity policy (FBE) was introduced by Eskom following suggestions made by the Department of Minerals and Energy (DME).

The government argued that ‘‘conventionally, the average poor household does not consume more than 50kWh of electricity per month” (Bureau of African Affairs, 2010) and therefore, this amount was to be offered free of charge. Additionally, it is difficult to determine a baseline as to who is poor and thus qualifies for this subsidy. That is why the subsidy became available to all consumers regardless of their income levels.

However, some questions were raised regarding the FBE. UCT (2003) argues that the FBE does not succeed in one of the main goals: the reduction of income disparities on household energy use. The main reasons is that the recipients of FBE do not fully comprehend the programme and the "... vendors are unwilling to supply the recipients with FBE credits without some form of compensation" (Bekker, Eberhard, & Marquard, 2008). Furthermore, Howells et al. (2006) worry whether low-income households have the necessary information and incentives to completely change their energy use from LPG or methane which is affordable, clean and easy to use, to electricity.

2.1.2 Electricity supply

According to Marquard (2006), the South African electricity system experienced three main phases. Phase one (late 19th century to 1900s), was characterised by the existence of small electricity systems set up by local authorities in cities and relatively bigger electricity systems that were set up by self-producers (mainly mines). Phase two (late 1900s till early 1920s) started with the development of an electricity generation monopoly in the Witwatersrand for the provision of electricity and compressed air to the gold-mining industry, namely the Victoria Falls and Transvaal Power Company (VFTPC). The third phase (from the early 1920s till today) started with the establishment of the state utility, Escom (now Eskom), which primarily aspired to produce bulk electricity and sell it to the local authorities, the railways and the mines. Eskom also had an agreement of co-existence with VFTPC that ended in the late 1940s (Marquard, 2006). The years following that can also be characterised as a new phase because the electricity system saw the transition towards an integrated national system, with Eskom being the generator, transmitter and main distributor of electricity.

Taking the above into account, there are two main role players in the development of the South African electricity system: a) Eskom and b) the local government. During the last couple of years, NERSA also found its place in the structure of the South African electricity system. Moreover, South Africa also trades electricity with mainly the Southern African Power Pool (SAPP) member countries.

Before analysing the key role players of the South African electricity market, selected electricity supply statistics are presented in Table 2.1 for 1992–2006. These figures show that the domestic supply increased slightly during the study period. However, the maximum generation capacity has a ceiling due to the existing electricity generation infrastructure. The need for new generation infrastructure in order to boost the current one and also to replace some of the older power stations is supported the last decade. However, the reasons for not building new capacity are mainly political and economic, and not reasons of questioning the necessity.

Table 2.1 Selected electricity supply statistics in South Africa: 1992–2006

	GWh				GW
	Indigenous production	**Imports**	**Exports**	**Domestic supply**	**Net maximum capacity**
1992	167,816	334	1,814	166,336	36.846
1993	174,581	100	2,589	172,092	37.636
1994	182,452	54	2,679	179,827	35.926
1995	187,825	149	3,000	184,974	35.951
1996	200,266	29	5,579	194,716	36.563
1997	210,052	5	6,617	203,440	37.175
1998	205,374	2,375	4,532	203,217	37.848
1999	203,012	6,673	4,266	205,419	38.517
2000	210,363	4,719	4,007	211,075	39.186
2001	197,908	9,200	6,996	200,112	39.810
2002	206,105	9,496	7,242	208,359	39.810
2003	221,642	8,194	10,263	219,573	39.810
2004	234,045	9,818	13,254	230,609	38.436
2005	230,024	11,079	13,422	227,681	38.644
2006	240,964	10,624	13,589	237,999	39.271

Source: (DME, 2010a)

2.1.2.1 Local government

From the start, the institutional development of the electricity system did not allow for an extended role by the local authorities although they were supposed to be the first suppliers of electricity.

Table 2.2 Gross energy sent out (GWh) in 2005

	Total	Eskom	Municipalities	Private
Gross energy	230,303	221,895	1,203	7,115
Ratio to total	100%	96.35%	0.52%	3.10%

Source: National Energy Regulator, n.d.

In 1940, only 25% of the local authorities bought electricity from Eskom or other private suppliers (DCGIS, 1940) and this percentage declined during the following years, until 2005 the local authorities produced only 0.6% of total electricity (National Energy Regulator, 2005), as shown in Table 2.2. This decrease was partially enforced by policies that allowed only Eskom to build new electricity generation plants.

2.1.2.2 Eskom

The state-owned company known as the Electricity Supply Commission (Escom) – later Eskom – was established in 1922 in terms of the 1922 Electricity Act and started its operations in 1923. Its initial responsibility was two-fold: a) to supply electricity anywhere in the country that it was needed, acting as the national electricity supplier; and b) to assist the local authorities in their electricity development plans, acting as a government unit to promote electrification.

Eskom's primary objective, as re-stated in the *1984 Annual Report* (Eskom, 1984, p. 8) was ".... to provide an adequate supply of electricity, at cost price, to be used for the economic advancement of South Africa". However, since the 1980s and towards the political transition of the country, Eskom acquired a second role. This role was to provide equal distribution of electricity for all. To do so, Eskom launched a new electrification programme which main objectives included providing electricity to poor black households and the development of a larger national grid.

During this initial period of existence (1923–1985), Eskom was governed by the Electricity Supply Commission. From 1985 until 2001, it was governed by a Management Board and an Electricity Council and their responsibilities were specified by the Electricity Amendment Act (50/1985). Since 2002, Eskom is being managed by a typical corporate governance structure.

As with any other state-owned enterprise, Eskom has been supervised by a number of government departments throughout the years:

- Department of Mines and Industry (until the 1930s)
- Department of Commerce and Industry (until the 1960s)
- Department of Industry (until 1980)
- Department of Mineral and Energy Affairs (until the end of 1980s)
- Office of Public Enterprise (OPE) (until 1994)
- Department of Mineral and Energy Affairs – now Department of Energy – for electricity policy matters, and the Department of Public Enterprises as its principle shareholder (to present)

The country's economic growth, industrialisation and the electrification programme resulted in high levels of demand for electricity. This in combination with the limited supply, led to countrywide power outages in 2008 that had a significant negative impact on the entire economy. Eskom was responsible, as the national electricity supplier, for managing the situation and focused on demand-side management

(DSM) and an energy efficiency programme in the short-run, while planning to maintain and expand the current infrastructure in the long-run.

Table 2.3 Generation power plants (Eskom)

Power plant	Type	Location	Capacity (GW)
Acacia	Gas	Western Cape	0.171
Ankerlig	Gas	Western Cape	1.338
Arnot	Coal	Mpumalanga	2.352
Camden	Coal	Mpumalanga	1.520
Drakensberg	Pumped storage	KwaZulu-Natal	1.000
Duvha	Coal	Mpumalanga	3.600
Gariep	Hydro	Free State	0.360
Gourikwa	Gas	Western Cape	0.746
Grootvlei	Coal	Mpumalanga	1.200
Hendrina	Coal	Mpumalanga	1.965
Kendal	Coal	Mpumalanga	4.116
Klipheuwel	Wind	Western Cape	0.003
Koeberg	Nuclear	Western Cape	1.930
Komati	Coal	Mpumalanga	0.940
Kriel	Coal	Mpumalanga	3.000
Lethabo	Coal	Free State	3.708
Majuba	Coal	Mpumalanga	4.110
Matimba	Coal	Northern Cape	3.990
Matla	Coal	Mpumalanga	3.600
Palmiet	Pumped storage	Western Cape	0.400
Port Rex	Gas	Eastern Cape	0.171
Tutuka	Coal	Mpumalanga	3.654
Vanderkloof	Hydro	Northern Cape	0.240

Source: (Eskom, 2010)

The current installed capacity per existing power plant presented in Table 2.3, shows that the maximum electricity generated cannot be exceeded in the short-run.

Eskom plans to build new power plants in a five-year period (ending 2013) enabling them to cover the difference between the demand and the supply of electricity (DME, 2010a) focusing more on the long-run increase of the electricity supply.

The previous building programme includes four new power plants (Kusile, 4,800MW; Medupi, 4,800MW; Ingula, 1,332MW; Sere wind-farm, 100MW) that will boost the electricity supply to the country. A new project has also been launched in Botswana: a coal-fired power plant with a capacity of up to 4,800MW. Moreover, it is also necessary to upgrade the older plants, hence the electricity entity's intermediate plans, known as the Simunye projects. This rise in electricity supply, however, will only be in effect by 2013 or later. Therefore, the maximum supply remains constant in the short-run.

In May 2011, the new Integrated Resource Plan for electricity 2010-2030 (Republic of South Africa, 2011) was promulgated. According to this, the future projects have classified based on three timeframes: 1) to be decided before the next IRP; 2) to be confirmed in the next IRP; and 3) to be possibly replaced during the next and subsequent IRPs. The new build options that are to be decided before the next IRP include: Coal fluidised bed combustion units 2014/15; Nuclear power plants ; Import hydro (2022 to 2024); Gas Fired power stations (2019); Solar photovoltaic units (2012-2015) connected to the grid; Wind installations (2014/15); Concentrating Solar Power (CSP) units (2016).

2.1.3 Electricity consumption

Electricity consumption in South Africa has increased significantly over the past decade: from 11.96% (between 1995 and 2000) to 34.58% (between 2000 and 2006). This unprecedented rise has raised serious concerns regarding the environmental effects, including higher CO_2-emissions as a result of the increased combustion of coal. There is a direct link between electricity generation and consumption and CO_2-emissions. Therefore, one possible effective mechanism to reduce CO_2-emissions is to reduce the demand for electricity by strengthening the demand response or demand elasticity for electricity.

Each year, the National Department of Energy in South Africa releases an Aggregate Energy Balance of the country, which indicates the electricity consumption by sectors in MWh. Electricity consumption per sector, as well as the sectoral shares of total consumption, for the years 1995, 2000 and 2006 are presented in Table 2.4.

Table 2.4 Sectoral electricity consumption in South Africa: 1995, 2000 and 2006

	1995		2000		2006	
	GWh	%	GWh	%	GWh	%
Total consumption	143,173	100.0%	160,300	100.0%	215,739	100.0%
Industry sector	80,657	56.3%	99,703	62.2%	116,631	54.1%
Iron and steel	16,251	11.4%	20,913	13.0%	21,342	9.9%
Chemical and petrochemical	3,603	2.5%	2,640	1.6%	10,081	4.7%
Non-ferrous metals	6,956	4.9%	15,038	9.4%	18,640	8.6%
Non-metallic minerals	1,190	0.8%	1,154	0.7%	2,606	1.2%
Transport equipment	9	0.0%	69	0.0%	92	0.0%
Machinery	104	0.1%	53	0.0%	42	0.0%
Mining and quarrying	33,176	23.2%	29,038	18.1%	31,503	14.6%
Food and tobacco	454	0.3%	639	0.4%	761	0.4%
Paper pulp and print	975	0.7%	1,494	0.9%	1,756	0.8%
Wood and wood products	534	0.4%	412	0.3%	296,890	0.1%
Construction	14	0.0%	34	0.0%	54	0.0%
Textile and leather	475	0.3%	376	0.2%	519	0.2%
Non-specified (industry)	16,916	11.8%	27,842	17.4%	28,938	13.4%
Transport sector	4,297	3.0%	5,411	3.4%	3,480	1.6%
Other sectors	58,218	40.7%	55,186	34.4%	95,629	44.3%
Agriculture	5,301	3.7%	3,954	2.5%	5,841	2.7%
Commerce and public services	17,307	12.1%	17,164	10.7%	28,833	13.4%
Residential	24,369	17.0%	28,680	17.9%	39,671	18.4%
Non-specified (other)	11,241	7.9%	5,387	3.4%	21,283	9.9%

Source: (Department of Minerals and Energy (DME), Various issues)

As seen in Table 2.4, the 'industrial' sector has been the largest consumer of electricity for each of the years presented. The industrial sub-sectors that showed the strongest growth are 'chemical and petrochemical' and 'non-metallic minerals'. The ‘construction’ sector, although not a big consumer in its own right, has almost doubled its electricity consumption over the study period, which is an indication of the growth in the sector in the 2000s.

In addition, the ‘non-ferrous metals’ sector also doubled its electricity consumption within the study period. The ‘residential’ sector’s electricity consumption has also increased, while keeping its share of the total consumption fairly constant at 17–18%. However, the ‘residential’ sector was the single largest consumer of electricity in 2005.

The electricity consumption of ‘commerce and public services’ increased in 2005. In comparison to other sectors, however, the ‘commerce and public services’ share remained at 12–13%.

The main reason why important changes are observed between the 1995 and 2000 sectors’ electricity consumption shares is the economic and social structural conversion the country underwent post-1994.

Figure 2.1 presents the contribution of the various economic sectors to the electricity consumption of the country in 2006. The trends more or less remain the same as in 2005: the ‘residential’ sector was the single main electricity consumer (18.4%).

From the industry part (which contributed approximately 54% of the total), the ‘mining’ sector consumed 14.6%, ‘iron and steel’ consumed 9.89% and ‘non-ferrous metals’ consumed 8.64% of the total electricity used. From the rest of the economy, ‘commerce and public services’ was a significant contributor (13.36%) while ‘agriculture’ and ‘transport’, which are labour-intensive rather than capital- or energy-intensive, contributed only 2.71% and 1.61%, respectively.

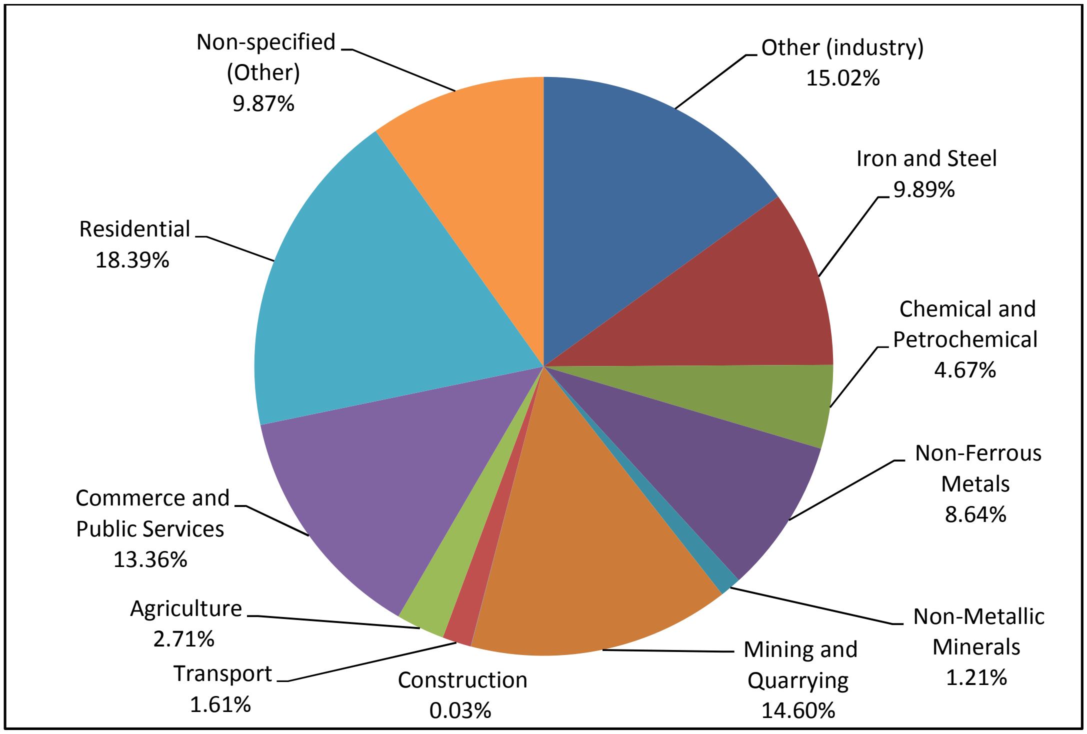

Figure 2.1 Electricity consumption by sector in 2006
Source: (Department of Minerals and Energy (DME), Various issues)

Note: From Figure 2.1 it can be seen that the 'industrial' sector in aggregate is the major electricity user. Of the industrial sectors, 'mining and quarrying' has the highest share of electricity consumption (14.6%). The 'residential' sector (with 18.39%) is the highest single electricity user while 'agriculture' and 'transport' do not use more than 5% of the total electricity use together.

The rising electricity demand in South Africa over the last few years and the need to restore its reserve margin led to the worst energy crisis this country has encountered at the beginning of 2008. Eskom made an effort to intervene in order to avoid this crisis through a national awareness strategy. As a last alternative, load-shedding was conducted in selected regions or sectors in order to prevent an economy-wide blackout. This however, had detrimental negative consequences for the South African economy. In 2009, the CEO of NERSA, while talking about the mining and metallurgical industry's response to the power crisis, stated that continuous load-shedding cost the economy R75 per kWh. NERSA estimated that approximately R50bn were lost during the 2008–2009 crisis (Mail & Guardian Online, 2008).

Although NERSA states that they were unaware of the significant problems in electricity supply, Eskom argues that it had experienced a lack of capacity in the generation and reticulation of electricity since 2007 (Inglesi, 2010). Eskom also says that substantial efforts were needed in order to convince both the private sector and the government that new capacity is necessary. However, the government was not convinced of the viability of this strategy and wanted to bring independent power producers into the market. In October 2004, the government had agreed to finance the construction of a new plant but due to insufficient time to finish the project, it could not be utilised to counter the deficit experienced in 2007−2008 (Eskom, 2010). An additional contributing factor was the increase of electricity demand (50%) in the country between 1994 and 2007. This increase might have been partially due to the implementation of the Free Basic Electricity Policy in 2001. Another contributing factor was the expansion of the economy after sanctions were lifted.

Pouris (2008) also argues that the lack of research on energy in general, and electricity in particular, before 2007 could be one of the factors responsible for Eskom's predicament. In his paper, Pouris (2008) states that South Africa produces only 0.34% of the international research publications reporting on topics of energy and fuels while it contributes 0.5% of the academic research papers in all scientific disciplines internationally. Furthermore, he found that energy research literature constitutes 0.45% of the national effort. This share is much smaller than the top disciplines of the country, such as medicine (6.04%) and plant sciences (5.07%). He concludes that the lack of academic research in this field deprives the relevant stakeholders and government from insight and debate based on independent views (Inglesi & Pouris, 2010). However, this has changed drastically during, and especially after, the crisis of 2007–2008, for example Ziramba (2008); Odhiambo (2009); Amusa, Amusa, & Mabugu (2010); Inglesi (2010); Inglesi and Blignaut, (2010); and Inglesi & Pouris (2010).

The main reason provided by Eskom for the energy crisis was the imbalance between electricity supply and electricity demand. Inglesi (2010) examines the contributing factors of the South African electricity demand for 1980–2005 by applying the Engle–Granger co-integration technique and Error Correction model. More specifically, she analyses the relationship between the electricity demand and income, prices and population. Her results show that the long-term impacts of income and price are significant and are both estimated to be inelastic (0.42 and 0.55, respectively). In the short-run, the demand for electricity is explained by the Gross Domestic Product (GDP) and the size of the population of the country.

Two different scenarios were introduced by Inglesi(2010) to forecast the electricity demand until 2030. In both of these the population growth was 1% per annum (International Monetary Fund (IMF), 2009a). The following assumption holds for both scenarios: the electricity price will increase and double from 2008 to 2011 and then it will remain constant until 2025. The main difference between the two scenarios is that the economic growth will average 4% for the period 2009–2030 in the first; whereas, accelerated growth of 6% in average over the period 2009–2030 is proposed in the second.

According to these scenarios, the demand for electricity will decline after the price restructure that is being promoted by Eskom and NERSA. Furthermore, significant forces that drive the decline in electricity use are the lower population growth and the lower, more stable, economic growth of the country.

Based on Inglesi's (2010) assumptions, South Africa can experience up to 27% less electricity demand (comparison of 2007–2030 values) if the price of electricity doubles by 2011 and then remains constant with an average economic growth of 4% for the period until 2030. The picture does not change much if the economic growth is higher: an increase to 6% causes the electricity demand to drop by 24% by 2030.

2.1.4 Electricity prices

Recently, the electricity prices and their increases have become a topic for continuous debate in South Africa. This section presents the evolution of electricity prices in the country since the beginning of the 1990s at aggregate and sectoral levels as well as in comparison with international best practice.

Literature abounds with information describing South Africa’s historic electricity prices (Van Heerden, Blignaut, & Jordaan, 2008) (Odhiambo, 2009). It is noted therein that South Africa has had low and declining real prices of electricity for a prolonged period of time. The average real prices of electricity for the period 1993 to 2004 are shown in Table 2.5. Even after increases in the nominal prices for the various sectors, the growth rates in real terms during the study period were very low, even negative, in most instances.

Table 2.5 Average real electricity prices in South Africa (2005=100) and annual percentage growth

	c/kWh						
	Industry	**Mining**	**Transport**	**Agriculture**	**Commerce**	**Residential**	**Average**
1993	17.49	19.94	28.69	41.55	34.47	26.55	28.12
1994	17.09	19.40	27.45	40.54	33.44	32.15	28.35
1995	18.37	18.75	25.87	38.83	32.94	32.05	27.80
1996	16.63	18.14	25.20	38.50	32.08	32.02	27.09
1997	16.33	17.67	22.79	37.36	30.65	32.32	26.19
1998	15.63	17.33	21.13	37.48	26.74	32.26	25.09
1999	14.25	17.01	20.49	35.86	30.04	34.21	25.31
2000	15.28	16.52	19.65	36.97	28.98	35.46	25.48
2001	13.99	16.16	18.99	32.50	21.72	37.40	23.46
2002	14.29	15.69	19.03	29.37	21.65	37.09	22.85
2003	14.85	15.80	19.90	30.55	21.62	38.35	23.51
2004/05	14.44	15.88	20.02	31.87	22.61	40.00	24.14
2006/07	14.75	16.19	20.25	32.86	22.69	40.08	24.47
2007/08	16.52	17.19	22.28	34.32	23.75	42.59	26.11
Average	**15.71**	**17.26**	**22.27**	**35.61**	**27.38**	**35.18**	**25.57**

	Year-on-year change						
	Industry	**Mining**	**Transport**	**Agriculture**	**Commerce**	**Residential**	**Average**
1994	-2.25%	-2.72%	-4.31%	-2.44%	-2.99%	21.08%	1.06%
1995	7.45%	-3.30%	-5.76%	-4.20%	-1.50%	-0.31%	-1.27%
1996	-9.48%	-3.28%	-2.59%	-0.86%	-2.59%	-0.11%	-3.15%
1997	-1.76%	-2.61%	-9.58%	-2.96%	-4.46%	0.94%	-3.40%
1998	-4.30%	-1.89%	-7.25%	0.30%	-12.77%	-0.19%	-4.35%
1999	-8.86%	-1.85%	-3.04%	-4.31%	12.37%	6.07%	0.06%
2000	7.28%	-2.86%	-4.12%	3.09%	-3.54%	3.63%	0.58%
2001	-8.46%	-2.22%	-3.35%	-12.09%	-25.03%	5.48%	-7.61%
2002	2.15%	-2.90%	0.21%	-9.62%	-0.35%	-0.82%	-1.89%
2003	3.89%	0.71%	4.58%	4.03%	-0.13%	3.40%	2.75%
2004/05	-2.74%	0.48%	0.60%	4.30%	4.60%	4.29%	1.92%
2006/07	2.15%	1.98%	1.15%	3.12%	0.33%	0.20%	1.49%
2007/08	11.97%	6.21%	10.02%	4.45%	4.68%	6.26%	7.27%
Average	**-0.23%**	**-1.10%**	**-1.80%**	**-1.32%**	**-2.42%**	**3.84%**	**-0.50%**

Source DME (2005b)

The 'industrial' sector experienced decreases in its electricity prices for 1996–2001 with the increase of 7.28% in 2000 as the only exception. This, however, did not neutralise the effects of all the previous reductions. The price in 2004 was 11.28c/kWh; approximately 17% lower than the price in 1993.

The picture for the 'mining' sector is not dissimilar. The electricity prices decreased from 1993 to 2002 on a year-on-year basis, although at lower rates than the 'industrial' sector. However, the continuous reduction resulted in an overall reduction of 20% from 1993–2004 (15.56c/kWh to 12.41c/kWh).

In the 'transport' sector, large reductions of the electricity prices were characteristic during the study period, with a larger annual decrease in 1997 (-9.5%). The average decrease was -2.85% for the study period, but comparing the 1993-value to the 2004-value, a decrease of 30% is observed.

In the other low consumer of electricity, the 'agriculture' sector, the prices did not have a stable trend over the study period. The greatest increase was in 1993 (5.43%) and the greatest reduction was in 2001 (-12.05%) followed by a successive reduction of 9.45% in 2002. All-in-all, the prices decreased by 23% from 1993 to 2004.

The trend was similar in the 'commercial' sector. This sector experienced continuous decreases during the study period with the biggest reduction (25%) of the entire period and among all the sectors in 2001. However, in 2004 the prices started picking up again with an increase of 4.32%.

Finally, the only sector that differs from the rest was the 'residential' sector. Although the prices decreased substantially (-24.37%) for 1992–1993, it increased substantially (21.32%) in 1994. During the next decade, the real prices decreased (by less than 1% on an annual basis) in some years but for the majority of the years, it increased by approximately 3–6%. The overall effect was an increase of 51% from 1993 to 2004.

Eskom’s prices are adjusted on a year-to-year basis on 1 April every year (which is the beginning of Eskom’s financial year). Figure 2.2 shows the annual price adjustment changes for the overall economy and the Consumer Price Index (CPI) changes for 1993–2009/10.

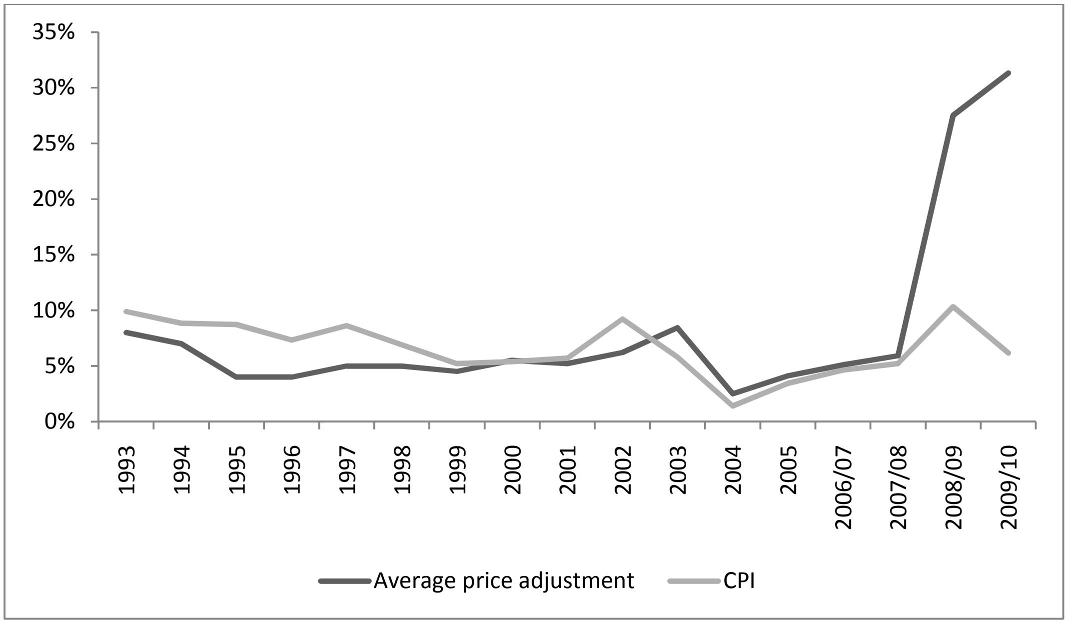

Figure 2.2 Average nominal price adjustments and CPI (%)
Source: Eskom website
Note: The average price adjustment was lower than the inflation rate in the country for the period 1993 to 2002. However, from 2004 the price restructuring changed the picture drastically. At the end of the period, the adjustments were even three times higher than the inflation rates.

As seen in Figure 2.2, the average price adjustment was lower than the inflation rate in the country for 1993–2002. In 2002–2003, Eskom's price reform started taking effect with significant increases from 2007/08 onwards. Figure 2.2 also shows that the average price adjustment for 2008/09 and 2009/10 was three times higher than the CPI change and has an increasing trend contrary to the inflation over that period.

To put the South African electricity prices in international perspective, Table 2.6 presents a comparison of the South African retail electricity prices and a number of upper-income and developing countries.

Table 2.6 Retail electricity prices (US$/kWh): International comparison 2004

Industrial electricity				Residential electricity			
Upper-income		Developing		Upper-income		Developing	
Australia	0.36	Czech Republic	0.06	Australia	0.06	Czech Republic	0.09
Belgium	-	Greece	0.06	Belgium	-	Greece	0.11
France	0.05	Hungary	0.09	France	0.14	Hungary	0.13
Germany	0.05	India	-	Germany	0.14	India	0.04
Italy	0.15	Korea	0.05	Italy	0.2	Korea	0.07
Japan	0.12	Mexico	0.06	Japan	0.17	Mexico	0.1
Netherlands	-	Poland	0.06	Netherlands	0.22	Poland	0.1
New Zealand	0.05	Slovak Republic	0.08	New Zealand	0.12	Slovak Republic	0.12
Spain	0.05	South Africa	0.01	Spain	0.11	South Africa	0.03
UK	0.06	Taipei	0.05	UK	0.13	Taipei	0.07
US	0.05	Turkey	0.09	US	0.08	Turkey	0.1
Average	0.1	Average	0.06	Average	0.14	Average	0.09

Source: International Energy Agency (2004b)

South Africa's industrial electricity is sold at 0.01US$/kWh which is lower than any other country and much lower than both the average for high-income countries (0.1US$/kWh) and the average for developing countries (0.06US$/kWh). With regards to residential electricity, South Africa's price (0.03US$/kWh) is the lowest of the sample; three times lower than the average of the developing countries (0.09US$/kWh).

The low price level of electricity can be attributed primarily to the relatively low production costs of the key inputs of electricity generation, mainly coal (Van Heerden, Blignaut, & Jordaan, 2008). With this historically low electricity prices, it is expected that for a period of time, electricity consumption was relatively insensitive to changes in price.

Therefore, South Africa offers no means of predicting what the demand response would be to price increases such as those proposed by Eskom in September 2009. In the third quarter of 2009, Eskom applied to NERSA for an increase in the electricity prices in order to fund their current and future investment plans. At the end of September 2009, NERSA's decision was made public: an approximate 25% per year increase of the electricity prices for the subsequent three years.

NERSA's latest decision on electricity price increases was announced in February 2010 (South Africa web, n.d.):

- 24.8% for 2010/11
- 25.8% for 2011/12
- 25.9% for 2012/13

Long before NERSA's latest decision, there was a debate on whether South Africa needs a price increase and what the consequences of such an increase would be. On the one side, it was believed that price increases will affect the economy negatively in the long-run. On the other side, energy policy-makers were concerned about the funding needed for the further expansion and maintenance of the existing power plants in the country.

With specific focus on long-term, Van Heerden, Blignaut & Jordaan (2008) estimates the effect of a 10% increase in electricity prices on main economic indicators, keeping the elasticities constant. Under such a scenario, the long-term economic consequences are alarming, with an estimated reduction in investment of 0.37%, a decrease of 0.16% in GDP, and a rise of 0.5% in the CPI. In addition, Inglesi (2010) forecasts the behaviour of total electricity consumption until 2030, assuming that the electricity price would double over the period 2008–2011 and then remain constant until 2030. Her findings show that electricity demand decreases substantially after the implementation of higher prices (-24% assuming an average economic growth of 4% for 2009–2030; -27% assuming an average economic growth of 6% over the same period). She assumes, however, that the price elasticity remains constant at -0.56 on electricity consumption until 2030.

In summary, before implementing any policies or changes in price regimes, the price sensitivity of each sector should be taken into consideration because each of the sectors responded differently in the period when prices were kept low (mainly until 2004–2005).

2.2 Energy efficiency and intensity

This section discusses in detail the concept of *energy efficiency and intensity*: its definition and importance, ways of measurement, and international as well as local efforts towards its improvement.

2.2.1 Definition

The definition of energy (sic. electricity) efficiency seems to be complex and depends largely on the context within which the term is being used. An economist, a politician and a sociologist may have different opinions in defining the energy efficiency. When the Energy Information Administration (Energy Information Administration , 1999) asked participants in workshops to define "energy efficiency", the answers varied, ranging from a service to a mechanistic perspective. The World Energy Council (WEC) (2008:9), however, provides the following guiding definition:

“Energy efficiency improvements refer to a reduction in the energy used for a given service (heating, lighting, etc.) or level of activity. The reduction in the energy consumption is usually associated with technological changes, but not always since it can also result from better organisation and management or improved economic conditions in the sector (‘non-technical factors’).”

Oikonomou et al. (2009) define energy efficiency as the technical ratio between the energy consumed and the maximum quantity of energy services obtainable (heating, lighting, cooling, mobility and others). According to them, energy savings can only be achieved through efficiency or behavioural changes.

Bernard and Cote (2002) define the energy intensity as “… the real level of energy consumption per production unit or activity, whereas adjusted energy intensity is the level of energy consumption per production unit or activity, after taking into account the relative changes in production or activity among sectors or components of a sector”. *And they continue that* “… energy intensity is attributed not only to the changes in energy intensity at the level of entities composing a segment of an economic activity, but also the division of the production or activity among its entities”.

In the European Union’s Action Plan for Energy Efficiency (European Union, 2000), the concept of energy efficiency is defined as “... reducing energy consumption without reducing the use of energy-consuming plant and equipment. The aim is to make better use of energy. Energy efficiency means promoting behaviour, working methods and manufacturing techniques which are less energy-intensive".

2.2.2 Importance of efficiency

The importance of electricity efficiency cannot be overstated. Globally, policies to this effect have been accepted as one of the most economical ways toward the reduction or slowing down of the increasing energy demand as well as its cost and environmental effects. Repetto and Austin (1997) further demonstrate the significance of electricity efficiency improvement for positive results not only in the energy sector and the environment, but also in the economy as a whole.

Knowledge of the evolution of energy intensity/efficiency is imperative because energy policy-makers should know how energy demand will increase or decrease if the economy faces critical changes in its structure and management (Markandya, Pedroso-Galinato & Streimikiene, 2006). For this reason, specific attention should be given to transition economies if the energy consumption increases a result of increased output.

In addition, Andrade-Silva and Guerra (2009) state that examining the energy intensity not only contributes to a more informed policy decision, but also reduces the risk related to energy firms. They mention that improvements in energy efficiency are an effective way of reducing greenhouse gas emissions. They also support the idea that striving for more energy efficient equipment might lead to increased competition with positive results for the consumers in the prices of products and services.

The European Union's Action Plan for Energy Efficiency (European Union, 2000) also states that "... [g]reater energy efficiency has a major role to play in meeting the targets set in the Kyoto Protocol. It encourages a more sustainable energy policy and is a key element in the security of energy supply in the European Community, a subject which has given cause for concern in recent years".

2.2.3 Measurement issues

In order to measure electricity efficiency, the Energy Information Administration (1999) proposes two methods: i) the market-basket approach and ii) the comprehensive approach. The market-basket approach refers to estimating the energy consumption for a set of electricity services based on their share in an index computed as the Index of Industrial Production. The comprehensive approach refers to estimating broader indicators and is an assessment of the changes that are not connected with electricity efficiency until only its effects remain.

In contrast to the above, Mukherjee (2008) proposes a measurement approach from a production theoretic perspective. His measurement models are based upon the objectives of energy management and cost minimisation as well as the capacity output of the economy. The conceptual difficulty in the analysis of energy efficiency, according to Bosseboeuf, Chateau & Lapillonne (1997), is that the evaluation and progress thereof is made after the implementation of energy efficiency policies. There is therefore a temporal, and even spatial, decoupling between the policy and its implementation, and that which is measured and observed later. This also complicates comparison among countries. For this reason, Bosseboeuf, Chateau &

Lapillonne (1997) make an effort to focus on the convergence of energy efficiency indicators globally by classifying the indicators used in the literature as follows:

- Macro-indicators versus micro-indicators: Macro-indicators are linked to the economy in its entirety or its main sectors. Micro-indicators are linked to the level of the main end-users such as companies or households.
- Ratios versus quantities: Ratios such as energy use per GDP or quantities such as variations in the demand for energy are both used in the literature.
- Descriptive versus explanatory indicators: The descriptive indicators explain the energy efficiency situation and progress; conversely the explanatory indicators describe the factors responsible for the evolution.

Following from the above, energy (read also electricity) efficiency is often measured in terms of the change in energy intensity in an effort to describe more accurately its quantitative nature. Energy intensity, in turn, is defined as the ratio of energy consumption to a unit of measurement (e.g. floor space, households, number of workers, GDP per capita) (Energy Information Administration, 1999). Freeman, Niefer and Roop (1997) critically assess the commonly used energy intensity indicators for analysis particularly of the ‘industrial’ sector, and in response Andrade-Silva and Guerra (2009) argue that there are six possible ways of calculating the energy intensity. These different measures are based on the definition of energy intensity as the energy consumption (numerator) divided by the production or economic activity (denominator) of the economy. Energy consumption can be measured according to its thermal equivalence (in joule), or in economic terms (price). Accordingly, the economic activity of a country can be measured as the value added, value of delivered goods (production value minus the value of inventories) or production value (Andrade-Silva & Guerra, 2009). Therefore, the proposed measures, in accordance with Bor (2008), are the following:

1. Thermal equivalence/added value
2. Thermal equivalence/value of delivered goods
3. Thermal equivalence/production value
4. Economic measure/added value
5. Economic measure/value of delivered goods
6. Economic measure/production value

Following a similar way of thinking, Markandya, Pedroso-Galinato and Streimikiene (2006) define energy intensity ε_{it} of a country i at time t as the country's total final energy consumption at time t (E_{it}) divided by total national income of country i at time t (Y_{it}): $\varepsilon_{it} = E_{it} / Y_{it}$

Andrade-Silva and Guerra (2009:2590) also state that:

"... even when the physical measures can be used at the desired levels (disaggregated and aggregated), the economic nature measures emerge more strongly within the upper aggregation levels. This feature leans on favouring the establishment of a standard consumption measure per national production unit such as the joule (J) per US$ of GDP".

Based on this, we have decided to standardise the definition of electricity intensity for our analysis as the ratio of electricity consumption divided by economic output. This is a common definition also used by Mukherjee (2008), Choi and Ang (2003) and Streimikiene, Ciegis and Grundey (2008). It is important to be noted here that in the literature, the intensity is considered the quantitative measure of the energy (electricity) efficiency. More specifically for the purposes of the decomposition exercise (section 3.3), the *intensity effect* is defined as changes in efficiency. In layman's terms, the more electricity intensive is a country/ household/ company/ individual, the more electricity it consumes per unit of output.

2.2.4 Global and South African efforts towards efficiency

The European Union countries focus on the environmental progress of energy conservation (Sebitosi, 2008:1592). The European Union presented its first Action Plan for Energy Efficiency (European Union, 2000) for the years 2000 to 2006. The main aim of the plan was to reduce energy consumption in order to protect the environment, improve security of energy supply and establish a unified energy policy.

According to this plan, numerous instruments, obligatory or voluntary, exist for its implementation in the European Union as a whole as well as each of the member countries individually. The proposed sub-actions are categorised in three main groups:

1. Channels to integrate energy efficiency into other policies

There are six main focus areas in this category: Transport; Modern Enterprise policy; Regional and Urban policy; Research and Development; Taxation and Tariff policy; International cooperation and pre-accession activities.

2. Motives to enhance the existing strategies

There is a need to enhance strategies of four priority areas that were identified: Transport; Household appliances, commercial and other equipment; Industry (including electricity and gas companies); Buildings. The proposed measures include both mandatory and voluntary mechanisms.

For the ‘transport’ sector, the European Union firstly focuses on the automobile industry and its high CO_2-emission rates. The Action Plan proposes a target of decreasing the average CO_2-emissions of new vehicles by a third by 2005/2010, with the aid of voluntary agreements with the industry’s players.

Regarding the ‘household, commercial and other equipment’ sector, the proposed measures are based upon labelling systems and minimum standards for energy efficiency. In an attempt to have alternatives to legislation and mandatory measures, the Action Plan proposes voluntary agreements between the member countries and the industry concerning minimum efficiency standards. “The Commission itself has concluded two agreements of this type (one on energy consumption by televisions and video recorders in standby mode and one on washing machines)” (European Union, 2000). In the future, these agreements are to be extended to other appliances such as water heaters.

Another priority area concerns the ‘industrial’ sector and the aim is to achieve long-term agreements on minimum energy efficiency by implementing specific guidelines for efficient processes and production methods. The Action Plan also pays attention to future plans of increasing combined production of heat and power as well as increasing the role of energy efficiency in the energy services.

Finally, the last priority area is 'buildings' energy efficiency'. With specific focus on boilers and lighting, the European Union proposed a directive on the energy performance of a building in addition to the existing one (93/76/EEC) concerned with the energy certification of a building in order to limit their CO_2-emissions.

Furthermore, the Action Plan specifies a group of motives ('horizontal') that affects all the economic sectors in improving energy efficiency:

- Decentralisation of energy management at local and regional levels
- Strengthening third-party financing (for example, private undertakings)
- Better dissemination of information and training through a renewed community information campaign and specialised training
- Better monitoring and evaluation methods through greater harmonisation of national monitoring programmes and definition of indicators

3. New Policies and measures

The following new strategies concerning the improvement of energy efficiency should be implemented by all the members of the European Union:

- Promotion of energy efficiency in public procurement
- Cooperative technology procurement
- Energy audits in the industry and tertiary sectors
- Best practice

The European Union updated its first Action Plan and released a new one for 2007–2012. The main target now is a 20% reduction in energy consumption by 2020 (compared to the energy forecasts for 2020). This objective corresponds to approximately 1.5% savings per annum until 2020.

"The Action Plan includes measures to improve the energy performance of products, buildings and services, to improve the yield of energy production and distribution, to reduce the impact of transport on energy consumption, to facilitate financing and Investments in the sector, to encourage and consolidate rational energy consumption behaviour and to step up international action on energy efficiency" (European Union, 2000).

The updated key points of the 2007 Action Plan are the following:

1. Potential energy savings

The Action Plan shows that the biggest energy savings can be made in the following sectors: residential, commercial, manufacturing and transport, with potential reductions of 27%, 30%, 25% and 26%, respectively. These savings will also help decrease CO_2-emissions by 780 million tons per year.

2. Measures proposed

Although all the proposed measures are equally important, the Action Plan specifies that some should be adopted without delay while others can be implemented throughout the six-year period. The proposed measures are:

- Improving energy performance with specific focus on appliances and equipment by setting appropriate standards and evaluating performance
- Improving energy transformation: "The Commission will develop minimum binding energy efficiency requirements for electricity generation facilities, heating

and cooling for facilities operating with less than 20 megawatts of power, and possibly for more powerful facilities too” (European Union, 2000).

- Limiting the costs linked to transport – the main targets are to achieve the threshold of 120g of CO_2/km by 2012 and to develop a European standard for rolling resistance and promoting tyre pressure monitoring.
- Financing, incentives and fares: the European Union plans to facilitate funding of investment with regards to the promotion of energy efficient methods. It also plans to relax the national legal barriers to shared savings, financing, energy performance contracting and recourses to firms providing energy services. Furthermore, it will revise the Energy Tax Directive and promote the potential for using tax credits as incentives for both firms and residential consumers.
- Changing behaviour
- Adapting and developing international partnerships

In 2007, US government set the basis for an energy efficient future by signing the Energy Independence and Security Act (US Congress, 2007). This Act includes mainly provisions designed to improve energy efficiency and promote the use of renewable energy. The highlights enacted into law with their standards are:

- Corporate Average Fuel Economy: target of 35 miles per gallon by 2020 for cars and light trucks
- Renewable Fuels Standard: starting at 9 billion gallons in 2008 and going up to 36 billion gallons by 2022

- Energy Efficiency Equipment Standards: new standards for lighting and residential and commercial appliances, such as residential refrigerators and commercial coolers and freezers

- Repeal of Oil and Gas Tax Incentives: repeal of two tax subsidies in order to counterbalance the cost of the Corporate Average Fuel Economy implementation

Two provisions were excluded from the Energy Independence and Security Act: the Renewable Energy Portfolio Standard and, as mentioned above, the repeal of tax incentives for oil and gas. Under the Renewable Energy Portfolio Standard, "retail electricity suppliers (electric utilities) must provide a minimum amount of electricity from renewable energy resources or purchase tradable credits that represent an equivalent amount of renewable energy production".

Especially the Appliance Efficiency Mandate concentrates on new criteria for appliances; while the rest of the mandates also advance the lighting efficiency, the vehicle fuel efficiency as well as the contribution of the government facilities towards the goal of a less energy-intensive country.

Japan, although among the high energy consumers globally, identified energy conservation and environmental protection as key issues for growth and development in 1979. In this thirty-year period, Japan was able to reduce its energy intensity levels by 37% in terms of oil consumption per GDP growth. Furthermore, the Japanese energy policy-makers released the *New National Energy Strategy* (Japanese Government, 2006) in 2006 and its main goal was a further improvement of efficiency by 30% by 2030. The measures proposed by the strategy targets four main sectors: industrial, civil, transport and a sector for cross-cutting issues.

However, the higher impact is expected by the industrial sector, according to the strategy.

Following the political transition in 1994, the new democratically-elected South African government considered energy issues as of great importance for the economic development of the country. In the first *White Paper on Energy Policy* (Department of Minerals and Energy (DME), 1998), energy efficiency was mentioned among the cross-cutting issues. More specifically for the industrial and commercial sectors, the government committed itself to the following:

- Promotion of energy efficiency awareness
- Encouragement of the use of energy-efficiency practices
- Establishment of energy efficiency standards for commercial buildings
- Monitoring the progress

While progress regarding these was slow due to pressing socio-economic and development considerations, the South African Department of Minerals and Energy released its first *Energy Efficiency Strategy* in 2005 (DME, 2005a). The purpose of this strategy was to provide a policy framework toward affordable energy for all and diminish the negative consequences of the extensive energy use in the country. Its national target for electricity efficiency was to improve efficiency by 12% by 2015. It is stated in the document that this target can be questioned and challenged, but it was set in the wake of the fact that the country was the seventh biggest emitter of greenhouse gases on a per capita basis (Sebitosi, 2008). Furthermore, the national electricity intensity was almost twice the average of the OECD countries and efficiency improvements are a necessity. The strategy, however, has had limited impact to date and is currently being revised.

2.3 Cap-and-trade systems

In this section, the theory of the cap-and-trade system is described, as well as its international applications during the last two decades. Also, an evaluation of the system is presented by discussing advantages and disadvantages.

2.3.1 Description of the system

A cap-and-trade is a system that aims to steadily decrease emissions of the economy in its entirety in a cost-effective matter (Centre for American Progress. 2008). The proposed cap-and-trade systems have three main elements: a) the cap, b) the tradable allowances, and c) the formula for distributing the allowances (Shammin & Bullard, 2009).

In layman's terms, the regulator (government or other institution) of a cap-and-trade system sets the participants and the total amount of emissions they are allowed to release, the "cap", for a specific time period. Then, it allocates permits ("allowances"), to the participants usually equal to the size of the cap. One way of doing this is to estimate the allowances relative to contributions to total emissions in a selected base year and then freely distribute them. The allowable emissions can remain constant or be updated frequently (Edelston et al., 2009). This manner of allocation is widely discussed and criticised in the literature, and auctioning the permits is the proposed solution. Michel (2009) states a few reasons why auctioning is preferable to free distribution based upon previous performance:

- It provides a mechanism to allocate reduction of emissions' responsibility.
- The price is a motivation for consumers to reduce their energy usage.
- It prevents profits to generators that would accumulate free allowances.
- The revenue of the auctioning process can be used by the government to benefit the society.

In some applications, the participants receive allowances based on their historical emissions adjusted for the specific system's commitment (Braun, 2009). The cap usually reduces over time so that higher reductions will be achieved (APX Power Markets, 2008).

The regulated entities can then either use their allowances or trade it among themselves (Profeta & Daniels, 2005). The participants that emit less than their allowance can sell their credits (permits or allowances) to those that are not able to easily cut their emissions. The main reasons for that are either that the production technology that the companies/sectors/countries used before the trade may be difficult to change in the short-run or that the cost for reduction of emissions varies (Centre for American Progress, 2008). The system thus rewards the participants that were already doing better than their cap and the ones that managed to cut their emissions with the profits from trading.

From an economic viewpoint, the aim of a cap-and-trade system is to internalise the externality of the emissions by creating a market that puts a price on the emissions (Fell, Mackenzie & Prizer, 2008). Figure 2.3 graphically represents the decisions that a participating member (in this case a sector) makes.

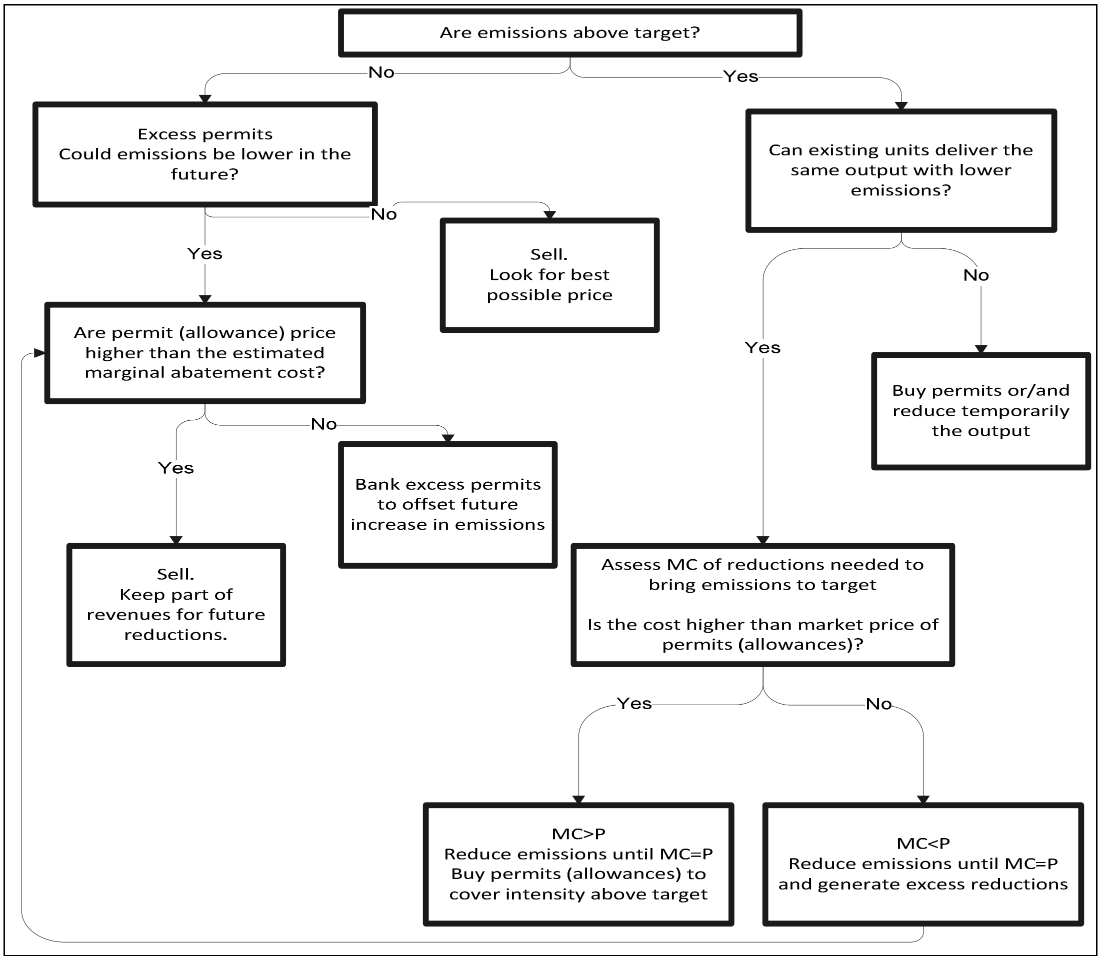

Figure 2.3 Participant's decision-tree in a benchmark-and-trade system
Source: International Energy Agency (International Energy Agency, 2001)
Note: Firstly the participants need to answer the question of whether their emissions are above the targeted level. That defines them as suppliers or consumers of permits in the market. If they are suppliers (emissions lower than target), they should evaluate if their emissions can be lower in the future. If no, they should sell the excess permits; if yes, they should compare the price of the permits with the marginal abatement cost: if the permit price is higher, then they should sell the surplus of permits – if not they should bank the permits for future use. On the other side, if the participant is a consumer of permits, first it needs to assess if it can lower its emissions. If no, it should buy permits; if

yes, the comparison of the permit price with the marginal cost of a reduction will assist it in deciding whether it should buy permits or reduce its emissions.

The first question in the decision-tree is the most significant for the position of the member. If the member's emissions are above the cap, then it can become a *buyer* in the system. However, if the member's emissions are below the cap, then it has the potential to be a *seller* and make revenue from the market.

2.3.2 International applications

The concept of cap-and-trade is neither recent nor new. This type of system has been used for different types of emission such as SO_2 and CO_2 as well as for greenhouse gas emissions (GHG) in general at a global level. Table 2.7 summarises the information on the most important applications of cap-and-trade systems since the 1980s around the world.

One of the first and most important cap-and-trade systems was that of the US in 1990s targeting SO_2-emissions which are linked to the phenomenon of acid rain, known as the *US SO_2 Trading Program* or as the *Acid Rain Program* (Ellerman, 2007). The overall goal of the programme was to reduce SO_2-emissions by 10 million tons taking into account the 1980s' levels.

Table 2.7 Main cap-and-trade systems since the 1980s

Programme	Year	Place	Focus	Goal
Leaded Gasoline Phasedown program	1980s	United States	Gasoline	Production of gasoline with a lower lead content
US Clean Air Act Amendments	1990	United States	SO_2 and NO_2	Reducing SO_2 to 50% of 1980 by 2000
Regional Clean Air Incentives Market (RECLAIM)	1994	Los Angeles air basin	NO_x and SO_x	Reducing emissions by 70% by 2003
Acid rain program – US SO_2 Trading Program	1995	United States	SO_2	Reducing SO_2-emissions by 50% of 1980 by 2000
North-eastern NO_x Budget Program	1999	USA: 12 north-eastern states and the District of Columbia	NO_X	Reducing emissions to 25% of 1990
NO_x Budget Program (SIP)	2003	USA: 22 states	NO_X	Reducing the transport of ozone pollution over broad geographic regions
European Emissions Trading System	1998	30 EU countries	GHG emissions	Reducing EU's GHG emissions (each EU member sets its own target, subject to review by the European Commission)
Carbon pollution Reduction scheme	to start in 2010	Australia	GHG emissions outside land and agriculture	Reducing GHG emissions by 5% at 2020 compared with 2000 levels

Sources: Schmalensee et al. (1998); Stavins (1998); Klepper and Peterson (2004); Profeta and Daniels (2005); Ellerman (2007); Stavins (2007); APX Power Markets(2008); Stavins (2008); Braun (2009); Ellerman (2009); Linn (2010); Monast (2010)

Its first phase commenced in 1995 and lasted for a period of five years. A total of 263 emissions-intensive units were allowed to emit SO_2 only if they had the appropriate allowances to cover their emissions (Stavins, 2007). Using the *grand-fathering method*, the Regulator allocated permits to each unit per year based on their share of heat input during a baseline period (1985–1987) in this programme. *Banking* and *borrowing* were allowed to promote cost-effectiveness and provide incentives.

In the second phase that started in 2000, the vast majority of power generating units participated in the programme. The main addition and greatest difference to the first phase was the introduction of *penalties* in case of non-compliance. The 'punishment fee' was $2,000 (in 1990 prices) for every ton of emissions above the assigned annual cap (Stavins, 2007).

Although as any newly-introduced policy, the programme had low levels of trading (Burtraw, 1996), its trading performance started to pick up in the later years (Schmalensee et al., 1998; Stavins, 1998; Burtraw & Mansur, 1999; Ellerman et al., 2000). On top of that, cost savings of approximately $1bn was the result of a well-designed market (Stavins, 2007). Regarding the environmental influence of the programme, Ellerman (2007) states that the reduction of SO_2-emissions was greater than expected: a 50% decrease in the first year. Furthermore, after the fifteen years, the SO_2-emissions decreased by 35% (US Environmental Protection Agency). Other benefits were the positive welfare effects (Burtraw et al., 1998) and the positive impact on human health affected by localised pollution. For Ellerman (2007), the creation of a market for SO_2 allowances was one of the important successes of the programme. The results of this market were even more impressive since the participation in the programme was voluntary, showing that economic incentives succeeded (Ellerman, 2004).

In 1994, the South Coast Air Quality Management District of US commenced a new two-fold cap-and-trade system with the goal of reducing NO_x and SO_x in the broader area of Los Angeles. All power plants, cement industries and any industrial source that emitted more than 4 tons per annum, were included. The programme's specific aim was to decrease emissions by 20% by 2003.

The NO_x sub-programme encountered difficulties in 2000–2001 that led to its partial suspension (Ellerman, 2007). The allowance prices hiked to $15,000 per ton – an increase of approximately 200% – within a few months resulting in the inability of the participants to comply with the rules. This price hike was caused by the absence of *banking* and *borrowing*, and the electricity crisis of California during the same period.

Two main aspects of the programme differentiated it from others. Firstly, it restricted trading from downwind to upwind resources, thus imposing a zonal restriction. Secondly, other forms of restriction did not provide the motivation to the participants for investing in equipment that can control pollution. For instance, Stavins (2007) indicates that in 2000–2001 the majority of the participants were unable to buy allowances for their emissions and therefore, the surplus of emissions spiked.

The environmental benefits of the programme were summarised in the *Annual RECLAIM Audit report for the 2004 compliance year* (South Coastal Air Quality Management district,2006): NO_x-emissions were reduced by 60% while SO_2 fell by 50% for 1994–2004. Furthermore, Anderson (1997) states that the system has the capability to offset the common cost-increasing setback of cap-and-trade systems by predicting 42% cost-savings or approximately $58 million per year.

In 1999, twelve US states and the District of Columbia launched an NO_x cap-and-trade system in the area. The main regulator distributed allowances to each state and their policy-makers decided how to allocate these allowances to individual units.

This programme also established the Northeast Ozone Transport Region, among others, including three geographic zones. In its first phase that lasted until 2003, a thousand units – mainly combustion sources – were included. In the second phase, when a new rule (NO_x SIP Call) was introduced and seven more states participated, more than 2,500 sources were incorporated in the programme (Market Advisory Committee, 2007).

From 1990 to 2006, under the NO_x budget programme, NO_x-emissions in the area decreased by 73% and the potential cost-savings were estimated to be between 40% and 47% for 1990–2003 in comparison with a command-and-control approach without trading (Farrell, Carter & Raufer, 1999). One of the main criticisms of the trade was the high price volatility in the first year. This was attributed to delays in the implementation of the programme as well as the allocation of the allowances. However, the prices stabilised in the following years (Stavins, 2007).

In Europe, the European Emissions Trading System (EU-ETS) was the first cap-and-trade system implemented among a number of countries. It was launched in 2005 (Ellerman & Buchner, 2007). The partial reason for its implementation was the need for the European Union to meets its commitments to the Kyoto Protocol (Stavins, 2007).

The EU-ETS covers approximately 50% of the EU CO_2-emissions (Ellerman & Buchner, 2007). Almost 12,000 greenhouse gas emitters in the energy and industry sectors were included: all combustion installations with at least 20MW thermal input capacity, coke ovens, steel plants, refineries and any installation producing bricks, glass and ceramics, pulp and paper (Stavins, 2007; Schleich, Rogge & Betz, 2009).

The EU-ETS is implemented in three phases. The first phase, referred to as the "learning phase" or the "pilot period", lasted from 2005 to 2007. During this phase, only trading in CO_2 was allowed and the penalties for violations were 40 Euros per ton of CO_2.

The second phase (from 2008 to 2012) is closely linked to the EU's commitment to the Kyoto Protocol. In addition to CO_2, the programme includes other greenhouse gas emissions and the fines increase to 100 Euros per ton of CO_2 (Stavins, 2007).

In both these phases, the caps and allowances are the individual members' responsibility. Every member state proposes its own cap based upon and linked to variables such as GDP, expected growth rate, energy type mixture and carbon intensity. These proposed caps are evaluated and approved or rejected by the European Commission. The Regulator also allowed the member states to distribute the allowances freely in these two phases.

The third phase is proposed to be from 2013 to 2020. The crucial difference of this phase will be that *National Allocation Plans* will not be required. An EU-wide cap of 21% reduction compared to 2005 emissions will be applied (Schleich, Rogge & Betz, 2009). Also, auctioning of the biggest proportion of the allowances may be approved.

Stavins (2007) argues that even though the EU-ETS has introduced a well-functioning CO_2 market, it is too soon to evaluate the system in its entirety as phase 2 has not ended. Schleich, Rogge and Betz (2009) specifically assess the incentives and motives provided by the EU-ETS for innovation and energy efficiency with regards to the allowance prices of the system. Their results show that due to the higher expected prices of phases 2 and 3, more incentives are given for carbon and energy efficiency and, to a certain extent, for a switch to demand-side energy efficiency. However, they express concern that this will not overcome market failures and other barriers such as information and transaction costs.

Among the market failures, high volatility in the prices of the allowances was proven to be a fragile point of the system. This was attributed to the lack of reliable data on emissions, oversupply of allocations and the absence of *banking of allowances* between the phases (Stavins, 2007). A characteristic example was observed during 2005–2006. In 2005, due to over-allocation of allowances, the prices of allowances dropped substantially. At the end of 2005, the prices rose again only to return to their 2005 levels in the next year.

Another mechanism that exists in the context of cap-and-trade or emissions trading schemes is the *Sector No-Lose Targets* (SNLTs) (Ward et al., 2008). This scheme is considered a form of sectoral agreement that can enhance sectors and sources where abatement potential exists in developing economies. SNLTs would be specified carbon emission targets that various developing countries take willingly for some economic sectors. The concept of “no-loss” indicates that in the case the targets are not met, the countries would not be penalised.

Developing economies are expected to be attracted in SNLTs for two reasons: a) through this mechanism, they will be able to seek investment from the private sector based on their development agendas; and b) in many emerging economies, carbon markets are not feasible and hence this type of policy tools are considered insufficient.

2.3.3 Advantages and general attractive characteristics

An emissions trading system has interesting features only if it is well designed and wholly accepted by the key role players. According to Shammin and Bullard (2009), a well-designed cap-and-trade system has all the desired characteristics of a policy instrument such as tax credits and regulations; however, it allows for efficiency and equity issues to be dealt with separately. On top of this, it ensures that the specific environmental goals will be achieved (Chameides & Oppenheimer, 2007).

According to Profeta and Daniels (2005) and APX Power Markets(2008), such a system has the following desired characteristics:

- Certainty of environmental performance: A well-established system will ensure that the emissions (or indicator targeted) will decrease to a certain level aimed for – the cap. Hence, the system 'works' towards a specifically established environmental goal.

- Business certainty: It provides certainty in its goals and assists the regulated entities with the monitoring and evaluation of their investments within the system.

- Flexibility: It allows the participating entities to look for the cost-minimising options within the entire system. The entities are free to either achieve their targets through technological improvements or buy allowances to cover any further emissions.

- Administrative ease: The main requirement for successful implementation is proper monitoring of the participants' reductions and ensuring the participants are in possession of the necessary allowances to cover their emissions.

APX Power Markets(2008) also stresses the importance of the technology investment and development that a cap-and-trade system can provide. Incentives are given to the participants to develop and use new technologies by "… providing a 'carbon price signal' that enables firms to capture the value of these technologies" (APX Power Markets, 2008:6). Some studies, furthermore, argue that cap-and-trade systems increase social welfare (Carlson et al., 2000; Ellerman et al., 2000).

Bosetti et al. (2008) measure the benefits based on the following four categories:

- Environmental effectiveness
- Economic efficiency
- Distributional implications
- Potential enforceability

The main incentive for countries, sectors or companies to participate in cap-and-trade systems is the possibility of increasing their profits by trading in the market. The literature presents contradicting results on whether the participants' profits increased or not. For example, for the *Nitrogen Oxides Budget Trading Program*

(NBP), Linn (2010) found that the firms' expected profits decreased by approximately $25bn. Palmer et al. (2001) also predicted that NBP would decrease profits. Conversely, studies on carbon dioxide regulation expect rises in profits, particularly in the electricity sector (Burtraw et al., 2001).

In conclusion, there are few key issues that are critical for the success of any cap-and-trade system, as identified by APX Power Markets (2008) and Profeta and Daniels (2005):

- Emissions measuring, reporting and evaluating: The success of the system is linked to the ability of the regulator to apply methods and procedures for measuring and evaluating the system's progress.
- Proper penalty system
- Transparency
- Companies/Sectors/Countries to be included
- Type of indicator (emissions) to be targeted
- Banking/Borrowing: Stavins (2008) explains that allowing for banking/borrowing can reduce some of the cost uncertainty for the companies by letting them shift the timing of their reductions depending on the high or low costs of the period.

However, the impact of any individual system specified for a single country is dependent on the actions of the rest of the countries (Stavins, 2008:318). Without an overall environmental climate agreement, the good results of one country's system would be cancelled by the inefficient policies of another. The opposite also holds: even if the countries reach a holistic environmental agreement, the good performance and commitment of each individual country is imperative. The fundamental purpose of cap-and-trade systems should be a solution that is scientifically reliable, economically efficient and politically realistic.

2.3.4 Points of criticism

As any other policy strategy, a cap-and-trade system is not perfect. There are design issues that should be addressed effectively by policy-makers before they are outweighed by the advantages of the system. Firstly, APX Power Markets (2008) argues that the system is as good as its cap. For example, the European Emissions Trading System (EU-ETS) was often criticised because it did not show any positive results in its first phase. The counter-argument to this is that the emissions cap was determined much higher than what was actually possible for such a short period of time.

Also, targeting the reduction of specific emissions requires advanced technological methods for the measurement and monitoring of the emissions. These data-capturing procedures could be time-consuming and prove detrimental to the overall cost of the method. Even worse, a lack of reliable data can over- or under-estimate the cap and the allocation of allowances (APX Power Markets, 2008).

Price volatility within the system also concerns the policy-makers. The auctioned prices may vary over time and hence, permit prices may fluctuate significantly. Participants will pay close attention for as long as the prices are high; however, low prices will not attract participants to the market and will not provide incentives to participants to invest in emissions reductions (Durning, 2008).

To ensure accountability in a cap-and-trade system, applying strict penalties for non-compliance is crucial. Lenient punishment is not an incentive for participants to obey the rules. For example, during the first years of the Regional Clean Air Incentives Market (RECLAIM), some entities found non-compliance less expensive than compliance (APX Power Markets, 2008) and hence, the desired goals were not achieved.

The disadvantages of a US cap-and-trade system with the ultimate purpose of addressing climate change are discussed in Stavins (2008), who summarises the main objections to the cap-and-trade system as follows:

- Cap-and-trade systems create hot spots of pollution.
- Upstream cap-and-trade will have minimal effects on the transportation sector.
- It would be better to begin with narrow coverage across a few sectors.
- A cap-and-trade system will create barriers to entry and reduce competition.
- The price strike in RECLAIM and the price drop in the EU-ETS demonstrate that extreme price volatility is an inherent part of cap-and-trade systems.
- A cap-and-trade system can put the US at a comparative disadvantage.

Other than the general criticism of cap-and-trade systems, numerous studies compared this market-based system with a tax on CO_2-emissions. Waggoner (2010) identifies the main disadvantages of a cap-and-trade system for the US economy in contrast to a tax measure.

A cap-and-trade system would not assist the US industry and its labour as their competition is foreign markets with factories and employees not subject to a cap-and-trade system. A tax on carbon emission would be better because it is imposed on the carbon content of imports and rebated on that of exports, similar to the function of Value Added Taxes.

Previous experience with SO_2 cap-and-trade systems should not be considered as a predictor for the success of a carbon cap-and-trade system as control of carbon is more demanding. Tax regimes are more trustworthy and are vastly implemented in numerous applications.

Reducing CO_2 will increase its price and it will effectively become a sales tax. In theory, to combat sales taxes, a rebate to low-income populations should be considered; something that a cap-and-trade system does not incorporate. According to Waggoner (2010), a carbon tax will create revenues from the onset of its implementation.

Waggoner (2010) is also concerned about the possible corruption an ill-designed cap-and-trade system might bring. In contrast, a carbon tax is simple and avoids administration problems and possible misconduct.

2.3.5 Comparison between cap-and-trade systems and taxation

The main alternative to a cap-and-trade system is taxation on the consumption of CO_2, mainly producing most of the harmful emissions. The South African National Treasury in its discussion document titled “Reducing Greenhouse Gas emissions: The carbon tax option” (National Treasury 2010) supports the idea that a carbon tax appears to be the most appropriate mechanism to reduce GHG emissions in South Africa.

Chameidis and Oppenheimer (2007) argue that a well-specified cap-and-trade system will have analogous results to an equivalent implementation of carbon tax. However, the advantage of the system is that the environmental goals would be achieved in a specific period of time. National treasury also agrees that in the short-term, a fixed quantitative reduction in emissions cannot be guaranteed with the implementation of a carbon tax even though in the long-run it has the potential of providing a strong price signal, acting as motivation to a behavioural change towards more environmental friendly energy usage.

But Parry (2007:3) stresses the main disadvantages of a cap-and-trade system, compared to the carbon tax implementation. Essentially, the main difference is that with a carbon tax the benefits are distributed over most households as compensation of higher electricity and fuel prices while the participating firms in a cap-and-trade system are the ones accumulating profits and are usually among the high-income groups.

Another constraint of a cap-and-trade system is the adjustment under new scientific or economic conditions and new information about the costs and advantages of SO_2-reductions. This type of system is usually regulated by ‘not-easily changeable’ documentation and agreements. Therefore, the new generation should be more flexible in response to new information, but such an approach must be joined with further improvement each time the conditions require it (Burtraw et al., 2001).

According to Parry (2007:3), the instability of prices is another possibly significant predicament of cap-and-trading systems. The CO_2 tax keeps the prices fixed allowing the emissions to fluctuate based on the economic situation. However, the demand of permits might change on a year-to-year basis due to changes in prices of fuels and energy.

There is also strong belief that the carbon tax approach leaves less chance for corruption compared to cap-and-trade systems where the permits are subject to change over time or according to future measurements (Nordhaus, 2007:39). Nonetheless, Burtraw et al. (2001) find that specifically the US SO_2 cap-and-trade system is “administratively transparent”. The fines are fixed and obedience by the participants has been exemplar.

From an environmental perspective, Bales and Duke (n.d.) argue that a cap-and-trade system provides “... more fundamental environmental certainty than a tax”. This is because such a system is designed to set a quantitative, legally enforceable limit on emissions, and continuously measure and monitor the performance towards the specific objective (Dikeman, 2010)

In conclusion, the main advantages of a cap-and-trade system are summarised by Dikeman (2010) and also discussed by Avi-Yonah and Uhlmann (2009) as disadvantages of a carbon tax. A cap-and trade system:

- assures the achievement of the targets, while desired reductions in emissions are not guaranteed with any tax level;
- grants the participants the power to decide how to meet their targets;
- defines the real price (or cost) of the targeted indicator;
- is better in equalising the price of credits so that the cost is the same for all participating members;

- is easier implemented in a multi-country environment;
- does not face the same political resistance as a tax regime probably would.

To conclude Chapter 2, it reviewed firstly, the characteristics of the South African electricity sector. Special focus was given to the past and current regulations and institutions, the main suppliers as well as the trends of electricity consumption and prices. Secondly, the concepts of energy efficiency and intensity were discussed in addition to a review of global and South African efforts towards efficiency. Finally, a review of the cap-and-trade systems was presented followed by a brief discussion of their advantages and disadvantages. From this chapter, it is evident that energy efficiency-related issues have attracted interest both locally and internationally and solutions are imperative towards future energy use reduction and environmental changes.

3 EMPIRICAL EVIDENCE

The third part of this dissertation presents the empirical analysis that is a prerequisite in understanding the South African electricity sector's status quo before proposing possible remedies. The evolution of price elasticity of electricity demand in South Africa is examined in Section 3.1; while the sectoral examination of price elasticity is investigated in Section 3.2. Then, the importance of other variables in the evolution of electricity consumption in South Africa is investigated in Section 3.3. Finally, the electricity intensity of South Africa at aggregate and sectoral levels is compared with OECD countries in Section 3.4.

3.1 The evolution of price elasticity of electricity demand in South Africa[1]

3.1.1 Introduction

According to international and local research, price has proven to be a significant factor in the electricity consumption of a region or a sector. However, the significance of this factor can change over the years due to fluctuations in price, changes in the conditions of the electricity market as well as the economic environment of the country. Therefore, the overall analysis starts with the investigation of the evolution of the aggregate price elasticity of electricity.

To contribute to the recent electricity debate, this analysis proposes that the sensitivity of the consumption to increases in electricity prices changes over the

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[1] This section has been published in *Energy Policy*.

years; that is, the price elasticity of the demand for electricity is time-varying. Since 2008–2009, the electricity sector in South Africa is in new, uncharted territory and hence, focus on variation is more important than only examining the level of change. The main purpose of this section is to estimate the price elasticity of electricity in South Africa for 1980–2005 by employing an advanced econometric technique, the Kalman filter.

This section is structured as follows: the next section presents international and local studies on price elasticity of electricity while the following two sections thoroughly discuss the Kalman filter methodology. This is followed by the description of the theoretical model. The data is presented in Section 3.1.6 and Section 3.1.7 discusses the empirical results. Finally, policy implications are provided.

3.1.2 Studies on price elasticity of electricity

During the last decade, energy studies have received great attention mainly due to the shortage of energy as well as the severe projected consequences to the environment. It is vital to examine and control the energy – and more specifically the electricity – consumption, and identify its affecting factors. The most important factor has been proven to be electricity price and hence, the complete understanding of electricity consumption’s sensitivity to price is essential for the future.

Table 3.1 give a brief summary of international studies, their methodologies and findings. This group of studies is indicative of studies investigating the aggregate electricity demand in a number of developed and developing countries for different time periods.

Table 3.1 Summary of selected international studies on price elasticity*

Authors	Country	Period	Methodology	Price elasticity
Al-Faris (2002)	GCC countries	1970–1997	Johansen Co-integration methodology	Short-run: -0.09; Long-run: -1.68; (average of GCC countries)
Amarawickrama & Hunt (2008)	Sri Lanka	1970–2003	Various models (such as Engle-Granger, Johansen, Fully modified OLS)	Long-run range from -0.63 to 0; Short-run: 0
Atakhanova & Howie (2007)	Kazakhstan	1990–2003	Panel data	Insignificant
De Vita, Endresen & Hunt (2006)	Namibia	1980–2002	ARDL-ECM	Long-run: -0.34
Diabi (1998)	Saudi Arabia	1980–1992	Panel data	Range from -0.139 to 0.01
Von Hirschhausen & Andres (2000)	China	1996–2010	Cobb-Douglas for forecasting purposes	(By assumption) -0.02
Kamerschen & Porter (2004)	US	1973–2008	Flow adjustment model and 3-stage least squares	Range from -0.51 to 0.02; Range from -0.15 to -0.13

*Studies organised in alphabetical order

From Table 3.1, it is observed that no consensus has been reached on the most appropriate methodology to be used for electricity modelling. Also, it is noted that the price elasticity estimated or assumed varies depending on the country and more importantly, the period investigated. The importance of the period of this analysis can also be confirmed by the inconclusive results of studies on the estimation of the price elasticity of the South African aggregate electricity demand (Table 3.2).

Table 3.2 Summary of local studies on price elasticity of aggregate electricity demand*

Authors	Period	Methodology	Price elasticity
Pouris (1987)	1950–1983	Unconstrained distributed lag model	-0.90
Amusa et al. (2010)	1960–2007	Auto-regressive distributed lag (ARDL) approach	Insignificant
Inglesi (2010)	1980–2005	Engle-Granger and ECM models	Long-run: -0.56 Short-run: insignificant

*Studies organised in chronological order

The common denominator in these studies is the assumption that the price elasticity remained constant during the periods examined. Therefore, there are differences among the results of the various studies. This study takes the analysis a step further, proposing that the price elasticity evolves over time due to a number of reasons and therefore policy-makers should not treat it as stable.

3.1.3 Methodology

Econometric modelling has evolved substantially during the last two decades with co-integration analysis being one of the main developments (Engle & Granger, 1987; Hendry & Juselius, 2000; Hendry & Juselius, 2001). Energy-related econometric analysis was not the exception to the trend.

Although popular, the co-integration approaches are highly dependent on the stationarity of the series and also on the assumption that the estimated parameters do not change substantially over time (the estimated coefficients are averages throughout the study period). Given these requirements, researchers are starting to doubt the overdependence on the co-integration analysis in some cases. Harvey (1997) mentions that all dynamic econometrics should not be based on autoregressions. Hunt, Judge and Ninomiua (2003) add that methodologies which allow for their coefficients to vary stochastically over time can be proven helpful.

The Kalman filter methodology that this study employs, presents all the above-mentioned required characteristics and provides the ideal framework for estimating regressions with variables whose impact varies over time (Slade, 1989). Morisson and Pike (1977) also argue that if the estimated coefficients do not vary over time, the Kalman filter and the least squares model are expected to produce similar results. However, in the presence of parameter instability, the Kalman filter proves superior to the least squares model (Morisson & Pike, 1977).

Therefore, before choosing the most appropriate technique for a specific case, the research needs to establish the possibility of existing parameter instability. To test for instability of parameters, a number of tests are proposed in the literature (Chu, 1989; Hansen, 1992; Andrews, 1993). Hansen (1992) proposes an extended version of past approaches to cover general models with stochastic and deterministic trends. The null hypothesis is parameter stability and the Lc statistic, which arises from the theory of Lagrange Multiplier tests, is used. Performing this test in this study will either confirm or reject the assumption of time-varying price and income elasticities, before estimating them. If the estimated coefficients are proven to vary over time, then the Kalman filter is the most appropriate method.

In addition, the Kalman filter is characterised as predictive and adaptive because it looks forward with an estimate of the covariance and mean of the time series one step into the future. What makes it efficient is that, as a recursive filter, it estimates the internal state of a linear dynamic system from a series of noisy measurements.

The Kalman filter is considered to be one of the simplest dynamic Bayesian networks. The Kalman filter calculates estimates of the true values of measurements recursively over time using incoming measurements and a mathematical process model.

3.1.4 Kalman filter application

The Kalman filter technique is based on the estimation of state-space models that were originally employed for engineering and chemistry applications (Wiener, 1949; Kalman, 1960; Kalman, 1963). Researchers only started applying the technique in economics in the 1980s (Lawson, 1980; Harvey, 1987; Cuthbertson, 1988; Currie & Hall, 1994).

According to Cuthbertson, Hall and Taylor (1992), there are two main types of models: a) unobservable components models and b) time-varying parameter models. In this study, the state-space model with stochastically time-varying parameters is applied to a linear regression in which coefficients representing price elasticity and income elasticity are allowed to change over time.

Firstly, the formal representation of a dynamic system written in state-space form suitable for the Kalman filter should be described. The following set of equations presents the state-space model of the dynamics of a nX1 vector, y_t.

Eq. 3.1: Observation (or measurement) equation

$$\boldsymbol{y_t = Ax_t + H\xi_t + w_t}$$

Eq. 3.2: State (or transition) equation

$$\boldsymbol{\xi_{t+1} = F\xi_t + v_{t+1}}$$

where A, H and F are matrices of parameters of dimension (n x k), (n x r) and (r x r), respectively, and x_t is a (k x 1) vector of exogenous or predetermined variables. ξ_t is a (r x 1) vector of possibly unobserved state variables, known as the state vector.

The following two equations represent the characteristics of the disturbance vectors w_t and v_t which are assumed to be independent white noise.

Eq. 3.3

$$\mathbf{E(v_t v'_\tau) = \begin{cases} Q\,,\ for\ t = \tau \\ 0,\ otherwise \end{cases}}$$

Eq. 3.4

$$\mathbf{E(w_t w'_\tau) = \begin{cases} R\,,\ for\ t = \tau \\ 0,\ otherwise \end{cases}}$$

where Q and R are (r x r) and (n x n) matrices, respectively.

As shown in the two previous equations, the disturbances v_t and w_t are uncorrelated at all lags.

Eq. 3.5

$$\mathbf{E(v_t w_\tau') = 0 \text{ for all } t \text{ and } \tau}$$

In the observation equation the factor x_t is considered to be predetermined or exogenous which does not provide information about ξ_{t+s} or w_{t+s} for s = 0,1,2,… beyond what is given by the sequence y_{t-1}, y_{t-2},…,y_1. Thus, x_t could include lagged values of y or variables which are uncorrelated with ξ_τ and w_τ for all τ.

The overall system of equations is used to explain a finite series of observations {y_1, y_2,…,y_T} for which assumptions about the initial value of the state vector ξt are needed.

With the assumption that the parameter matrices (F, Q, A, H or R) are functions of time, the state-space representation (equations 3.1 and 3.2) become:

Eq. 3.6

$$\mathbf{Y_t = a(x_t) + [H(x_t)]'\xi_t + w_t}$$

Eq. 3.7

$$\mathbf{\xi_{t+1} = F(x_t)\xi_t + v_{t+1}}$$

Where

- $F(x_t)$ is a (r x r) matrix whose elements are functions of x_t
- $\alpha(x_t)$ is a (n x 1) vector-valued function
- and $H(x_t)$ is a (r x n) matrix-valued function.

Equations 3.6 and 3.7 allow for stochastically varying parameters, but are more restrictive as a Gaussian distribution is assumed.

3.1.5 Theoretical model

In the past, local and international models primarily assumed that the price elasticity of electricity remained constant over time. However, electricity models have to allow price sensitivity to change over time in order to capture the changes in economic conditions as well as developments in the electricity market.

Equation 3.8 includes standard variables, such as prices of electricity and output of the economy, to explain the electricity consumption.

Eq. 3.8: Theoretical model 1

$$\mathbf{Ln\_elec\_cons_t = \alpha * ln\ \_elec\_price_t + \beta * ln\ \_output_t + \varepsilon_t}$$

where elec_cons is the electricity consumption, elec_price is the price of electricity and output is the gross domestic product of the economy in time t. All variables are in their natural logs, as indicated by ln.

The estimation of this equation would result in a constant coefficient α representing the price elasticity of electricity and a constant coefficient β representing the income elasticity of electricity. However, by applying Kalman filter estimation, the coefficients α and β are time-varying and hence, the equation to be estimated looks as follows:

Eq. 3.9: Theoretical model 2

$$\mathbf{Ln\_elec\_cons_t = \alpha_t * \ln\ \_elec\_price_t + \beta_t * \ln\ \_output_t + \varepsilon_t}$$

In order to estimate this, the model contains four equations based on the notation of *Eviews* software to allow for time varying coefficients:

Eq. 3.10: Theoretical model (Eviews)

$$\mathbf{\ln\ \_elec\_cons_t = sv1 * \ln\ \_elec\_price_t + sv2 * \ln\_output_{\,t} + sv3}$$

Eq. 3.11

$$\mathbf{sv1 = sv1(-1)}$$

Eq. 3.12

$$\mathbf{sv2 = sv2(-1)}$$

Eq. 3.13

$$\mathbf{sv3 = c(2) * sv3(-1) + [var = exp(c1)]}$$

Equations 3.11 and 3.12 show that the time-varying coefficients evolve over time according to a random walk process.

3.1.6 Data

To apply the Kalman filter technique, local and international sources of data were used. Aggregate electricity consumption is derived from two different sources: the *South African Energy Statistics* of the National Energy Council (National Energy Council, 1990) and the *Energy Balances* of the Department of Minerals and Energy (DME, various issues). The series on real average electricity prices is obtained from the *Energy Price Report, 2005* (Department of Minerals and Energy (DME), 2005b); while the data series on Gross Domestic Product was obtained from the *World Economic Outlook (WEO)* of the International Monetary Fund (IMF, 2009a).

The aggregate electricity consumption is measured in GWh, the electricity prices in ZAR cents/kWh (constant prices 2000), and the GDP in ZAR billion (constant prices 2000). Table 3.3 summarises the descriptive statistics of the series (in their linearised version and the difference of the linear). These elementary descriptive statistics (in their majority averages over the period) are reported only as an indication of the nature of the raw data to be used in the analysis. The series employed in the exercise were also integrated of order 1 (I(1)).

Table 3.3 Data descriptive statistics

	Electricity consumption		**Electricity price***		**Output***	
Unit of measurement	GWh		Rand cents/kWh		R billion (constant 2000)	
	Ln	diff(ln)	Ln	diff(ln)	Ln	diff(ln)
Mean	11.913	0.033	2.756	-0.022	6.725	0.022
Median	11.852	0.032	2.734	-0.015	6.674	0.027
Maximum	12.332	0.173	3.004	0.020	7.016	0.050
Minimum	11.631	-0.056	2.562	-0.074	6.564	-0.022
Std. Dev.	0.188	0.047	0.173	0.027	0.137	0.021
Skewness	0.669	1.066	0.223	-0.363	0.664	-0.589
Kurtosis	2.715	5.118	1.450	1.991	2.277	2.248
Jarque-Bera	1.714	8.280	2.386	1.418	2.097	1.792
Probability	0.425	0.016	0.303	0.492	0.350	0.408
Sum	262.095	0.734	60.637	-0.479	147.947	0.490
Sum Sq. Dev.	0.745	0.046	0.627	0.016	0.394	0.009

* Exchange rate: R6.94=US$1

Figure 3.1 presents the electricity consumption and electricity prices in South Africa for 1980–2005. The overall negative relationship is observable from this figure since the electricity consumption shows a clear upward trend over time while the real electricity prices have decreased over the same period.

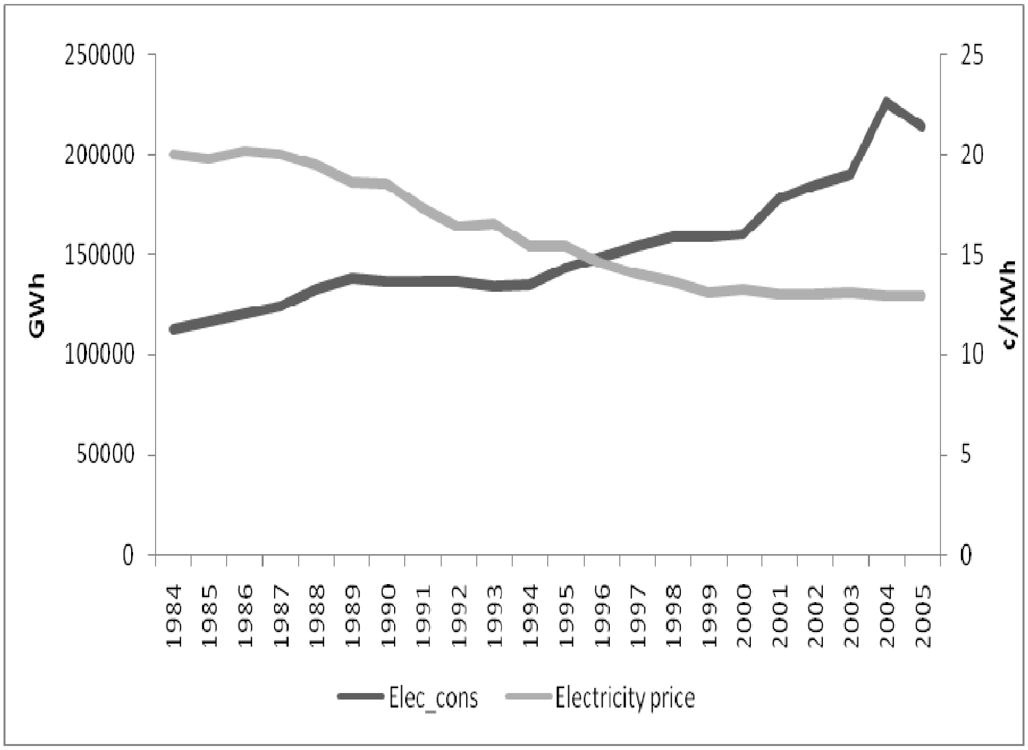

Figure 3.1 Electricity consumption and price in South Africa (1984 to 2005)
Source: DME (2005b); DME (Various issues); National Energy Council (1990)
Note: The black line represents the increasing electricity consumption of the study period in GWh, while the grey line illustrates the declining average real prices of electricity in c/kWh.

However, the relationship between electricity consumption and the total output of the economy is positive, since both of them show an upward trend over the study period (Figure 3.2).

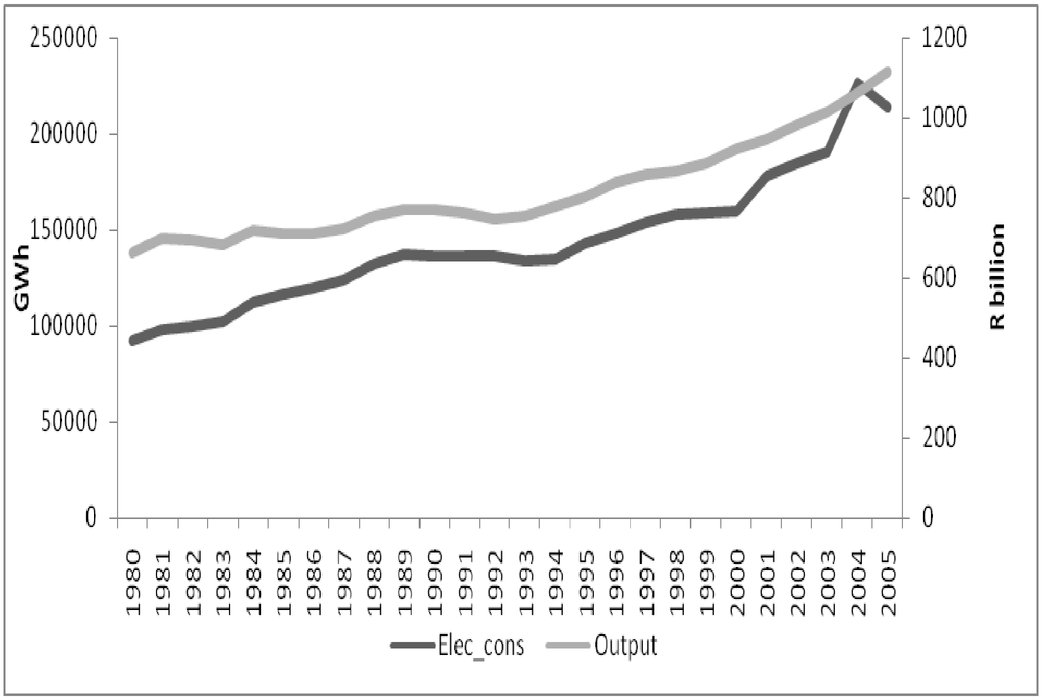

Figure 3.2 Electricity consumption and GDP in South Africa (1980 to 2005)
Source: DME (Various issues); IMF (2009a); National Energy Council (1990)
The black line represents the increasing electricity consumption of the study period in GWh, while the grey line illustrates the country's economic output which increased substantially in ZAR billion.

3.1.7 Empirical results

As discussed earlier, before applying the Kalman filter the Hansen test will confirm whether the estimated parameters change over time or not. The null hypothesis of the test is that the parameters are stable; contrary to the alternative that indicates parameter instability. The results are presented in Table 3.4.

Table 3.4 Hansen test results for parameter instability

Series	Ln_elec_cons ln_elec_price ln_output
Null hypothesis	Parameters are stable
Lc statistic	0.679
P-value	0.015**
Conclusion	Ho can be rejected→ parameters are not stable

Note: ** indicates statistical significance at 5% level of significance

The test-statistic is 0.679 with p-value of 0.0149. Since the p-value is smaller than the 5% level of significance, the Hansen test rejects the null hypothesis that the parameters are stable. Given this result, the Kalman filter is applied.

Although this analysis focuses on the evolution of the price elasticity of electricity demand, the model also allows us to observe the evolution of income elasticity for the same period.

Table 3.5 represents the Kalman filter estimation results, where C(1) and C(2) are the constant parameters of the estimation; sv1 and sv2 are the average of the time series for price and income elasticity, respectively[2]; and sv3 is the value of the rest of the factors affecting the dependent variable (electricity consumption).

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[2] The average values for the study period are -0.237, 0.799 and 7.232 for sv1, sv2 and sv3, respectively.

Table 3.5 Kalman Filter estimation results

Sspace model		
Sample	1983–2005	
Included observations	23	
Number of iterations to convergence	7	
Variables	**Estimated coefficients**	**P-values**
c(1)	-6.213	0.000
c(2)	1.002	0.000
	Final state	**P-values**
sv1 (price coefficient)	-0.075	0.077
sv2 (income coefficient)	0.794	0.073
sv3 (intercept)	6.908	0.037
Residuals		
Std. Dev.	0.109	
Normality	1.075	
Skewness	-0.404	
Kurtosis	2.278	
Long-run variance	0.028	
Q-stat (6)	43.012	
Goodness of fit		
Log likelihood	14.275	
Akaike info criterion	-1.067	
Schwarz criterion	-0.969	
Hannan-Quinn criterion	-1.043	

Figure 3.3 illustrates the evolution of price and income elasticities. In the 1980s, the income elasticity experienced a downward trend, during 1985–1990, it was close to zero (not seriously affecting the electricity consumption), but from the beginning of

1990s, the income elasticity has been close to 1, showing the high impact that a small change in income/output has on the electricity demand.

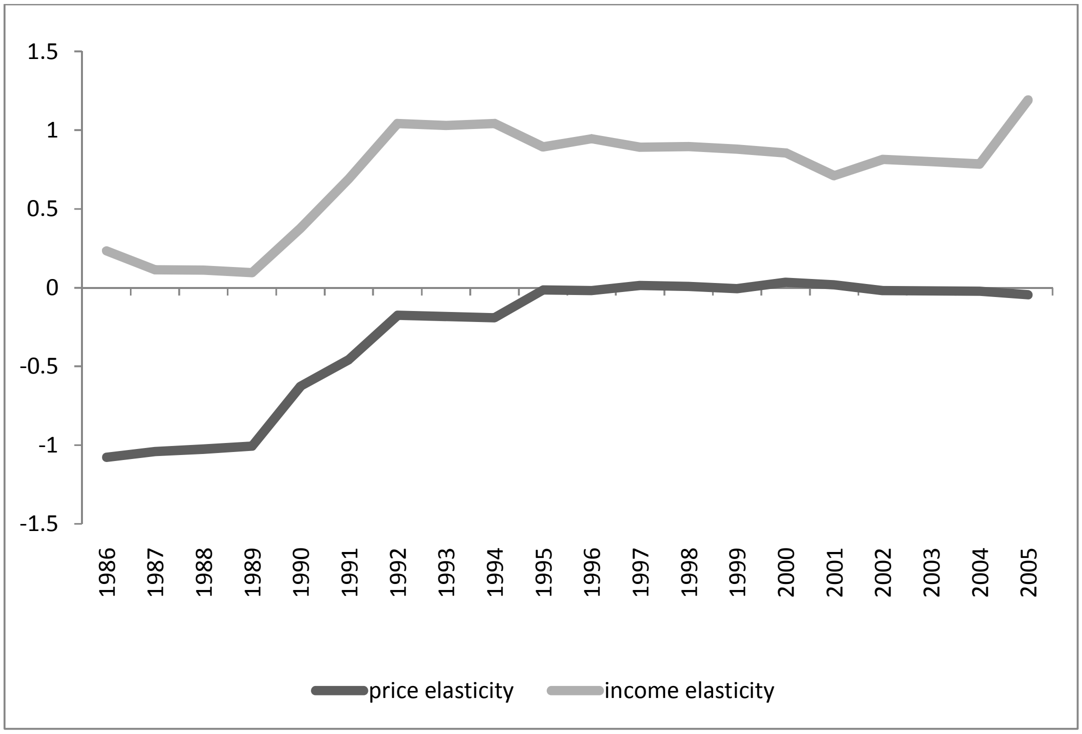

Figure 3.3 Price and income elasticities (1986–2005)
Source: Author's estimation
The black line represents the estimated price elasticity of the model while the grey line shows the estimated income elasticity of the model. It can be seen that the price elasticity was close to -1 for the first part of the study while the income elasticity was low and close to zero. Both changed drastically during 1989–1993. For the rest of the study period, the price elasticity is almost zero while the income elasticity is close to unity.

The demand for electricity was close to unit elastic regarding price during the 1980s and beginning of 1990s. However, from 1991–1992, it has decreased in absolute values from -1.077 in 1986 to -0.045 in 2005. The economy, therefore, has experienced an inelastic demand since the beginning of the 1990s or, in other words, the price has not played a significant role in the increase of electricity consumption during this period.

3.1.8 Discussion and policy implications

The findings of the Kalman filter application showed price and income elasticities that changed substantially over the last two decades. The price elasticity was significantly negative during the 1980s and early-1990s. However, since then it has become less negative over time with values close to -0.04 (-0.045 in 2005). Over the same period, the effect of income to electricity consumption has become more significant from close to zero in the middle of 1980s to almost unit elastic in the 2000s.

International and local studies estimate the price elasticity of aggregate (but also residential) electricity within the range of -2 and 0 and income elasticity between 0 and 2 (Taylor, 1975; Inglesi, 2010; Nakajima & Hamori, 2010). Therefore, it is important to mention that our results for the price and income elasticities are within these estimated ranges.

Several points are worth noting in these results. The evolution of the estimated price elasticity and the real prices for 1986–2005 are presented in Figure 3.4. The importance of this figure lies in the fact that the price elasticity decreased, in absolute terms, and therefore price was a less important factor to electricity consumption while the real prices of electricity started declining. That shows that the higher the real prices are, the higher the price elasticity and hence, the low level of the prices can explain the lack of price impact during the 1990s and 2000s.

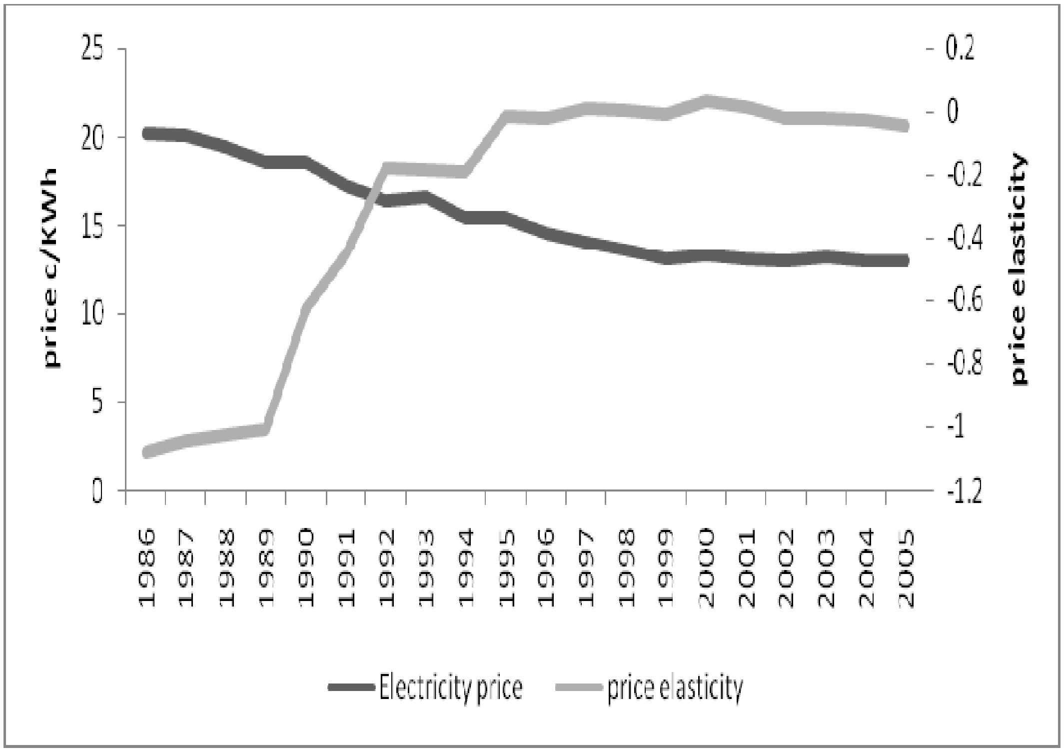

Figure 3.4 Electricity prices and price elasticity 1986-2005

Source: DME (2005b) and Author's results

The black line represents the average real prices of electricity in c/kWh while the grey line shows the evolution of price elasticity as estimated by the model. The two variables present a negative relationship: the higher the prices the lower the price elasticity and vice versa.

Moreover, the price elasticity started becoming less significant while the income showed a greater impact on electricity consumption (Figure 3.4). The economic growth of the country has proven to be one of the main drivers of electricity consumption (Inglesi & Blignaut, 2010). In comparison, electricity prices have almost no effect on consumption trends due to two main reasons: i) the prices are relatively low compared to international standards, and ii) the prices are not market-driven but rather a monopolistic decision.

These results can be of great significance to the energy policy-makers of the country after NERSA's recent decisions on price increases. Although it is too early to identify the effects of the recent price increases, one can speculate. Initially the first price increase might not affect the electricity consumption significantly and directly since the price elasticity is close to zero. However, if the real prices return to high levels (close to or higher than the levels of the 1980s), it may lead to changes in the behaviour of electricity consumers and their sensitivity to prices. Hence, price elasticity will become greater than zero again and prices will play an important role in electricity consumption.

These results can also explain the differences between the estimation results of Amusa et al. (2010) and Inglesi (2010). Amusa et al. (2009) conclude that electricity price is insignificant as a factor affecting electricity consumption. This can be connected to the ‘almost’ zero elasticity values for a period. Therefore, focusing on short-term dynamics (as in the Auto-regressive Distributive Lag (ARDL) approach employed), price can be estimated as insignificant. It was also confirmed by Inglesi (2010) and Inglesi and Pouris (2010) that price did not play a significant role in the short-run in the evolution of electricity consumption. In contrast, taking into account that real prices of electricity were higher than in the last part of the period examined, prices played a significant role in the long-run.

To summarise, these results show that the economy in its entirety changes its behavioural response regarding electricity consumption over time. It would be interesting to examine whether all the economic sectors of South Africa followed the unresponsive behaviour to changes in electricity prices for the period while the electricity prices were relatively lower. Therefore, the next section examines the sectoral price and income elasticities within a panel data framework.

3.2 Estimation of the demand elasticity for electricity by sector[3]

3.2.1 Introduction

As noted before, electricity is a low valued yet necessary good within any economy and it is one of the pillars of economic growth (Blignaut, 2009). The generation, supply and distribution of electricity, and access to it, have the potential to unlock economic development. South Africa, with almost 50 million residents, has about 39,000MW of installed electricity capacity. Nigeria, in contrast, has an installed capacity of 4,000MW serving 150 million people. This comparison indicates a key reason why South Africa could develop in the way it has, while Nigeria could not, despite its natural resources, climate and arable land.

During 2007–2008, South Africa experienced periods of severe lack of electricity supply that led to continuous blackouts and load-shedding resulting from the problematic situation regarding the generation and reticulation of electricity. Eskom often argued that the solution would be the expansion of the current network of power plants.

Recently (from 2008 onwards), Eskom embarked on a price restructuring process that implied sharp increases in the price of electricity across all sectors. These increases are admittedly from a low base but have been given high profile in the media and among various decision-makers and large electricity users. Given these recent developments there is not an adequate dataset capturing both the price and the electricity usage data to reflect any possible behavioural change. The question,

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[3] The work of this section is accepted for publication in the *South African Journal of Economic and Management Sciences*.

however, is whether price played a role in determining historic electricity consumption.

This section seeks to answer this question by examining the price elasticities of various economic sectors in South Africa for the period before the price reform. This was done by employing panel data techniques for 1993–2006. The results will likely indicate if the sectors' behavioural response played an important role in the current mismatch between the demand for and the supply of electricity.

The rest of this section is structured as follows: a brief review of literature that dealt with energy (electricity) demand and its determinants is presented. The situation of the electricity market in South Africa is then described. Next, the research method and data used are presented, while the empirical results are presented and discussed thereafter. Finally, the conclusions and policy implications of the findings are discussed.

3.2.2 International literature review

Energy studies have attracted attention internationally during the last decades due to its connection to global environmental problems and the relationship between energy and countries' growth and development trajectory. More specifically, the investigation of the demand response sensitivity in the electricity sector on both an aggregate and an industrial level has received increasing interest by analysing the trend of electricity consumption.

A number of studies for both developed and developing countries focused their investigation on the demand for energy or, more specifically, electricity (Diabi, 1998;

Al-faris, 2002; Hondroyiannis, 2004; Atakhanova & Howie, 2007; Narayan, Smyth & Prasad, 2007; Amarawickrama & Hunt, 2008; Dergiades & Tsoulfidis, 2008). The demand for any good or service is typically affected by its own price, the income of the buyers, the price of the substitutes and other variables based on the type of the good or service. Although different methodologies were used, the majority of studies concentrated on income (or production/output) and electricity price as the main variables to explain electricity demand.

De Vita, Endresen and Hunt (2006) estimated the long-run elasticities of the energy demand for three types of energy, namely electricity, petrol and diesel, in Namibia for 1980–2002. They estimated the aggregate energy consumption as a function of Gross Domestic Product (GDP) and the price of energy. Depending on the type of energy in question, they also test for the importance of other variables such as air temperature, HIV/AIDS incidence rate, and the price of some alternative forms of energy. Their results show that energy demand is mainly affected positively by the changes in GDP and negatively by the changes in energy price and air temperature.

Special attention has also been paid to developing economies. Ghaderi, Azade and Mhammadzabeh (2006), for instance, investigated the electricity demand function of the industrial sector in Iran. A similar sectoral analysis on Russian industries was conducted by Egorova and Volchkova (2004), who found that the electricity prices were a factor of energy consumption – although other factors such as the output of the industries proved more significant. Studies were also carried out for developed countries by, for example, Lundberg (2009), who derived a demand function of Swedish industrial electricity use as well as the changes in demand trends over time. By dividing the sample into two periods (1960–1992 and 1993–2002), his findings showed that output was a more significant factor in the first period while price had become more significant in the second. A possible explanation for this change was the more efficient use of energy in the latter period.

In Romania, electricity consumption is also considered of significant importance for the development of the country (Bianco et al., 2010). In their study, Bianco et al. (2010) modelled non-residential electricity consumption as a function of GDP, non-residential electricity price and the non-residential electricity consumption of the previous year. First, they estimated the GDP and price elasticities for the non-residential electricity consumption for 1975–2008, identifying these as the main determinants of the consumption’s evolution. They then proceeded with a forecasting exercise. Their findings show that price elasticities varied between -0.075 in the short-run and -0.274 in the long-run; while the income elasticities varied between 0.136 in the short-run and 0.496 in the long-run.

In a panel data framework, Narayan, Smyth and Prasad (2007) examine the residential electricity demand and its determinants for the G7 countries. The electricity consumption is determined as a function of its price and real income per capita. They proposed two models that differ only in the treatment of the prices. The one model includes real electricity prices while the other includes electricity prices relative to gas prices. Their main result is that residential demand for electricity is income inelastic but price elastic in the long-run.

Regarding industrial electricity consumption, Dilaver and Hunt (2010) examine the relationship between industrial electricity consumption, industrial value added and electricity prices with regards to the Turkish industrial sector for 1960–2008. They conclude that output and real electricity prices are the significant factors in determining electricity consumption (price elasticity = -0.16 and income elasticity = 0.15).

Locally, Blignaut and De Wet (2001) examine the industrial electricity consumption with regard to price by estimating the price elasticities for the various sectors between 1976 and 1996. They found weak relationships between electricity price and consumption, some of them positive. Ziramba (2008) analyses residential electricity demand, showing that price did not have a significant impact on the residential sector during 1978–2005; instead, income was an important determinant of electricity demand. These results, however, are challenged by Inglesi (2010) who shows that price is a significant factor of total electricity demand for 1980–2005, but at an aggregate or economy-wide level.

Given the conflicting evidence, this study attempts to expand the work done by Blignaut and De Wet (2001) and Inglesi (2010), and examine the price sensitivity of the electricity consumption for various economic sectors separately.

3.2.3 Panel data analysis

‘Panel data’ refers to the representation of data of different households, countries or companies over several time periods (Baltagi, 2008). Before analysing the main categories of panel data and several of their applications, it would be imperative to explain the benefits of panel data analysis, as well as some of its drawbacks.

Hsiao (2003) mentions the following the advantages of using panel data techniques:

- Controlling for individual heterogeneity
- More informative data
- More variability of data
- Less collinearity among the variables
- More degrees of freedom
- Better for studying dynamics of adjustment
- Identification of effects not easily detectable in cross-section or time-series analysis
- Reduced biases due to aggregation of households or individuals

However, panel data analysis also has a number of disadvantages. Kasprzyk et al. (1989) discuss problems regarding the design and data collection such as problems with coverage, non-response and reference period selection. Measurement errors may also occur (Baltagi, 2008). In addition, short-term time dimension and cross-section dependence can prove problematic for the analysis.

Panel applications can be found in both micro and macro levels. Examples of micro panels include analysis of individuals and households (N) over a time period (T); while the equivalent macro panels involve numerous countries (N) over time (T).

An infamous example of micro panel data is the Panel Study of Income Dynamics (PSID) collected by researchers at the University of Michigan. The study started in 1968 with gathering descriptive statistics of 4,800 families and its coverage increased to 7,000 families in 2001. It focuses on economic, health and social behaviour. An interesting aspect of the study is that it not only covers the substantial number of individuals but also continuously reports on them, for some it has been as many as 36 years. Hence, this micro panel database is able to provide researchers with dynamic aspects of the households and individuals' actions. In addition, special attention is given to children and caregivers of the sample by collecting information on education, health, behavioural development and use of time (http://psidonline.isr.umich.edu/).

Micro panel data analysis has recently been applied to several topics and countries. The investigation of trends in household income and consumption has attracted attention among researchers working with micro panel databases. Gorodnichenko and Schitzer (2010) employed a micro dataset from the Russia Longitudinal Monitoring Survey for 1994–2005. Their analysis focused on 2000–2005 due to the country's economic recovery and results showed that falling volatility of transitory income shocks is the main driving factor of the decrease in income inequality during the period. They also found that consumption was less influenced by income shocks towards the end of the period.

Literature on firm price-determination analysis also found applications of micro panel data. The price determination of manufacturing companies was the focus point in the study by Lein (2010). By employing micro panel quarterly data from 1984 to 2007 for Swiss manufacturing firms, the study found that variables such as costs for intermediate products are crucial determinants of price adjustments. Changes in revenue are significant factors to price decision. When the upwards and downwards movements in prices are examined separately, macroeconomic factors are significantly linked to inflation.

Another study on manufacturing price-setting behaviour of Spanish firms conducted by Alvarez, Burriel and Hernando (2010) used micro panel data. They confirmed that cost structures were important in price adjustments. Other factors were the degree of market competition, demand conditions and inflationary pressures.

In the energy literature, a number of studies were recently conducted using micro panel data analysis. For example, Arnberg and Bjorner (2007) estimated factor demand models with electricity, other forms of energy, labour and capital as flexible inputs, based on micro panel data for Danish industrial firms. They stress that policy-makers need to comprehend the dynamics of energy demand and the influence of different types of policy towards the reduction of energy use and CO_2-emissions. This understanding should start, according to Arnberg and Bjorner (2007), at the company level. Their results show small price elasticities and hence, they conclude that it is difficult to use taxation in order to change the use of alternative production factors and reduce the energy use and CO_2-emissions of the companies.

On macro level, well-known panel databases used by economists are:

a) the Penn World Tables (http://pwt.econ.upenn.edu/) that provides main macroeconomic variables for almost 200 countries for 1950–2004;

b) the International Monetary Fund’s (IMF) World Economic Outlook (http://www.imf.org/external/index.htm) that provides time-series data for GDP, inflation and other selected macroeconomic information for 183 developed and developing economies from 1980 to present; and

c) the World Bank’s World Development Indicators with data on more than 300 indicators for more than 200 countries (http://data.worldbank.org/).

Main macro panel applications deal with topics on economic growth, financial development and capital mobility of countries. De Wet and Van Eyden (2005) examined the degree of capital mobility in sub-Saharan Africa. Data from 36 countries for 1980–2000 were employed to confirm Vamvakidis and Wacziarg (1998) and Isaksson (2000) results that the less developed countries are more dependent on international finance and aid and that openness in the economy is a positive contributing factor towards a higher level of capital movement. In order to investigate the impact of macroeconomic development on earnings inequality in Brazil, Bittencourt (2009) employed panel data for six Brazilian regions from 1983 to 1994. His results indicate that the inflation had a high positive relationship with earnings inequality for the study period. However, unemployment and the minimum-wage index had mixed effects on earnings inequality.

In the energy literature, macro panel data analysis is used to answer different questions. Morley and Abdullah (2010) try to determine the existence of a causal relationship between environmental taxes and economic growth. A macro panel data of European and OECD countries for 1995–2006 was used. Their results propose that in the long-run, economic growth causes an increase in the revenue from environmental taxes.

Hubler and Keller (2010) employ data from 60 developing countries for the period 1975 to 2004 to investigate the relationship between foreign direct investment (FDI) and energy intensity. Their results suggest that FDI does not help to reduce energy intensities. However, foreign development aid intensifies the energy efficiency gains.

A frequent question in energy economics is whether or not there is a relationship between energy consumption and total income. By employing panel data techniques, Sadorsky (2009) focus on renewable energy and prove that rises in real per capita income have a significant impact on per capita renewable energy consumption. This is also confirmed by Apergis and Payne (2010) who examine the existence of interaction between renewable energy consumption and economic growth in a panel data context. Six countries in Central America were examined for the period 1980–2006. The results indicate that in the long-run, a 1% rise in per capita income increases the renewable energy consumption by 3.5%. Also, the price elasticity of renewable energy consumption was approximately -0.7.

Another characteristic example of panel data analysis in energy is the study by Miketa (2001) that investigates the energy intensity developments in the industrial sectors of both developed and developing countries. The relationship between energy intensity and sectoral economic development was examined for ten industrial sectors of 39 countries for 1971–1996. The results show that capital formation has a positive effect on energy intensity and that this effect is higher, the bigger the size of the sector.

The pooled effects model is considered to be limited for a number of applications since it does not take into account any cross-section heterogeneity among the sectors. The pooled effects model presents a joint estimation of coefficients, depicted as follows:

Eq. 3.14

$$\mathbf{y_{it} = \beta_0 + \beta_1 X_{1,it} + \beta_2 X_{2,it} + \varepsilon_{it}, for\ i = 1, \ldots N\ and\ for\ t = 1, \ldots . T}$$

Where y_{it} is the dependent variable observed for individual i at time t, $X_{1,it}$ and $X_{2,it}$ are the time-variant regressors; β_0 is the constant; β_1 and β_2 are the slope coefficients and ε_{it} is the error term.

However, 'pooling' has some specific characteristics, such as the increase in the degrees of freedom and hence, the potential low standard errors on the coefficients as a result. Except for the same slope coefficients, it also assumes a common intercept.

The next step would be to relax the assumption of a common intercept for the regression. Formally, and to be able to distinguish between different effects, Equation 3.14 can be rewritten as follows:

Eq. 3.15

$$\mathbf{y_{it} = \beta_0 + \beta_1 X_{1,it} + \beta_2 X_{2,it} + \alpha_i + u_{it}, for\ i = 1, \ldots N\ and\ for\ t = 1, \ldots . T}$$

Where α_i is the unobserved individual effect and u_{it} is the error term.

There are two methods to deal with the unobserved individual effect: the fixed effect model and the random effects model. The fixed effect model assumes that α_i is not independent of $X_{1,it}$ and $X_{2,it}$ while the random effects model's assumption is that α_i is independent of $X_{1,it}$ and $X_{2,it}$ or $E(\alpha_i \mid X_{1,it}, X_{2,it})=0$.

Taking the analysis further, the final aim is to estimate a set of equations which will allow different coefficient vectors. The Seeming Unrelated Regression (SUR) model provides the researcher with that possibility.

Recently, Lee and Lee (2009) used a dataset of 109 countries for 1971–2003 to investigate the stationarity properties of CO_2-emissions and GDP per capita within a SUR context. This methodology was preferred due to its ability to account for the presence of cross-country correlations. The results of their analysis stress an important aspect of panel data analysis: different orders of integration between countries for some variables can lead to misleading conclusions.

Therefore, Equation 3.15 should be amended (by representing a different coefficient for each i) in order to represent a SUR, as follows:

Eq. 3.16

$$\mathbf{y_{it} = \beta_{0,i} + \beta_{1,i}X_{1,it} + \beta_{2,i}X_{2,it} + \alpha_i + u_{it}, for\ i = 1, \ldots N\ and\ for\ t = 1, \ldots . T}$$

3.2.4 Theoretical model

For an investigation of the effects of prices and industrial output on electricity consumption of different economic sectors, a balanced panel data of five production sectors for 1993–2006 was developed. Furthermore, it is assumed that the electricity consumption is a function of changes in electricity prices and output. It should be noted here that the prices are exogenously determined by the national supplier of electricity, Eskom; hence, prices are not determined by the interaction of supply and demand but by policy decisions. As a result of this and in combination with the fact that electricity supply in the country has a specified ceiling, electricity supply is not considered as a factor affecting electricity demand.

First, a pooled panel test was done to investigate the overall relationship between electricity prices and output, and electricity consumption. Second, to capture sector-specific effects, a fixed effects analysis was employed to account for cross-section dynamics.

Finally, to determine how the various sectors respond to electricity price changes in terms of their own production output, and to describe inter-sectoral dynamics, a SUR model is estimated. Following the international literature review, the equation used has the following functional form:

Eq. 3.17

$$\mathbf{LnCons} = \alpha_{0,i} + \alpha_{1,i}\,\mathbf{LnPrice}_{it} + \alpha_{2,i}\,\mathbf{LnOutput}_{it}$$

Where cons is the electricity consumption, price is the price of electricity and output is the gross value added of the sector i at time t. The Ln in front of the variable notates that all the variables are in their natural logs. Linearising the variables will also be useful in estimating elasticities that are defined as ratios of percentage changes.

3.2.5 Data

To apply panel data techniques for the analysis, local sources of data are used. Sectoral electricity consumption is derived from the *Energy Balances* of the Department of Minerals and Energy (DME, various issues) and is measured in MWh. Based upon the *Energy Balances*, the economy consists of five sectors (i.e. industrial, commercial, agricultural, residential and transport) disaggregated in 22 industries. The data is collected by the Trade and Industry division of Statistics South Africa (StatsSA) in collaboration with the Department of Energy using a questionnaire via post or fax. The main source of information is Eskom followed by municipal power stations and other industries (sugar, paper, petroleum and mine). The data is supplied under an agreement of confidentiality. The DME does not conduct any surveys themselves, and they do not perform regular data audits. The DME solely relies on the data providers and the reports released by Eskom and NERSA. In an effort to verify the data the DME has a quality control process in place which involves manually checking data and comparing the current data with datasets from previous years, querying observed inconsistencies. Thereafter the data is subject to review by various committees and key energy specialists. After this initial peer-review process, the data is released to a number of international organisations such as the International Energy Agency, the South African Development Community (SADC), academic institutions, government departments and other stakeholders (StatsSA, 2009). Following the approval of the data by these institutions, it is released to the public. While it can be assumed that the data is not perfect, it is currently the best available data and it should be noted that the data did undergo considerable scrutiny.

The data series on the sectoral electricity prices is obtained from the *Energy Price Report, 2009* (DME, 2010) which is not always released annually due to limitations. In this publication, tariffs for various types of energy (including electricity) in South Africa are presented. The tables for the electricity charges are derived from Eskom's Statistical Yearbooks and Annual Reports.

More specifically, the electricity prices are presented as sectoral averages and represent Eskom’s revenue per kWh (selling price of electricity, VAT excluded) by customer category: Bulk, Domestic and Street Lighting, Commercial, Industrial, Mining, Rural/Farming, Traction, and International. The data is only applicable to Eskom tariffs to the categories and exclude the sales by local authorities. The prices are presented in nominal terms and were converted to real prices by using the annual Consumer Price Index (CPI), with 2005 being the base year, from Statistics South Africa (StatsSA).

Finally, the data series on real total output was obtained from the *Quarterly Bulletin* of the South African Reserve Bank (SARB, various issues) and *Industry trends database* from Quantec (n.d). The output is measured in Rand millions, transformed in real prices of 2005 by using the CPI from StatsSA. Table 3.6 presents the variables' basic descriptive statistics.

Table 3.6 Data descriptive statistics

	Lncons	**Lnprice**	**Lnoutput**
Mean	16.573	-3.804	12.287
Median	16.720	-3.892	12.092
Maximum	18.436	-3.182	13.887
Minimum	14.950	-4.269	10.961
Std. Dev.	1.058	0.326	0.855
Skewness	0.053	0.347	0.322
Kurtosis	1.593	1.793	1.984
Jarque-Bera	5.805	5.655	4.224
Probability	0.055	0.059	0.121
Sum	1160.099	-266.263	860.093
Sum Sq. Dev.	77.194	7.315	50.392
Observations	70	70	70
Cross sections	5	5	5

For a more detailed picture of the relationship of the electricity consumption, electricity prices and the economic output per sector, Figure 3.5 presents a summary of graphs for the ‘industrial’, ‘mining’, ‘transport’, ‘agriculture’ and ‘commercial’ sectors for 1993–2006.

From Figure 3.5, it is obvious that not all the sectors behaved the same way during the study period with regards to electricity consumption. From the industrial sector’s graphs, it can be observed that electricity consumption showed a positive relationship to economic output while it was negative to the electricity real prices, which decreased throughout the study period.

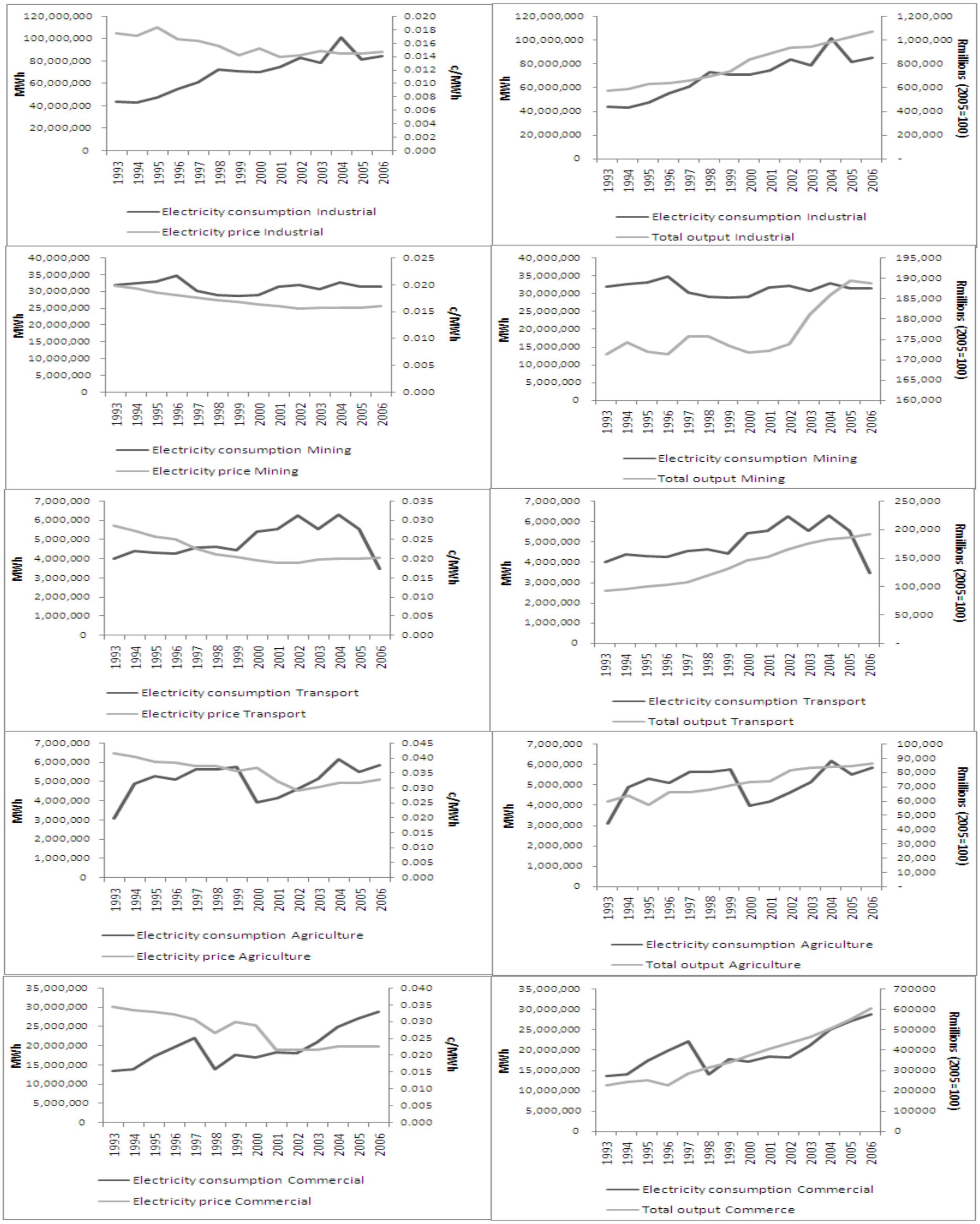

Figure 3.5 Electricity consumption, prices and economic output for the Industrial, Mining, Transport, Agriculture and Commercial sectors, 1993–2006
Source: DME (various issues); DME (2010a) and Quantec (n.d)

The mining sector's electricity consumption looks as though it is not affected by its output or the electricity prices. The consumption experienced a sharp decrease at the end of the 1990s, picking up during the 2000s; while the mining sector's output increased substantially at the beginning of the 2000s following the internationalisation of the economy and the end of the sanctions. However, the real electricity prices decreased steadily until 2002.

The transport sector presents a similar situation with electricity consumption fluctuating throughout the years, having an average increasing trend but a severe decrease in the last years of the sample. Its economic output increased continuously for the study period while its electricity prices started increasing again only after a period of critical decrease from 1993 to 2002.

The electricity consumption of the agricultural sector presents high increases (in 1993–1994 and 2001–2003). A structural change is seen in 1999–2000 with consumption decreasing by 31%. In contrast, its output showed a steady increasing trend throughout the years while the electricity prices followed the economy's overall price trend: decreasing until 2002–2003 and slowly rising thereafter.

Finally, the commercial sector's electricity usage had an upward trend during the entire period with the exception of 1997. The graph for its real economic output was exactly the same; however, its price fluctuated with a decreasing overall trend for half of the study period and it more or less stabilised since 2001.

Looking at this analysis, and according to economic theory, there are two ways of dealing with electricity consumption: a) from the supply side, as an input to the output of a sector, or b) from the consumers' side as a result of output and prices.

Figure 3.5 shows that output and electricity consumption have similar trends. So indicatively, ordinary least squares (OLS) regressions are run to establish the role of electricity consumption as an input to each sector's output (Table 3.7).

From these simple regressions, it can be concluded that electricity consumption is not a significant factor in explaining the output trends of the sectors during the specific period (1993–2006).

Table 3.7 OLS regressions for each of the five studied sectors:
Ln_output$_t$=a*Ln_capital$_t$+b*Ln_labour$_t$+d*Ln_electricity_consumption$_t$+constant

Dependent variable: Ln_ouput$_i$

	Industry	Mining	Transport	Commerce	Agriculture
Ln_capital$_i$	1.811	1.153	4.020	4.042	-4.107
	0.079	**0.001**	**0.000**	**0.004**	**0.065**
Ln_labour$_i$	-2.209	0.103	-0.403	0.462	-0.195
	0.023	**0.126**	**0.091**	**0.022**	**0.593**
Ln_electricity_consumption$_i$	0.162	-0.181	0.197	-0.115	0.106
	0.522	**0.239**	**0.018**	**0.399**	**0.327**
C	19.013	-0.300	-37.842	-43.640	59.980
	0.222	**0.924**	**0.000**	**0.002**	**0.008**
Adjusted R^2	0.890	0.655	0.989	0.963	0.795
F-statistic	35.964	9.229	390.038	114.108	17.829
	0.000	0.003	0.000	0.000	0.000

Based both on these results and on the common approach of the international literature discussed above, the electricity demand is examined from the consumers' point of view by using a single equation approach in which the quantity of electricity demanded is a function of electricity prices and the output produced in each sector.

Testing for the existence of unit roots in time-series econometrics has become the norm, but in a panel context the application of tests is more recent. Studies that proposed new tests for stationarity in panel data analysis (Levin, Lin & Chu, 2002; Im, Pesaran & Shin, 2003) argue that individual unit root tests have limited power against alternative hypotheses, especially in small samples. Levin, Lin and Chu (2002) suggest that panel unit roots tests are more powerful.

A common test used for determining the univariate characteristics of the variables in panel datasets was recently proposed by Levin, Lin and Chu (2002). Its null hypothesis is that each individual time-series contains a unit root against the alternative that each time-series is stationary.

The hypothesis is presented as follows (Baltagi, 2008):

Eq. 3.18

$$\boldsymbol{\Delta y_{it} = \rho y_{i,t-1} + \sum_{L=1}^{p_i} \theta_{iL} \Delta y_{it-L} + \alpha_{mi} d_{mt} + \varepsilon_{it}}$$

With d_{mt} being the vector of deterministic variables; α_{mi} the corresponding vector of coefficients for model m=1,2,3. The three-step procedure proposed by Levin, Lin and Chu (2002) is presented in Appendix 1. The results of the test are presented in Table 3.8.

Table 3.8 Unit root test results

Variable	Possible deterministic structure	Statistic	p-value	Level of significance	Conclusion
Lncons	None	0.95	0.83	-	-
	Intercept	2.272	0.01	**	stationary
	Intercept and trend	0.16	0.56	-	-
Lnprice	None	1.19	0.88	-	-
	Intercept	-4.448	0.00	***	stationary
	Intercept and trend	1.74	0.96	-	-
Lnoutput	None	5.96	1.00	-	-
	Intercept	0.15	0.56	-	-
	Intercept and trend	-2.062	0.02	**	stationary

Note: *, **, *** denote 1%, 5% and 10% level of significance respectively

3.2.6 Empirical results

The results of the pooled and fixed effects are presented in Table 3.9. The pooled effects model is considered to be limited for a number of applications since it does not take into account any cross-section heterogeneity among the sectors. The fixed effects model, on the other hand, does allow for cross-section heterogeneity and assumes a different intercept for each sector.

Table 3.9 Pooled and fixed effects results[4]

Lncons	Pooled effects	Fixed effects
Lnoutput	0.803 **0.000**	0.603 **0.011**
Lnprice	-0.950 **0.000**	0.259 **0.389**
Constant	3.087 **0.000**	
Constant of industrial sector		7.060 **0.000**
Constant of transport sector		6.000 **0.000**
Constant of commercial sector		6.453 **0.000**
Constant of agricultural sector		6.183 **0.000**
Constant of mining sector		7.113 **0.000**
Adjusted R^2	0.757	0.970

Note: Numbers in bold denote the p-values.

The results indicate that both electricity price and output of the industries are significant factors in electricity demand in its entirety. Output has a positive impact while an increase in price leads to a decrease in the electricity use. However, when the effects of the different sectors (fixed effects model) are taken into account, the

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[4] Both specifications' results are after correction for the serial correlation and heteroskedasticity present. White-heteroskedasticity-consistent standard errors and covariances were used to correct for heteroskedasticity, and the Prais-Winston transformation was used to correct for serial correlation, as proposed by Baltagi (2008). Also, the Hausman test concluded that there is no misspecification in the model. For the results of all the tests, see Appendix Table A4.

coefficient of electricity prices becomes insignificant while output becomes less significant. The results of the fixed effects analysis show that cross-section heterogeneity might be the cause of the insignificance of the electricity prices because sectoral differences are allowed in the fixed effects model, and the price became insignificant.

Next, a SUR model is estimated to capture the importance of electricity prices in each of the sectors separately and their inter-sectoral dynamics, knowing that the sample is characterised by heterogeneity in behaviour towards electricity use (see Table 3.10).

Table 3.10 SUR model results

Lncons	Industrial	Transport	Commercial	Agriculture	Mining
Lnprice	-0.869	-1.220	0.677	0.152	0.204
	0.004	**0.229**	**0.145**	**0.865**	**0.506**
Lnoutput	0.712	-0.242	0.767	0.032	0.030
	0.004	**0.694**	**0.029**	**0.955**	**0.954**
Constant	3.059	8.749	6.081	10.076	11.430
	0.132	**0.001**	**0.005**	**0.000**	**0.004**
Adjusted R-squared=0.967					
Total number of observations: 65					
Corrected for serial correlation and heteroskedasticity					

Note: Numbers in bold denote the p-values.

The coefficients of the variable Lnprice are considered to be the price elasticities of electricity demand for each of the sectors. The results are in accordance with the expectations following a careful study of Figure 3.5. The industrial sector has an inelastic electricity demand (elasticity = -0.869) for 1993–2006. The price does not play a significant role in the demand for electricity for the rest of the sectors (their coefficients are all highly insignificant). In contrast, sectoral output is found to be a significant factor that influences electricity consumption only for the industrial and commercial sectors. However, the output of the other three sectors does not significantly affect the electricity consumption. Some of the plausible reasons for this behaviour are discussed below.

3.2.7 Discussion and policy implications

The results of the analysis above suggest that the relationship between electricity consumption and electricity prices differs among the various sectors. The price elasticity in the industrial sector is highly significant and negative. In contrast, the rest of the sectors present insignificant price elasticities. These sector-specific results demand careful consideration when planning changes to the pricing regime as these sectors will most likely respond differently to changes in electricity prices.

Before discussing the results of the main question of this study, it is important to discuss whether or not the output affected the electricity consumption in the various economic sectors. Economic output was a positive contributing factor in only two of the five sectors, namely industrial and commercial. For the other three sectors the output did not play a statistically significant role in electricity usage.

The agricultural sector in South Africa is a relatively labour-intensive sector still using traditional methods of production. Hence, it is not expected that the output is related to the electricity consumption of the sector. Regarding the transport sector, one of its main electricity users during the early part of the study period was freight rail. This user all but collapsed during the study period with freight transport shifted to road and long-haul. This implies that the electricity consumption declined significantly, but the output/production did not. The South African transport sector experienced a switch from electricity to other forms of energy, such as oil or petroleum.

Finally, in the mining sector during the study period, mines engaged in a process of co-generation whereby they started to generate their own electricity, or create smaller power units. Hence, their electricity demand from the national supplier has declined.

The level of the electricity prices, being historically very low, is also a cause of the lack of behavioural response to price changes, as suggested by Blignaut and De Wet (2001). Moreover, the real prices in a number of sectors declined significantly until 2002, when the price reform started taking effect. There was a long period during which consumption increased more rapidly than prices due to other factors, such as product demand or technological change. This is not uncommon as Miketa (2001) found similar results when studying various countries and attributed this lack of behavioural response to the fact that energy prices were not constructed as an industry-specific energy price.

The low level and declining trend of electricity prices in South Africa has also been the reason why the cost of electricity as a percentage of total cost is significantly low. Blignaut and De Wet (2001) show that the ratio of electricity to total costs is less than 10% for the majority of the South African economic sectors for the years 1976, 1979, 1982, 1985, 1988, 1991, 1993 and 1996. Table 3.11 confirms this for the year 2005. The low proportion of electricity costs, showing the low relative importance of the specific product to the consumers' budget, makes one expect low (or even insignificant) price elasticities.

Table 3.11 Electricity cost as a percentage of total cost in South African sub-sectors: 2005[5]

Plastics in primary forms	14.05%	Builders' carpentry and joinery	0.91%	Services relating to printing	0.34%	Bakery	0.13%
Soap, detergents, polishing, perfumes	5.83%	Carpets, rugs and mats	0.80%	Chrome	0.33%	Plastic	0.12%
Other mining and quarrying	3.70%	Lifting and handling equipment	0.80%	Steam generators	0.32%	Furniture	0.12%
Finishing of textiles	3.37%	Treatment and coating of metals	0.70%	Machinery for textile, apparel, leather	0.32%	Knitting, crocheted fabrics	0.12%
Glass and glass products	2.81%	Copper	0.66%	Machinery for mining, quarrying, construction	0.32%	Other special purpose machinery	0.11%
Platinum	2.30%	Aircraft	0.60%	Other chemical n.e.c	0.31%	Recycling of metal, non-metal waste and scrap n.e.c.	0.10%
Structural non-refractory products	2.11%	Service activities	0.55%	Parts, accessories for motor vehicles	0.30%	Tanning, dressing of leather	0.10%
Refractory ceramic products	2.01%	Bodies of motor vehicles, trailers	0.52%	Other rubber tyres	0.28%	Rubber tyres, tubes, rethreading	0.08%
Non-structural, non-refractory ceramicware	2.00%	Corrugated paper, containers of paper	0.51%	Building, repairing of boats and ships	0.25%	Other manufacturing n.e.c.	0.08%
Other metal ore	1.67%	Basic precious and non-ferrous metal	0.51%	Fish	0.25%	Newspaper, journals and periodicals	0.08%
Forestry	1.43%	Iron ore	0.50%	Veneer sheets, plywood, laminboard	0.23%	Pump, compressor, taps and valves	0.08%

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[5] The table excludes all the sub-sectors whose ratio of electricity to total costs was lower than 0.05%

Agriculture	1.37%	Pulp, paper, paperboard	0.50%	Other special purpose machinery	0.22%	Cordage, rope, twine, netting	0.08%
Basic iron and steel	1.22%	Other textiles	0.49%	Structural metal products	0.21%	Motor vehicles	0.07%
Household appliances n.e.c	1.17%	Gold	0.47%	Agriculture, forestry machinery	0.21%	Paints, varnishes, printing ink, mastics	0.07%
Casting of metals	1.06%	Spinning, weaving of textiles	0.45%	Machine tools	0.18%	Cocoa, chocolate	0.06%
Tanks, reservoirs, containers of metal	1.06%	Machinery for food, beverage, tobacco	0.45%	Industrial process control equipment	0.18%	Manganese	0.06%
Fishing	1.03%	Other fabricated metal products n.e.c.	0.44%	Other food	0.17%	Engines and turbines	0.06%
Coal	0.99%	Grain mill	0.44%	Wooden containers	0.16%	Wearing apparel	0.06%
Railway, tramway locomotives, rolling stock	0.96%	Cutlery, hand tools, general hardware	0.43%	Accumulators, primary cells, batteries	0.15%	Television, radio transmitters, apparatus	0.06%
Basic chemicals	0.93%	Forging, pressing, stamping of metal	0.43%	Fruit, Vegetables	0.14%	Insulated wire cable	0.05%
Other transport	0.92%	Other articles of paper	0.38%	Cement, lime, plaster	0.13%	Electricity distribution, control apparatus	0.05%

Source: Authors' calculations with data from StatsSA (2010)

The price policies followed in this country, in addition to the results of the above analysis on electricity, resulted in an enhancement of electricity consumption as reflected by lack of price sensitivity in all but the industrial sector. Moreover, the stronger the demand for electricity, given the electricity supply mix which is heavily, dominated by coal, the stronger the demand for power and the more the CO_2-emisisons. The lack of behavioural response to changes in price, implying that prices and consumption move in the same direction, has not only led to the rapid crowding-out of electricity capacity, but also to a strong increase in CO_2-emissions from the specific sectors.

3.2.8 Conclusion

To address the mismatch between electricity supply and demand such as the one South Africa currently experiences, the underlying behavioural responses due to changes in price must be understood. The sector-specific approach employed here highlights each of the sector's behaviour to price changes before the recently proposed increases.

Using panel data analysis, this study examined the price effect on electricity consumption by sector and the respective price elasticities were estimated. The findings of this analysis points towards ambiguous results and even 'abnormal' behaviour towards price changes in all but the industrial sector, the only one in which consumption declined with price increases and vice versa.

According to this analysis, a lack of behavioural responses to price changes is a contributing reason for the insecure and uncertain environment in which the current policy-makers find themselves. More disconcerting, however, is that the lack of sensitivity to price changes also acted as a strong stimulus for the increase in CO_2-emssions. If South Africa wishes to curb the emissions of CO_2 from electricity generation it will do well to induce change that would enhance a behavioural response to price changes, that includes both efficiency improvements and technology changes.

In the future, a structural change is expected due to the large increases in the electricity tariffs. As shown in Section 3.1, the past insensitivity to price changes will disappear and different sectors will either cut down on their electricity consumption or turn to more efficient technologies and other – cheaper – forms of energy.

The major findings of Sections 3.1 and 3.2 summarise the lack of behavioural response of the South African economy to changes in the electricity prices in combination with the fact that different sectors behaved differently during the study period. Without ignoring the fact that this behaviour might change considerably in the future, after the price restructuring, the next section examines how other factors such as the structural changes of the economy and the efficiency improvements might affect the electricity usage of the economy in its entirety as well as at a sectoral level.

3.3 Sectoral decomposition analysis of the South African electricity consumption[6]

3.3.1 Introduction

South Africa took the bold step at the beginning of 2010 to commit itself to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) in taking all the necessary actions to decrease the country's greenhouse gas emissions by 34% to below the "business-as-usual" scenario by 2020 (Republic of South Africa, 2010). The bulk of the country's greenhouse gas emissions (more than 60%) originate from the electricity generation sector which is heavily depended on coal-fired power stations (Blignaut, Mabugu & Chitiga-Mabugu, 2005). It therefore goes without saying that the road towards the reduction of greenhouse gas emissions passes through the reduction of electricity usage.

To achieve such a reduction in the use of electricity, it is imperative to understand the underlying factors which led to the historic increases in electricity consumption. Historically, studies for both developed and developing countries (e.g. Schipper et al., 1997; Ang & Liu, 2001; Metcalf, 2008; Andrade Silva & Guerra, 2009; Webber, 2009) have indicated that there are mainly three factors behind the rate of increase in electricity consumption. These are production changes, changes in the structure of the economy and efficiency improvements, measured as the change in electricity intensity.

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[6] This section has been published in *Applied Energy.*

In this section, a decomposition analysis is conducted to determine the significance of each of these three factors. First, the annual changes of the factors' contribution to total electricity consumption are considered. This is followed by a sectoral decomposition analysis for 1993–2006. This time period was selected to coincide with the post-apartheid period up until the latest available figures. If there are significant differences among the various sectors' electricity consumption profile and the underlying drivers for growth; this will indicate the necessity of sectoral electricity reduction policies.

This section is structured as follows: first, a brief description of the decomposition methodology is presented, followed by a review of decomposition applications in the energy literature. The data used in this exercise are then presented, followed by the empirical results of the decomposition analysis of the South African electricity consumption. Policy implications are discussed in the conclusion.

3.3.2 Decomposition methodology

Decomposition techniques as an analytical tool have attracted much interest in the energy literature over the last two decades (Sun, 1998; Ozawa et al., 2002; Markandya, Pedroso-Galinato & Streimikine, 2006; Korppoo et al., 2008; Metcalf, 2008; Andrade-Silva & Guerra, 2009; Liddle, 2009; Mendiluce, Perez-Arrigi & Ocana, 2010; Zhao, Ma & Hong, 2010; Zhou et al., 2010). The decomposition of energy (sic. electricity) consumption is not unlike the use of indices to investigate the contribution of changes in quantity and price to changes in aggregate consumption (Mendiluce, Perez-Arrigi & Ocana, 2010). Decomposition analysis is employed to separate changes in electricity consumption over time into mainly three driving factors, namely i) changes in the structure of the economy, ii) changes in efficiency and/or iii) production changes (Ang & Liu, 2001; Metcalf, 2008; Andrade-Silva & Guerra, 2009; Webber, 2009).

The decomposition techniques can be classified into two main categories, namely the index decomposition analysis (IDA) (Korppoo et al., 2008; Salta, Polatidis & Haralambopoulos, 2009; Zhao, Ma & Hong, 2010) and the structural decomposition analysis (SDA) (Wachsmann et al., 2009). The main difference between these two methods is that SDA can explain indirect effects of the final demand by dividing an economy into different sectors and commodities, and examining the effects on them individually (Wachsmann et al., 2009) while IDA explains only direct (first-round) effects on the economy. The IDA applies sectoral production and electricity and the SDA requires data-intensive energy input-output analysis (Webber, 2009). The advantages and constraints of each of these methods are discussed in depth by Hoekstra and Van den Bergh (2003) and Ma and Stern (2008). Because of the data constraint concerning SDA, the IDA is generally perceived to be the method of choice by a number of studies (Ang & Zhang, 2000; Ang, 2004; Liu & Ang, 2007).

According to the IDA literature, there are two main methods previously used: the Laspeyeres or the simple Divisia method. Ang (2004) based his study's classification on the theoretical foundation of index numbers and the desirability of the decomposition method. Figure 3.6 presents a categorisation between methods linked to Laspeyres and those linked to the Divisia index.

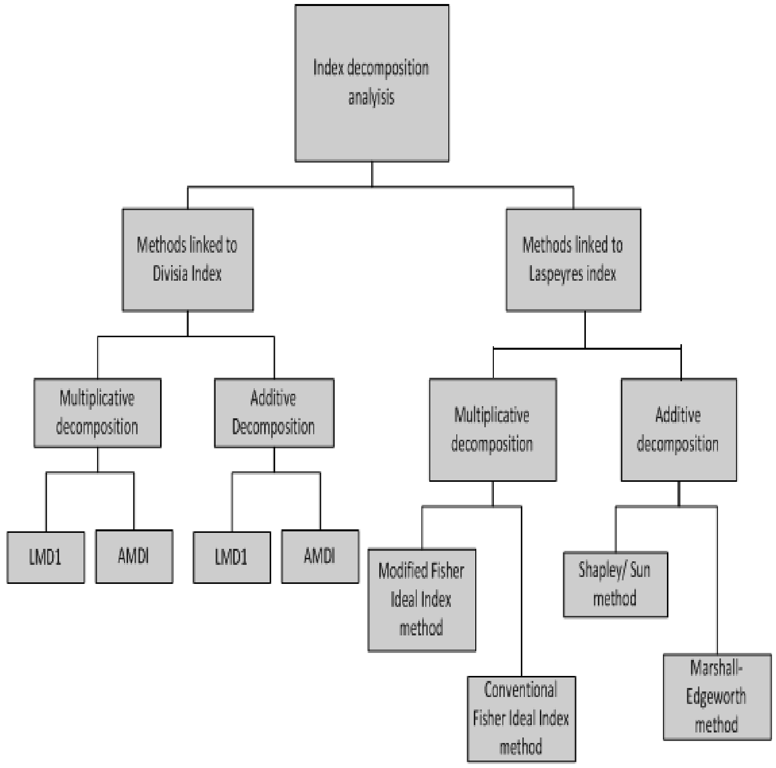


Figure 3.6 Recommended decomposition techniques
Source: Ang (2004)
Note: The index decomposition analysis can be divided in two main categories: the methods linked to Divisia index and those linked to Laspeyres index. Further, the Divisia index are categorised based on the specific technique in multiplicative decomposition and additive decomposition and both of them can be categorised in LMD1 and AMDI. On the other side, the multiplicative decomposition techniques linked to Laspeyres index are the conventional Fisher ideal index and the modified Fisher ideal index; while under the additive decomposition linked to Laspeyres index, one can find the Shapley/Sun method and the Marshall–Edgeworth method.

The Laspeyres method measures the change in some characteristic of a group of variables over a time period employing weights based on a particular year. The Divisia index is a weighted sum of logarithmic growth rates where the relevant weights are calculated as the components' proportions to total value (Ang, 2004). Ang (2004) also points out that although the Divisia index is more difficult to understand (log growth rates compared to percentage growth rates of Laspeyres), it is more scientific and presents symmetry in the results.

Greening, Davis and Khrushch (1997) conducted a more extended critical assessment and comparison of six existing decomposition methods applied to energy intensity for manufacturing in ten OECD countries. According to their study, all the index decomposition methods can be included in a more general parametric category. The following methods were compared in their study:

- Laspeyres
- Simple average Divisia
- The adaptive weighting Divisia

All three of these can be separated in two groups, namely:

a) with fixed base year: they compare each of the components with a fixed base year, while holding the other components constant; and

b) with rolling base year: they include analysis on changes in the effects over time or how the variable to be decomposed has changed over time.

The comparative analysis was conducted by applying all six methods to the energy intensity of the manufacturing sectors in ten OECD countries (Denmark, Finland, France, Germany, Japan, Italy, Norway, Sweden, the United Kingdom and the United States). The main points for comparison were: a) the size of the residual term; b) the variability of the residual; and c) the difficulty of application. Their results conclude that for the decomposition of energy intensity, the AWD and the

Divisia with a rolling base year presented the smallest residual term with the lower variability.

The main criticism of the decomposition techniques is the unexplained residual they leave. Greening, Davis and Khrushch (1997) discuss *how small* the residual is within the different methods without questioning its existence. The main goal of a decomposition analysis is to measure the relative contributions of different factors to the changes in the interested aggregate variable; hence, the existence of a residual leaves a portion of this change unexplained (Liu, Ang & Ong, 1992; Ang and Choi, 1997).

Although Ang and Choi (1997) propose a method, called Log Mean Divisia Index II (LMDI II) that accounts for this problem and gives a perfect decomposition, it presents a different problem: it is not consistent in aggregation. Decomposition analyses are performed at a disaggregated or sub-group level and consistency allows the results to be summed at an aggregated level in a consistent manner.

In 2001, Ang and Liu (2001) presented a new energy decomposition method, called Log Mean Divisia Index Method I (LMDI I). This method resolves the predicament from the existence of residuals and also provides aggregation in the results. Another feature of the LMDI I decomposition method is that it presents symmetry between decomposition of changes in terms of ratios or differences (Choi & Ang, 2003), which means that decomposition of either ratios or differences provide the same results.

Ang (2004) conducted a comparative study of all the decomposition techniques mentioned in Figure 3.6, only to conclude that the LMDI I method is the most appropriate for the purposes for energy analysis because it contains all the desired characteristics: a) theoretical foundation; b) adaptability; c) ease of use, and d) ease of results interpretation.

Next, reference is made to the example that Ang and Liu (2001) provided to algebraically explain the concepts of perfect decomposition (absence of residual) and consistency in aggregation. A common topic in energy studies is the decomposition of energy related CO_2-emissions (C) in terms of changes in production (Y), energy emission factor (U), fuel mix (S) and energy intensity (I). The CO_2 is decomposed as follows:

Eq. 3.19

$$\mathbf{C = \sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij} = \sum_{i=1}^{n}\sum_{j=1}^{m} Y_i U_{ij} S_{ij} I_i}$$

Where C_{ij} is the CO_2-emissions for fuel j in sector i; U_{ij} is the emission factor of fuel j in sector i, S_{ij} is the energy consumption share of fuel j in sector i and finally, I_i is the intensity of sector i.

To proceed with the decomposition, the logarithmic differentiation of Equation 3.19 with respect to time is taken:

Eq. 3.20

$$\mathbf{\frac{dlnC}{dt} = \sum_{i=1}^{n}\sum_{j=1}^{m} \frac{Y_i U_{ij} S_{ij} I_i}{C}\left(\frac{dlnY_i}{dt} + \frac{dlnU_{ij}}{dt} + \frac{dlnS_{ij}}{dt} + \frac{dlnI_i}{dt}\right)}$$

The next two steps will be to integrate Equation 3.20 over the time [0,T] with Equation 3.19 and then take the exponential.

Eq. 3.21

$$\ln\left(\frac{C_T}{C_0}\right) = \sum_{i=1}^{n}\sum_{j=1}^{m}\int_{0}^{T} w_{ij}(t)\left(\frac{d\ln Y_i(t)}{dt} + \frac{d\ln U_{ij}(t)}{dt} + \frac{d\ln S_{ij}(t)}{dt} + \frac{d\ln I_i(t)}{dt}\right) dt$$

Where

Eq. 3.22

$$w_{ij}(t) = \frac{Y_i(t)U_{ij}(t)S_{ij}(t)I_i(t)}{C(t)} = \frac{Y_i(t)U_{ij}(t)S_{ij}(t)I_i(t)}{\sum_{i=1}^{n}\sum_{j=1}^{m} Y_i(t)\, U_{ij}(t)S_{ij}(t)I_i(t)}$$

And

Eq. 3.23

$$\frac{C_T}{C_0} = \exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_{0}^{T} w_{ij}(t)\frac{d\ln Y_i(t)}{dt}dt\right) exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_{0}^{T} w_{ij}(t)\frac{d\ln U_{ij}(t)}{dt}dt\right)$$

$$exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_{0}^{T} w_{ij}(t)\frac{d\ln S_{ij}(t)}{dt}dt\right) exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_{0}^{T} w_{ij}(t)\frac{d\ln I_i(t)}{dt}dt\right)$$

The point of difference between various Divisia indices proposed is the calculation of the weights w_{ij}. Boyd, Hanson and Sterner (1988) proposed an arithmetic average of two end-point weights; Ang and Choi (1997) proposed a log-mean weight function; and finally, Ang and Liu (2001) argue that the preferred procedure is the logarithmic mean of the factorial value. Substituting that into Equation 3.23 at point $t^* \in [0,T]$, the following identity is derived:

Eq. 3.24

$$\frac{\mathrm{C_T}}{\mathrm{C_0}} = \exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\widetilde{w}_{ij}(t\,*)\ln\frac{Y_{i,T}}{Y_{i,0}}\right)\exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\widetilde{w}_{ij}(t\,*)\ln\frac{U_{ji,T}}{U_{ji,0}}\right)$$

$$\boldsymbol{\exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\widetilde{w}_{ij}(t\,*)\ln\frac{S_{ji,T}}{S_{ji,0}}\right)\exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\widetilde{w}_{ij}(t\,*)\ln\frac{I_{i,T}}{I_{i,0}}\right)}$$

Equation 3.24 can be re written as $D_{tot} = D_{pdn}D_{emi}D_{mix}D_{int}$ where $D_{tot} = C_T/C_0$ and the rest are the factorial effects related to each of the contributors.

To prove that Equation 3.24 is an identity (nothing remains unexplained), the right-hand side of the equation should be resolved to result to the left-hand side (Ang & Liu, 2001):

Eq. 3.25

$$\exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_{0}^{T} w_{ij}(t)\frac{\mathrm{dln}Y_i(t)}{\mathrm{d}t}\mathrm{d}t\right)\exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_{0}^{T} w_{ij}(t)\frac{\mathrm{dln}U_{ij}(t)}{\mathrm{d}t}\mathrm{d}t\right)+$$

$$\exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_{0}^{T} w_{ij}(t)\frac{\mathrm{dln}S_{ij}(t)}{\mathrm{d}t}\mathrm{d}t\right)\exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_{0}^{T} w_{ij}(t)\frac{\mathrm{dln}I_i(t)}{\mathrm{d}t}\mathrm{d}t\right)$$

$$= \exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\widetilde{w}_{ij}(t\,*)\left(\ln\frac{Y_{i,T}}{Y_{i,0}} + \ln\frac{U_{ji,T}}{U_{ji,0}} + \ln\frac{S_{ij,T}}{S_{ij,0}} + \ln\frac{I_{i,T}}{I_{i,0}}\right)\right)$$

$$= \exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\frac{L(C_{ij,0}, C_{ij,T})}{L(C_0, C_T)}\left(\ln\frac{Y_{i,T}}{Y_{i,0}}\frac{U_{ji,T}}{U_{ji,0}}\frac{S_{ij,T}}{S_{ij,0}}\frac{I_{i,T}}{I_{i,0}}\right)\right)$$

$$= \exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\frac{(C_{ij,T} - C_{ij,0}/\ln\,(\frac{C_{ij,T}}{C_{ij,0}})}{(C_T - C_0)/\ln\left(\frac{C_t}{C_0}\right)}\ln\left(\frac{C_{ij,T}}{C_{ij,0}}\right)\right)$$

$$= \exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\ln\left(\frac{C_T}{C_0}\right)\left(\frac{C_{ij,T} - C_{ij,0}}{C_T - C_0}\right)\right)$$

$$= \exp\left(\ln\left(\frac{C_T}{C_0}\right)\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}(C_{ij,T} - C_{ij,0}}{C_T - C_0} = \frac{C_T}{C_0}$$

As Ang and Liu (2001) and Ang (2004), Mendiluce, Perez-Arriaga and Ocana (2010) and Ang and Zhang (2000) also propose that both the multiplicative and additive LMDI I should be the preferred methods for energy decomposition analysis.

Given the above rationale, and the international support, this section uses the additive LMDI I method and applies it in the same way as Zhao, Ma and Hong (2010). The variables and terms to be used are defined as follows:

- E_t: total Industrial & Agriculture electricity consumption in year t;
- E_{it}: electricity consumption in sector i in year t;
- Y_t: total Industrial & Agriculture output in year t;
- Y_{it}: output of sector i in year t;
- S_{it}: output share of sector i in year t (=Yi,t/Yt);
- I_{it}: electricity intensity of sector i in year t (=Ei,t/Yi,t);

Total Industrial & Agriculture electricity consumption:

Eq. 3.26

$$E_t = \sum_i Y_t \frac{Y_{it}}{Y_t}\frac{E_{it}}{Y_{it}} = \sum_i Y_t S_{it} I_{it}$$

Change in total Industrial & Agriculture electricity consumption between year 0 and year t:

Eq. 3.27

$$\Delta\ \mathbf{E}_{\mathbf{tot}} = \mathbf{E}_{\mathbf{t}} - \mathbf{E}_{\mathbf{0}} = \Delta\mathbf{E}_{\mathbf{out}} + \Delta\mathbf{E}_{\mathbf{str}} + \Delta\mathbf{E}_{\mathbf{int}}$$

Where out denotes change in real output, str denotes structural change and int denotes intensity change, which equates to changes in efficiency. For each of the sectors, the following equation holds:

Eq. 3.28

$$\Delta\ \mathbf{E}_{\mathbf{i}} = \mathbf{E}_{\mathbf{i,t}} - \mathbf{E}_{\mathbf{i,0}} = \Delta\mathbf{E}_{\mathbf{i,out}} + \Delta\mathbf{E}_{\mathbf{i,str}} + \Delta\mathbf{E}_{\mathbf{i,int}}$$

Based on the approach followed by Ang (2004) and Zhao, Ma and Hong (2010), the above-mentioned changes are defined as follows:

Eq. 3.29

$$\Delta\mathbf{E}_{\mathbf{prod}} = \sum\nolimits_{\mathbf{i}} \mathbf{w}_{\mathbf{it}}\,\mathbf{ln}\left(\frac{\mathbf{Y}_{\mathbf{t}}}{\mathbf{Y}_{\mathbf{0}}}\right)$$

Eq. 3.30

$$\Delta\mathbf{E}_{\mathbf{str}} = \sum\nolimits_{\mathbf{i}} \mathbf{w}_{\mathbf{it}}\,\mathbf{ln}\left(\frac{\mathbf{S}_{\mathbf{it}}}{\mathbf{S}_{\mathbf{0}}}\right)$$

Eq. 3.31

$$\Delta\mathbf{E}_{\mathbf{int}} = \sum\nolimits_{\mathbf{i}} \mathbf{w}_{\mathbf{it}}\,\mathbf{ln}\left(\frac{\mathbf{I}_{\mathbf{it}}}{\mathbf{I}_{\mathbf{0}}}\right)$$

Eq. 3.32

$$\Delta\mathbf{E}_{\mathbf{tot}} = \mathbf{E}_{\mathbf{t}} - \mathbf{E}_{\mathbf{0}} = \sum\nolimits_{\mathbf{i}} \mathbf{w}_{\mathbf{it}}\,\mathbf{ln}\left(\frac{\mathbf{Y}_{\mathbf{t}}\mathbf{S}_{\mathbf{t}}\mathbf{I}_{\mathbf{it}}}{\mathbf{Y}_{\mathbf{0}}\mathbf{S}_{\mathbf{i0}}\mathbf{I}_{\mathbf{i0}}}\right)$$

Where w is the logarithmic weighting scheme, as proposed by Vartia (1976; as cited in Ang & Liu, 2001):

Eq. 3.33

$$\mathbf{w_{it} = L(E_{it} - E_{i0}) = (E_{it} - E_{i0})/ln\,(\frac{E_{it}}{E_{i0}})}$$

Such as:

Eq. 3.34

$$\mathbf{L(x, y) = (y - x)/ln\,(y/x)\,, x \neq y}$$

The production effect being equal to the 'change in production' is self-explanatory. The structural effect, however, is equal to the 'change in sectoral share' and one could argue that the sum total of this effect should be zero. However, it should be noted that the structural effect is not a simple summation. Rather, it is a summation of the weighted changes (as it is also for the production and efficiency effects) and hence the total is not equal to zero. For example, if the proportions of electricity-intensive sectors increased and the less electricity-intensive sectors decreased, the structural effect will be positive and the economic system will be considered more electricity-intensive. Lastly, the efficiency effect (also called either the intensity or technology effects in literature) refers to the 'change in the level of intensity'. A change in the efficiency effect therefore refers to the weighted change in the level of electricity intensity.

3.3.3 Decomposition applications in energy literature

Decomposition techniques have attracted increasing attention in the energy literature. Numerous studies have used this method to examine changes in energy consumption and energy efficiency, but a number of studies also applied energy examples to develop the decomposition methodology further or explain important related concepts.

Sun (1998) addressed the common problem of the existence of an unexplained residual by proposing a complete decomposition model. As an application of the theoretical model, he decomposed the world energy consumption and energy intensity for 1973–1990. This analysis was divided into four parts: a) the OECD developed economies; b) the developing economies (excluding China); c) China; and d) Eastern Europe and USSR. The three main contributing factors are: a) the activity effect (energy demand of economic activity); b) the structure effect (shift of economic groups within the economy); and c) intensity effect (changes in intensity of energy usage).

For the study period, the downward trend in the world energy intensity was influenced mainly by the intensity effect. When dividing the period into two sub-periods (1973–1985 and 1925–1990), differences can be observed. During the first period, the structure effect was negative to the decline of energy intensity while its contribution became positive to the decline of the world energy intensity. Looking at the contribution of the different country groups, the effect of developed countries was the dominant contributor of the decline of energy intensity.

Taking the analysis a step further, Sun (1998) examined the contribution of the three factors to world energy consumption. The overall period was separated into three sub-periods. The results of this exercise are presented in Table 3.12. For the first two periods, the activity and structural effects affected the energy consumption positively while the intensity effect was the only contributor on the decreasing side. This trend changed for 1985–1990, when the structural effect also influenced the consumption negatively.

Table 3.12 Summary of decomposition results (in Mtoe)

	Activity effect	**Structural effect**	**Intensity effect**
1973–1980	977.6	70.5	-419.5
1980–1985	652.17	96.43	-516.53
1985–1990	841.35	-0.48	-322.92

Source: Derived from Sun (1998)

The case of China attracted significant attention. China's energy intensity was decreasing during the 1980s and 1990s but the trend has reversed since 1998. Hence, Zhao, Ma & Hong (2010) investigated the reasons for the increase of China's energy intensity from 1998 to 2006. Their results showed that the production effect was the main reason behind the increase of approximately 20% per annum in the country's industrial energy consumption. On the decreasing side, efficiency or intensity changes contributed to a decrease of 812.27Mtoe to total change.

Also, according to Zhao, Ma and Hong (2010), it is imperative to examine the contribution of each industrial sector to each of the factors and to total change. The first important result of this analysis is that energy-intensive sectors contribute the most to changes in energy consumption. Secondly, the same sectors also contribute the most to efficiency improvements over the study period.

With regards to the other big energy consumer internationally, namely the US, Wing (2008) tries to explain the decline in US energy intensity over the last four decades of the 20th century. The results show that the sectoral composition of the economy was the main driving force of the decrease until 1973, while the decrease in intensity during the 1980s and 1990s was attributed to a substantial decline of industrial energy demand ending up 15 percentage points lower that its 1958 level.

In addition, Webber (2009) examined the aggregate energy use in the US for 1997–2002 in order to explain the 12% decrease in intensity. His results show that structural changes of the economy were the main driving force of this decrease rather than improvements in the efficiency. Two main reasons are provided for the shift in the economy’s structure: a) households were consuming proportionally more services (which are produced with less energy requirements), and b) international trade, led to the population consuming imported goods, services and energy itself.

A study focusing on the iron and steel industry of Mexico was conducted by Ozawa et al. (2002). To decompose the energy consumption of the sector, they used the output, intensity and structural effects as contributing factors. Their results point out that the considerable growth in steel production was the main contributing factor in the increase in consumption; while the structural and intensity changes would have decreased the sector's energy consumption if the production remained constant at 1970 levels.

The innovation of their study was the CO_2-emissions decomposition. The CO_2-emissions are considered to be determined by activity, structural and energy efficiency changes as well as the final fuel mix in the iron and steel industry and in the generation of power. The main contributor to the increasing side of CO_2-emissions is the same as in the first analysis: the significant increase in the sector's production. However, the fuel mix has also contributed positively to the increase of carbon emissions: if all the other factors remained constant the CO_2-emissions would have increased by 0.2MtC due to the fuel mix used.

More recently, Mendiluce, Perez-Arriaga and Ocana (2010) examined the differences between the evolution of energy intensity in Spain and the EU15 by employing decomposition techniques to identify the key sectors driving the increasing trend in Spain. The analysis was two-fold. Firstly, they decomposed energy intensity in the EU15 and Spain between 1995 and 2006 into three factors: a) structural effect; b) intra-sectoral effect; and c) residential effect. The structural effect was defined as the influence of changes in the structure of the economy; the intra-sectoral effect portrays the energy efficiency that is not dependent on structural changes; and the residential effect shows the evolution of the household energy consumption in comparison to the total GDP of the country. Their study show a number of interesting findings: a) the largest difference per sector comes from the evolution of the transport and residential sectors; b) among the industrial sectors, the main difference is contributed by the non-metallic minerals and basic metals which, in the case of Spain, are highly linked to the construction sector; c) the basic metals and chemicals present a deteriorating intra-sectoral effect which can be attributed to a price reform since 2006.

Secondly, it was important to identify how much of the overall evolution of an indicator results from a specific country if the researcher wants to compare countries with different energy profiles and economic size. Therefore, by using the same technique (Logarithmic Mean Divisia Index LMDI), Mendiluce, Perez-Arriaga and Ocana (2010) decompose the change in energy intensity in the EU15 into two effects: a) the structural change (how changes in every country's GDP influence total GDP), and b) the intensity effect (how each country's energy intensity affects the total EU15 intensity).

Eq. 3.35

$$\frac{\boldsymbol{E_{EU,T}}}{\boldsymbol{Y_{EU,T}}} = \sum_{\boldsymbol{c}} \frac{\boldsymbol{E_{c,T}}}{\boldsymbol{Y_{c,T}}} \frac{\boldsymbol{Y_{c,T}}}{\boldsymbol{Y_{EU,T}}}$$

Where $E_{EU,T} = \sum_c E_{c,T}$, $Y_{EU,T} = \sum_c Y_{c,T}$ and c represents each of EU15 countries.

The main results of this analysis are as follows:

- The changes in the economic structure did not influence the energy intensity significantly.
- A total of 61% of the energy intensity decrease in the EU15 is because of energy intensity reductions in Germany (37%) and the UK (24%).

- Spain is an exception in the studied group of countries: it contributes towards the increase of energy intensity and it is the only country that's structural effect is also a positive factor towards the increase of energy intensity.

3.3.4 Data

The study period of this part of the analysis was selected owing to data restrictions and also to avoid capturing abnormalities from the period before the country's democratisation, which occurred during 1990–1994. The analysis covers 1993–2006 and the sectoral data on electricity consumption and real output is collected accordingly.

The selection of sector level disaggregation is mainly focused towards the primary and secondary sectors due to the nature of the economy. Therefore, more emphasis is placed on the agriculture, mining and industrial sectors than on the pure service-orientated sectors. The government and household sectors are not included in the analysis. The government's output is considered to be its expenditure and this is highly influenced by the political agenda of the government of the day. As for the household sector, there is not a specific indicator of its output. The residential electricity consumption profile is also not comparable with the country's economic sectors.

Real output per sector data was collected from the *Quantec Standardised Industry Database* (Quantec,n.d.) and the data for the electricity consumption was obtained from the *Aggregate Energy Balances* of the Department of Minerals and Energy (DME, various issues). All economic measures are reported as Rand millions (constant 2005 prices) and the electricity consumption is measured in GWh.

3.3.5 Empirical results

The results of the decomposition analysis are provided in Table 3.13. It shows, among other things, the large increase in the electricity consumption in South Africa from 1993 to 2006, which amounts to a total increase of 131,024GWh.

Table 3.13 Decomposition of South Africa's total electricity consumption: 1993–2006 (GWh)

	Change in electricity consumption	Production effect	Structural effect	Efficiency effect
1993–1994	12,728	10,019	7,956	-5,248
1994–1995	12,621	10,608	8,263	-6,250
1995–1996	16,539	11,574	10,635	-5,670
1996–1997	6,232	10,059	5,972	-9,799
1997–1998	7,327	10,905	7,256	-10,833
1998–1999	6,408	10,739	6,101	-10,432
1999–2000	8,138	14,537	6,794	-13,193
2000–2001	13,476	9,171	4,923	-617
2001–2002	19,415	20,444	15,020	-16,049
2002–2003	9,000	11,542	8,125	-10,667
2003–2004	14,660	12,356	7,887	-5,583
2004–2005	2,815	11,107	5,883	-14,174
2005–2006	1,665	9,303	3,407	-11,045
1993–2006	131,024	152,364	98,220	-119,560
		116%	64%	-122%

Source: Author’s analysis

As expected for an economy that grew rapidly over the last two decades, the dominant force driving electricity consumption is the output changes. The output effect is responsible for 152,364GWh (or 116%) of the total increase in electricity consumption. This effect is to be understood in the light of the fact that South Africa has undergone major political, social and economic changes during the period resulting in a sharp increase of its economic activity. Furthermore, the structural changes (changes in the contribution of each sector to the total output of the economy) also contributed to the increase of the electricity consumption (98,220GWh or 64%).

In contrast, the efficiency effect (changes in electricity intensity) was, as expected, the only contributing factor in decreasing electricity consumption. Although both electricity consumption and total output increased substantially over the study period, increasing the overall electricity intensity of the country, the efficiency improvements were the only factor that contributed towards the reduction of electricity consumption. From this analysis, it can be concluded that the electricity intensity of the economy, although showing an increase, did so at a decreasing rate.

The efficiency improvements contributed a decrease of 119,560GWh in the total change. This implies that if it was not for the slowdown in the increase of electricity intensity, electricity consumption would have been higher by about 120,000GWh, which is the same as 120TWh (Table 3.12). This important result is particularly useful for policy-making: further improvements on efficiency are needed to intensify its decreasing influence on electricity consumption.

The overall effects of the three factors for 1993–2006 are illustrated in Figure 3.7.

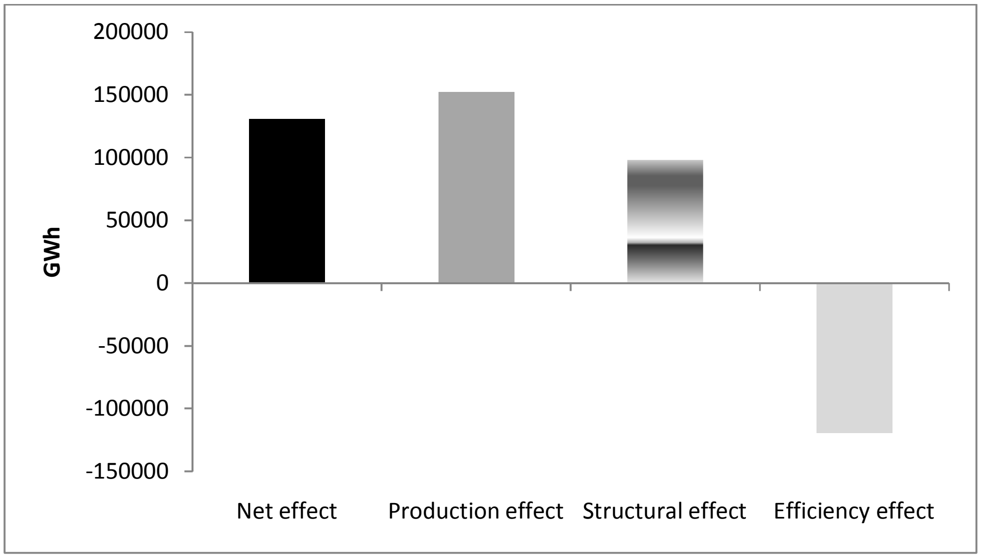


Figure 3.7 Contribution of output, structural and efficiency effects to total electricity consumption for 1993–2006
Source: Author’s estimations

The positive but declining growth rate of electricity efficiency indicates that the South African economy could be approaching the top of the electricity environmental Kuznets curve. While this is still unconfirmed, it can be stated that achieving a certain level of income growth is not sufficient to improve the total electricity efficiency levels. To accomplish such a goal, appropriate policies and institutions should be in place (Yandle, Vijayaraghavan & Bhattarai, 2002) by knowing and taking into account the contributing factors of electricity consumption and the position of the country on the electricity environmental Kuznets curve. More importantly, the results show the significance of technological improvements to electricity demand. The efficiency effect (or technology effect) is the only contributing factor towards a downward pressure on electricity consumption. This is because the technology effect can work in one of two ways (or a combination thereof), namely i) technological progress can motivate consumers to switch to other cost-effective and cleaner forms of energy, and/or ii) it could encourage them to decrease their electricity consumption. Policy-makers should, therefore, implement appropriate policies to promote technological progress and the use of cleaner forms of energy.

These results correspond with findings for China (Zhao, Ma & Hong, 2010). Their results show that efficiency improvements are the only factor that contributes towards a downward pressure on electricity consumption. This effect, however, is not enough to completely offset the high contributions of the production and structural changes that pushes up the demand for electricity.

These results, however, are different from that of a number of other studies. Studies for developed economies (Sinton & Levine, 1994; Zhang, 2003) conclude that efficiency improvements are the most influential factor to the economy-wide electricity consumption. But the results for South Africa show that the production effect is the main factor that leads to the increasing demand for electricity. Even though South Africa is an emerging economy that has seen much political change over the last two decades, the structural effect was not a dominant factor, as was the case in other developing countries (Smil, 1990; Kambara, 1992).

To gain further insight into the trends of electricity consumption, it is necessary to turn from a national level analysis to a sectoral one. This is since no two sectors' electricity consumption profile and economic activity are the same (Inglesi & Blignaut, 2010). This analysis is useful in identifying the dominant economic sectors that determine South Africa's electricity consumption trend and specify the importance of each of the factors responsible for this trend per sector.

The results are presented in Table 3.14. The sectors are organised according to their efficiency effect, with the sector in which efficiency improvements in absolute terms was the greatest listed first. In the last column, the sectors' ranking with regards to their aggregate effect to electricity consumption for 1993–2006 is provided.

The majority of the sectors, with the exception of 'mining and quarrying', 'wood and wood products', 'machinery' and 'textiles and leather', have experienced an increase in their electricity consumption from 1993 to 2006.

The top three contributors to national electricity consumption are 'non-ferrous metals' (14,089GWh), 'iron and steel' (13,027GWh) and 'chemical and petrochemical' (8,449GWh). Increases in production are part of the rising electricity usage in all the sectors of the South African economy. 'Iron and steel', 'transport' and 'non-ferrous metals' are responsible for 40% of the total production effect.

As far as the second-most important driving factor of electricity consumption (i.e. efficiency improvements) is concerned, it played a role in only five of the fourteen sectors in the reduction of electricity consumption (i.e. 'transport', 'iron and steel', 'mining and quarrying', 'wood and wood products' and 'machinery').

Table 3.14 Decomposition of South Africa's electricity consumption by sector: 1993–2006 (GWh)

	Production effect	Structural effect	Efficiency effect	Aggregate effect	Aggregate Ranking
Transport	9,168	6,805	-9,705	6,268	(4)
Iron and steel	14,767	4,291	-6,031	13,027	(2)
Mining and quarrying	3,081	-16,973	-3,603	-17,496	(14)
Wood and wood products	248	6	-437	-183	(13)
Machinery	31	-14	-98	-81	(12)
Construction	16	-1	27	42	(10)
Textiles and leather	85	-199	45	-69	(11)
Transport equipment	31	13	56	100	(9)
Paper, pulp and print	769	-28	117	857	(7)
Food and tobacco	200	-142	192	250	(8)
Non-metallic minerals	715	-326	927	1,316	(6)
Agriculture	1,563	-1,172	1,170	1,562	(5)
Chemical and petrochemical	5,082	1,385	1,982	8,449	(3)
Non-ferrous metals	8,834	1,683	3,572	14,089	(1)
Total manufacturing*	30,761	6,667	326	37,755	

Source: Author's analysis

*It includes 'iron and steel', 'wood and wood products', 'machinery and equipment', 'textiles and leather', 'transport equipment', 'food and tobacco', 'paper, pulp and print', 'non-metallic minerals', 'chemical and petrochemical' and 'non-ferrous metals'.

However, 'non-ferrous metals' which contributed much to the aggregate effect (i.e. contribution to electricity consumption) is the sector that presented the highest positive efficiency effect (i.e. a worsening of efficiency) (3,572GWh). From this it is clear that even though the national, economy-wide effects shown in Table 3.14 indicate a slowdown in the rate of increase in electricity intensity, and hence efficiency improvements, this effect is not a country-wide phenomena. It is highly sector-specific. The efficiency effect is mainly dominated by the 'transport', 'iron and steel' and 'mining' sectors which warrants closer scrutiny.

One of the transport sector's main electricity users during the early part of the study period was freight rail. This sector all but collapsed during the study period with freight transport being shifted to road and long-haul. This implies that the electricity consumption for the sector declined significantly, but the output/production did not. The South African transport sector experienced a switch from electricity to other forms of energy, such as oil/petroleum. The efficiency effect reported here is therefore not necessarily that of improved use of electricity-based transport, but rather a change in transport mode (i.e. a technology change). It is, therefore, not a *bona fide* efficiency improvement.

The 'iron and steel' sector presents an efficiency effect of 6,031GWh for the study period. This is the result of an economic change rather than a technology or efficiency change, *per se*. The overall output of the sector has increased by 143.5% for 1993–2006, while the demand for electricity increased by 70% for the same period. This might seem like an efficiency effect, while the reality is that the price formation process within the 'iron and steel' sector changed during the study period. South Africans enjoyed the benefit of having relatively cheap locally produced steel during the early part, the country was faced with steel increases during the latter part as the industry moved towards exchange rate linked (export-party) prices.

The mining sector also provides a unique example. During the period under investigation, the mines engaged in a process of co-generation whereby they started to generate their own electricity, or create smaller power units (Independent Online (IOL), 2010). Hence, their electricity demand from the national supplier has declined.

Structural change was a negative contributor to the electricity consumption of a number of sectors (eight of the fourteen). However, it contributed towards the increase of electricity consumption to the highest electricity consumers, such as ‘transport’ (6,805GWh), ‘iron and steel’ (4,291GWh) and ‘non-ferrous metals’ (1,683GWh).

3.3.6 Discussion and policy implications

The findings of this analysis show that electricity consumption is mostly affected by output changes followed by efficiency improvements and lastly, by structural changes. Also, the output changes’ contribution to electricity consumption trends increased over the years. From 1993–1994 to 1996–1997 (see Table 3.12), changes in the structure of the economy considerably influenced the increase in electricity consumption. Thereafter, efficiency improvements contributed more towards the decreasing side of the consumption. Until the end of the study period, intensity has shown a decreasing influence (lower than production effects) on the electricity consumption trend.

Although these findings present an important development, examination of the factors that affected each individual economic sector would provide useful information for the South African energy policy-makers. First, through a sectoral decomposition analysis, dominant electricity consumer sectors can be identified. The top three contributors to the national electricity consumption were ‘non-ferrous metals’ (14,089GWh), ‘iron and steel’ (13,027GWh) and ‘chemical and petrochemical’ (8,449GWh). Increases in production are proven to be part of the rising electricity usage in all the sectors of the South African economy with ‘iron and steel’, ‘transport’ and ‘non-ferrous metals’ being the main contributors.

On the decreasing side of electricity consumption, however, only five of the fourteen sectors were affected substantially by efficiency improvements while, for the rest, efficiency did not assist in the reduction of consumption. However, ‘non-ferrous metals’ that contributed much to the aggregate effect (i.e. contribution to electricity consumption) is the sector that presented the highest positive efficiency effect (3,572GWh).

Finally, the structural changes of the economy did not affect the electricity consumption in the same manner for all the sectors. For eight out of the fourteen sectors it was a negative contributor, but it contributed to the rising effect of consumption for the highest electricity consumers such as ‘transport’, ‘iron and steel’ and ‘non-ferrous metals’. In conclusion, the results show that various production sectors in the South African economy have different electricity usage profiles.

According to the decomposition analysis, the change in production was the main factor that increased electricity consumption, while efficiency improvement during the period was a driver in decreasing the electricity consumption. However, this improvement is dominated by the positive scale effect (income or population increase) and hence, it was not able to offset the influence of the output changes. This important result from the analysis is particularly useful for policy-making: further improvements on efficiency are needed to intensify its decreasing influence on electricity consumption.

The main aim of macroeconomic policies is the increase of a country's production. However, the results show that such an increase would contribute to the increase of the electricity demand, and therefore consumption, contributing to more greenhouse gas emissions. Environmental policies, including environmental fiscal reform, should therefore aim to develop the economy on an alternative growth path which will promote the reduction of electricity intensity and greenhouse gas emissions without compromising the welfare of the country as a whole.

In contrast, improving the electricity efficiency on a national level becomes the solution towards the decrease of electricity consumption. Unfortunately, for the study period, its negative effects on electricity consumption were outweighed by the high positive effects of changes in production. But the negative effect shows that there is scope for further improvement of the status quo in electricity efficiency that, in the future, will be able to neutralise or even outperform the positive effects of output increase.

According to the results, the improvement of electricity efficiency on a national level might prove to be the desired solution towards the decrease of electricity consumption without neglecting the importance of the country's economic growth. Over the study period, the efficiency improvements' impact on electricity consumption was outweighed by the high positive effects of changes in production. Moreover, the results show various inter-sectoral differences concerning electricity consumption. This necessitates the implementation of sector-specific strategies. For instance, industries such as 'non-ferrous metals' and 'chemical and petrochemical' require stricter energy efficiency policies than 'transport' and 'iron and steel', according to their efficiency effects.

After having established that electricity efficiency is an important contributing factor towards the reduction of electricity consumption, the next question is whether South Africa is able to improve its electricity intensity levels. This study proceeds by comparing the country’s electricity intensity levels at aggregate and sectoral levels to find out what the potential efficiency improvements based on international best practice.

3.4 Electricity intensities of the OECD and South Africa: A comparison

3.4.1 Introduction

Improving the electricity efficiency of a country is an important step towards decreasing greenhouse gas emissions originating from fossil fuel based electricity generation and consumption, as discussed in the previous section. Studying the intensity of electricity use (the quantitative measure of electricity efficiency) is important from an energy policy-making perspective since it is a measure that combines the electricity consumption with the economic output (Liddle, 2009). It is equally imperative for the energy authorities to understand how electricity demand will change under conditions of structural change in the economy (Markandya, Pedroso-Galinato & Streimikiene, 2006).

In the past a large number of studies were conducted to identify the dynamics, determinants and characteristics of electricity intensity in developed and developing economies (Tiwari, 2000; Andrade-Silva & Guerra, 2009; Mendiluce, Pérez-Arriaga & Ocaña, 2010; Zhao, Ma & Hong, 2010). From these studies it is derived that electricity intensity first increases as a consequence of rising economic growth and development, but subsequently falls as a result of a shift to a services-based economic structure (Medlock III & Soligo, 2001). This trend can be compared to the famous environmental Kuznets-curve (Baker, 2003; Gergel et al., 2004), but applied to electricity intensity. A general policy objective is to 'tunnel through' the curve and hence the need to compare one's own position relative to the objective. This is to be followed by policies to achieve such tunnelling.

This section seeks to answer the question whether South Africa follows the international trends regarding electricity intensity, by comparing South Africa's national and sectoral electricity intensities with the equivalents thereof of the member countries of the Organisation for Economic Co-operation and Development (OECD).

While this analysis will indicate whether there is any scope for improvement on a national level, from a South African perspective, it will also do so on a disaggregated sectoral level, providing at least two benefits. First, the economic sectors of a country have dissimilar economic and energy characteristics and it is therefore important to understand these differences (Inglesi & Blignaut, 2010). Second, not all the economies produce the same basket of goods in the same proportion. Hence, there is a need to examine the country's electricity intensity profiles on a sectoral level to be able to make comparisons as well as use the example of successful case studies (Webber, 2009).

This section proceeds as follows: a discussion of the comparative analysis in electricity intensity is provided, followed by a presentation of the data. In the last two sections, the results and their policy implications are presented.

3.4.2 Comparative analysis

Several studies concerned with inter-country comparison of electricity intensities have been conducted (International Energy Agency, 1994; Economic Commission

For Europe , 1996; Bosseboeuf, Chateau & Lapillonne, 1997). These studies have, however, encountered certain difficulties, namely:

1. the heterogeneous definition of variables;
2. the ratios to calculate electricity intensity differ from country to country; and
3. the diverse interpretations of the ratios calculated.

To avoid these problems, the electricity intensities for each country are calculated using the same definition (i.e. electricity consumption/gross domestic product (GDP)) and the information was derived from the same datasets.

The group of OECD countries is selected for four distinct reasons: a) among the OECD countries, there is a group (admittedly a small minority) of developing countries (according to IMF classification); b) South Africa should be compared to international 'best practice' in order to have the opportunity to learn and improve; c) the country's major trading partners as well as trade competitors are included in the OECD panel, hence South Africa needs to be compared against their industrialisation levels and their sophisticated energy sectors; and d) South Africa has mixed characteristics resembling that of both developing and developed countries alike. This is also recognised by the US Department of State (2010) which argues that the country has a two-tiered economy: "... [o]ne rivalling other developed countries and the other with only the most basic infrastructure". The main aim however is not to be good among the developing countries, but to be good overall. Being compared with developed countries in energy matters is therefore appropriate, given that South Africa's energy and industry sectors resembles that of the OECD.

Moreover, South Africa is one of the many non-member economies with which the OECD has working relationships in addition to its member countries. The OECD Council at Ministerial level adopted a resolution in 2007 to strengthen the co-operation with South Africa through a programme of enhanced engagement. While enhanced engagement is distinct from accession to the OECD, it has the potential in the future to lead to membership. This makes South Africa a unique developing economy and is not far from being considered a developed one.

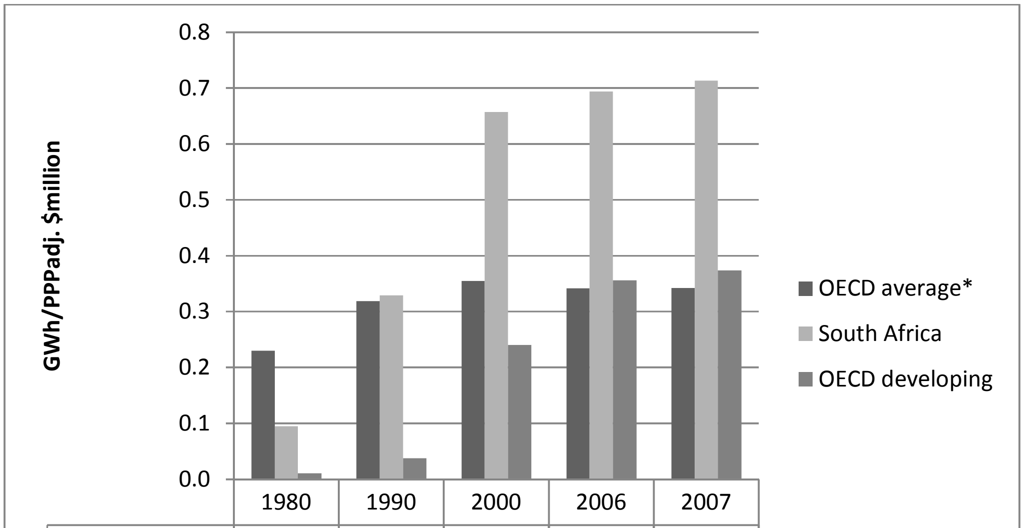
Also, the OECD's data and definitions are consolidated under one umbrella organisation. This limits the risk of data inconsistencies.

3.4.3 Data

The data for electricity consumption (total and sectoral) was obtained from the *Energy balances for OECD countries* (OECD, 2009a) and the *Energy balances for non-OECD countries* (OECD, 2009b). The national GDP data (in current prices), the Consumer Price Index (base year 2000) and the Power Purchasing Parity (PPP) adjusted real exchange rate values for all the countries were derived from the *World Economic Outlook April 2010* of the International Monetary Fund (IMF, 2009b). The disaggregated data for the output for OECD members were derived from the STAN Database for Structural Analysis of OECD .

3.4.4 Results

In 1980, South Africa’s electricity intensity was substantially lower than that of OECD countries (see Figure 3.8). This is to be expected to some extent given the high level of welfare that was enjoyed by a minority of people based on an industrial sector that serviced only a few with limited focus on exports at that point in time. Given the country’s skew income distribution, a skew electricity consumption was also presented: the higher income sectors were the most electricity-intensive too.



	1980	1990	2000	2006	2007
OECD average*	0.2302	0.3184	0.3544	0.3418	0.3422
South Africa	0.0948	0.3291	0.6573	0.6935	0.7132
OECD developing	0.0105	0.0378	0.2406	0.3560	0.3742

Figure 3.8 Evolution of electricity intensity: OECD and South Africa
Source: Authors’ calculations based on IMF (2010) and OECD (2009a and 2009b)
Note: OECD average* excludes Czech Republic, Slovak Republic and Turkey due to lack of data for 1980 and 1990.

The country’s electricity use rose sharply since the early 1990s with the abolishment of sanctions, the internationalisation of the markets to trade, and the more stable economic and political situation after the first democratic elections in 1994. After 1994, the country's export of electricity has increased and its growth has been in the economy. These facts led to a strong upwards impact on the electricity consumption and since the 1990s the electricity intensity in South Africa kept rising at an alarming rate. Currently it far exceeds that of the OECD countries with no sign of any change.

While the OECD countries kept their average electricity intensity relatively constant in the range of 0.34–0.35GWh/$ million (PPP adj.) over the period 1990–2007, South Africa's electricity intensity almost doubled from 0.329GWh/$ million (PPP adj.) in 1990 to 0.657GWh/$ million (PPP adj.) in 2000 and increased even further to 0.694GWh/$ million (PPP adj.) in 2006 and 0.713GWh/$ million (PPP adj.) in 2007.

In Figure 3.8, the developing economies of the OECD group (i.e. Hungary, Poland, Mexico and Turkey) were also extracted and their average weighed against South Africa for a better view of the country's position compared to emerging economies. South Africa's electricity efficiency was significantly higher over the years than that of the average of the OECD developing economies. Although they also showed a substantial increase from 1990 to 2000 (536.5%), the starting point in 1990 was significantly lower than that of South Africa.

Following this analysis, the OECD average was disaggregated to examine how South Africa compares with the OECD countries individually over the study period. The economy-wide percentage change of electricity intensity for 1990–2007 as well as the electricity intensity of 2007 for the OECD members and South Africa is presented in Figure 3.9.

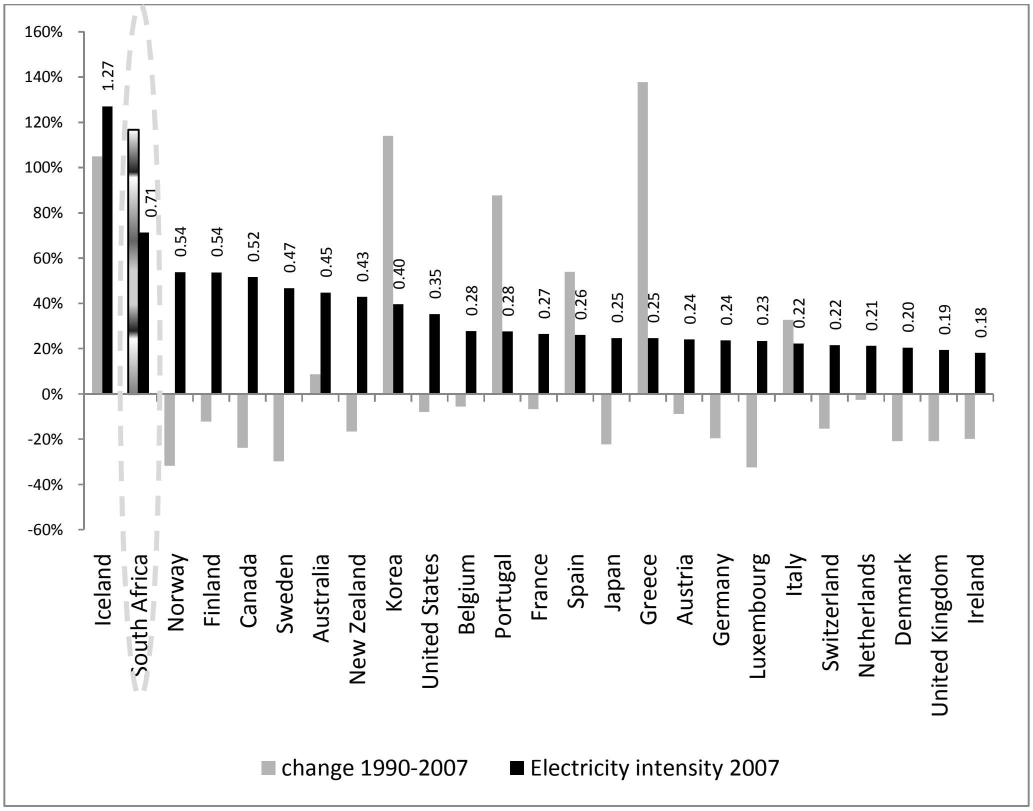


Figure 3.9 Electricity intensity in 2007 (in GWh/$millions (PPP adj)) and its growth: 1990 to 2007 for South Africa and OECD members
Source: Authors' calculations based on IMF (2010) and OECD (2009a and 2009b)

It should be noted that Poland, Hungary, Mexico and Turkey were outliers (therefore, excluded from the figure) with changes in electricity intensity for the examined period of 382%, 401%, 493% and more than 1000% (from 0.0006 in 1990 to 0.723 in 2007) respectively. Also, the Czech and Slovak Republics were excluded due to lack of data points for 1990.

From Figure 3.9 it is clear that South Africa has shown an increase in electricity intensity of 117% over the study period. This is in sharp contrast to the average of the OECD members (excluding Poland, Hungary, Mexico, Turkey, and the Slovak and Czech Republics), which showed an increase of only 10.09%. Only the Mediterranean countries (Spain, Greece, Portugal and Italy) as well as Korea and Iceland experienced an increase in their electricity intensities. Both their electricity consumption and output increased substantially, but the increase in consumption was higher than the increase in output and therefore their intensities increased sharply. All the other countries' intensity levels declined over the study period indicating remarkable improvements in electricity efficiency.

From Figure 3.9 it can also be observed that there is a statistically significant negative, or inverse, relationship between the level of electricity intensity in 1990 and its growth rate over the study period (see Table 3.15).

Table 3.15 Statistic test pertaining to the trend in electricity intensity and its growth rate

Test	Chi-square	Barlett chi-square
Statistic	3.63	3.41
p-value	0.057	0.065
Conclusion	Statistically significant	Statistically significant

Source: Author's analysis

This implies that the higher the electricity intensity of a country in 1990, generally speaking, the more negative its growth was from 1990 to 2007. Countries such as Norway, Canada and Sweden, which were the most electricity-intensive in 1990, managed to decrease their intensity of electricity consumption meaningfully, namely by 32%, 24% and 30%, respectively. This is in contrast with Italy, Portugal and Greece, which had the lowest intensities in 1990, but the highest increases.

South Africa, however, does not fit this trend well. It had an average electricity intensity in 1990 and yet it had the second highest increase (after Greece) in its intensity (117%).

Figure 3.10 presents the South African intensity in 2007 and its growth since 2000 in comparison with only the developing countries of the OECD group: Hungary, Mexico, Poland and Turkey.

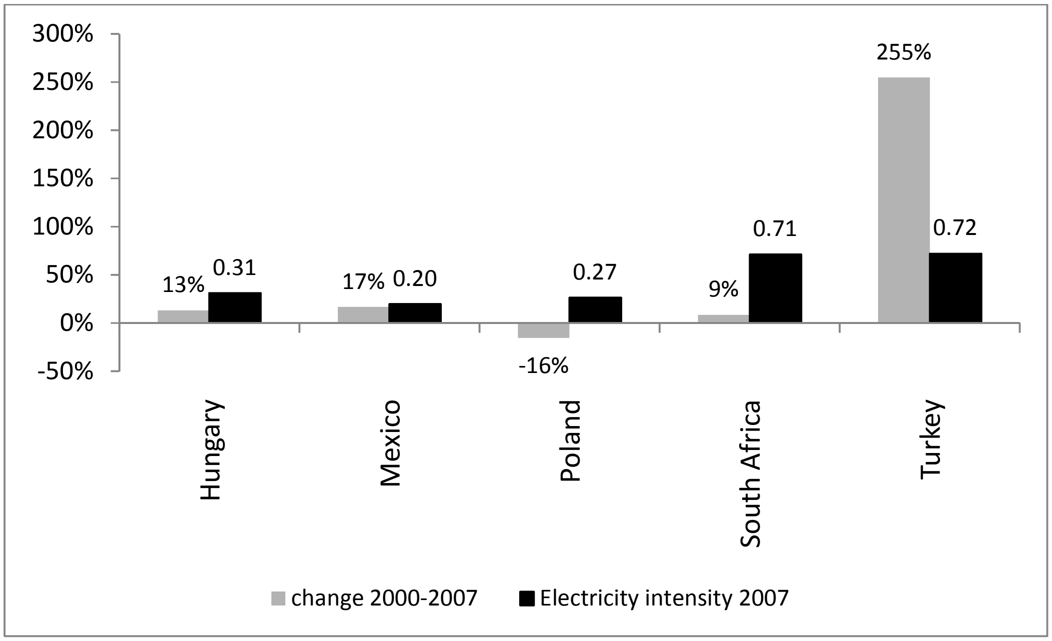


Figure 3.10 Electricity intensity in 2007 (in GWh/$ million (PPP adj)) and its growth: 2000 to 2007 for South Africa and OECD developing countries
Source: Authors' calculations based on IMF (2010) and OECD (2009a and 2009b)

Figure 3.10 depicts a rather dismal picture for South Africa's electricity intensity compared to the developing countries of the OECD. Its growth for 2000–2007 was significantly less than that of Turkey (255%) and less than Hungary and Mexico (13% and 17% respectively). However, Poland managed to reduce its electricity intensity by 16% for the same period. It is interesting to see that South Africa and

Turkey had similar intensities in 2007 (0.71 and 0.72), but Turkey increased sharply (255%) to 'catch up' with the South African level. South Africa, therefore, does not follow international trends in this regard either.

Such a comparison might not do justice to the relative growth of the countries. What is of importance is also to be able to take into account the different starting or ending years. For instance, two countries might present the same growth rate for a certain time period but the one's electricity intensity at the end of the period might be substantially higher than the other's. For this study, South Africa is the country to be compared with the rest. Hence, in order to take into account both the changes as well as the final electricity intensity levels of the respective countries over the study period, the weighted growth rate is calculated for each of the countries. This was done using Equation 3.36 and normalising the answer so that South Africa's growth equals 1. The results are presented in Figure 3.11.

Eq. 3.36

$$\mathbf{Weighted\ growth}_{\iota} = \frac{\mathbf{electricity\ intensity}_{\mathbf{i,2007}}}{\mathbf{electricity\ intensity}_{\mathbf{SA,2007}}} \times \mathbf{real\ growth}_{\mathbf{i}}$$

Where electricity intensity,i,2007 is the electricity intensity of country i in 2007; electricity intensity SA,2007is the electricity intensity of South Africa in 2007 and real growth i is the (positive or negative) growth of electricity intensity of country i from 1980 to 2007.

The weighted growth of electricity intensity per country takes into account that

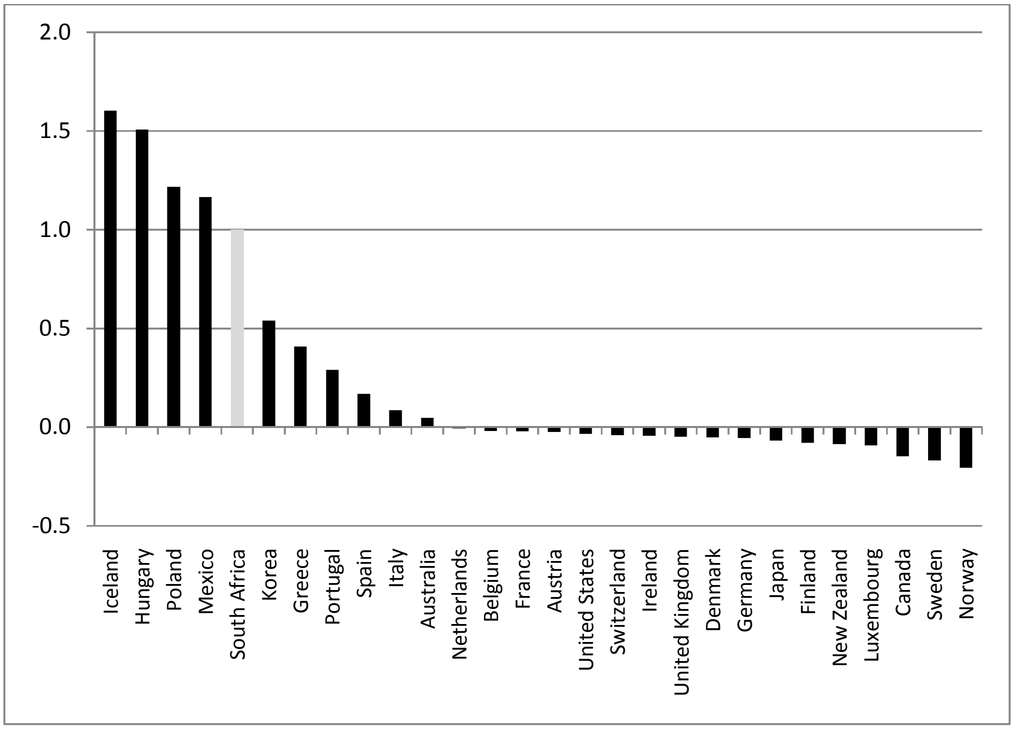


Figure 3.11 Weighted electricity intensity growth relative to South Africa's electricity intensity (where SA (2007) = 1)
Source: Authors' calculations based on IMF (2010) and OECD (2009a and 2009b)

From Figure 3.11 it can be seen that the only countries that performed worse than South Africa were Iceland and the developing OECD countries (Hungary, Poland, Mexico and Turkey with the last being excluded from the graph as an outlier). All the other OECD members' (excluding the outliers as discussed for Figure 3.9) weighted growth was either positive, but lower than South Africa (six of the twenty-eight countries), or negative (seventeen of the twenty-eight countries). The results from Figures 3.9–3.11 clearly indicate that South Africa's electricity intensity was not only higher than the majority of OECD countries in absolute terms (for 2007), but also showed an excessive increase for the period 1990 to 2007, compared to the rest of the countries in the study group. The next question that arises is whether or not this trend and big difference to OECD countries holds true for all the economic sectors of South Africa.

To investigate the differences among the industrial sectors, Table 3.16 presents the average sectoral electricity intensities for South Africa and the OECD in 2006 and their differences. The last column presents a weighted difference relative to the output shares of each sector and was calculated as shown in Equation 3.37.

Eq. 3.37

$$\mathbf{Weighted\ difference}_{i} = \frac{\mathbf{sector's\ output\ share_{OECDave}}}{\mathbf{sector's\ output\ share_{SA}}} \times \mathbf{difference}$$

Where sector's output share OECD ave is the average output share of sector i in the OECD economies in 2006; sector's output share SA is the share of sector i in South Africa in 2006 and difference i is the percentage difference of electricity intensity between South Africa and the average of the OECD members in 2006.

The majority of the South African sectors were more electricity intensive than the OECD average. Only four of the thirteen sectors were more efficient than the OECD, namely 'construction', 'food and tobacco', 'machinery' and 'transport equipment'. The order of magnitude in which they outperformed their OECD counterparts was, on average, 150.5%. This is in stark contrast to the degree in which the sectors with worse intensity levels compared to their OECD counterparts, namely 980.7% – a 6.5-fold difference.

'Basic metals' have the highest electricity intensity in both South Africa and the OECD countries. Comparatively speaking, however, South Africa's 'basic metals' sector was significantly more intensive (886%) than the OECD average before adjusting it to its respective size (or contribution to output) (644%).

Table 3.16 Sectoral electricity intensities in 2006: South Africa and OECD

Sectors	South Africa		OECD		Difference	Weighted relative to output difference
	Electricity intensity	Output share	Electricity intensity	Output share		
Agriculture and forestry	0.316	6.00%	0.016	4.00%	1870.90%	1242.40%
Basic metals*	1.095	7.10%	0.111	5.10%	887.30%	644.20%
Chemical and petrochemical	0.203	16.30%	0.034	15.20%	494.70%	462.90%
Construction	0.002	10.50%	0.087	16.60%	-97.90%	-155.90%
Food and tobacco	0.021	12.00%	0.023	8.30%	-11.30%	-7.80%
Machinery	0.005	2.90%	0.028	15.00%	-81.20%	-416.90%
Mining and quarrying	0.634	14.60%	0.026	3.00%	2305.60%	482.10%
Non-metallic minerals	0.524	1.60%	0.02	2.00%	2517.70%	3169.70%
Paper, pulp and printing	0.207	2.80%	0.021	5.50%	891.50%	1758.60%
Textile and leather	0.067	2.50%	0.01	1.90%	548.80%	398.30%
Transport equipment	0.003	9.80%	0.004	10.50%	-20.10%	-21.70%
Transport sector	0.089	12.50%	0.013	11.20%	563.40%	505.70%
Wood and wood products	0.069	1.40%	0.027	1.50%	153.60%	162.50%

Note * Includes ‘iron and steel’ and ‘non-ferrous metals’

The most efficient sector was ‘construction’, mainly owing to its high labour intensity and lower use of electricity-demanding technologies. On top of that the South African ‘construction’ sector was significantly more efficient than the OECD average. The reasons why the ‘construction’ sector was more efficient compared to the rest can only be speculated owing to a number of inter-linked factors – one of them being the labour intensity of the sector. Also, all the South African sectors are more labour intensive in comparison with the OECD countries, especially 'construction', which is 600% higher than its OECD equivalents. The difference of the rest of the South African sectors to the OECD ones was in the range of 100–300%. The weighted difference shows that the South African intensity was 156% lower than the OECD average.

While the most electricity-intensive South African sectors (i.e. 'basic metals' and 'non-metallic minerals') present high differences compared to the OECD average (644% and 2517%), 'mining and quarrying' does not follow suit. The South African electricity intensity was 2305% higher than the OECD average. However, considering that the South African mining sector is a dominant one for the economy (14.6%) while it is a very small proportion of the OECD production (3%), the weighted difference is considerably lower (482%), albeit still very meaningful.

3.4.5 Discussion and policy implications

It is evident from the above analysis that South Africa's electricity intensity was at a much higher level than that of the OECD countries and that the gap between South Africa and the OECD is increasing at an alarming rate. While distressing, it also points towards the available scope for improvement. Not only is there scope, but it will also be necessary if South Africa is to remain competitive and trade with its OECD counterparts under the more stringent trade regimes, including carbon and climate change considerations, given that South Africa's electricity sector has a large carbon footprint (Blignaut, Mabugu & Chitiga-Mabugu, 2005; Van Heerden et al., 2006).

South Africa has shown an increase in electricity intensity over the study period of 117% – more than doubling its electricity intensity from 0.32 to 0.71GWh/$ million (PPP). This is in sharp contrast to the average of the OECD members (except Poland, Hungary, Mexico, Turkey and the Slovak and Czech Republics), which was only 10.09%. After weighing the growth by taking into account the different starting levels in 1990, it was evident that South Africa's performance was significantly worse than that of the OECD member states.

The economy-wide results show that South Africa is perhaps slowly reaching the level of development that would place it at the top of the environmental Kuznets curve with a positive but declining growth rate of efficiency. Moreover, the main objective of countries is to tunnel through the curve. It is, therefore, important to know what the aim is and be compared with countries with improved conditions, that is countries on the 'other (or downhill) side' of the curve. Furthermore, reaching a certain development level or income growth is a necessary but not sufficient condition to improve the country's electricity efficiency levels. As Yandle, Vijayaraghaven and Bhattarai (2002) argue, the improvement of efficiency levels and the environment together with economic prosperity is not automatic but relies on appropriate policies and institutions. Hence, high-income economies that do not have the necessary and appropriate policies in place are placed on their way down the Kuznets curve in contrast to South Africa.

In order to identify the possible differences between the economic sectors of the OECD members and those of South Africa, the differences between the South African economic sectors' electricity intensities and their equivalent of the OECD countries are examined. Nine of the thirteen South African sectors are more intensive than their OECD equivalents, and by a considerable margin. Although 'basic metals', 'mining and quarrying' and 'non-metallic minerals' were the most electricity-intensive sectors, they presented the greatest gap between South Africa and the OECD, with these sectors in the OECD being more efficient. It was also observed that the economic sectors' electricity efficiency behaviours are radically different. Therefore, a sector-specific approach is required to improve efficiency levels in South Africa.

Next it is necessary to identify possible reasons that led the South African electricity intensity to a worse position than the OECD members (both developed and developing). One possible reason might be the low and stable prices of electricity in the country for the study period. South African producers were not concerned with electricity efficiency given the relatively low price levels of electricity over the period. Figure 3.12 plots the average electricity prices in comparison with the total electricity intensity in South Africa for 1993–2005.

Figure 3.12 illustrates the existence of low and stable electricity prices for 1993–2002; while price restructures are responsible for the structural break in 2002 and 2003 where the prices increased by 182% (DME, 2010b). In contrast, the electricity intensity has been increasing since 1993 but at a decreasing rate, especially after the rise of the electricity prices. The period 2005–2006 was characterised by a notable decrease in the electricity intensity of 8.4% while the prices increased by only 3.5% in the same period.

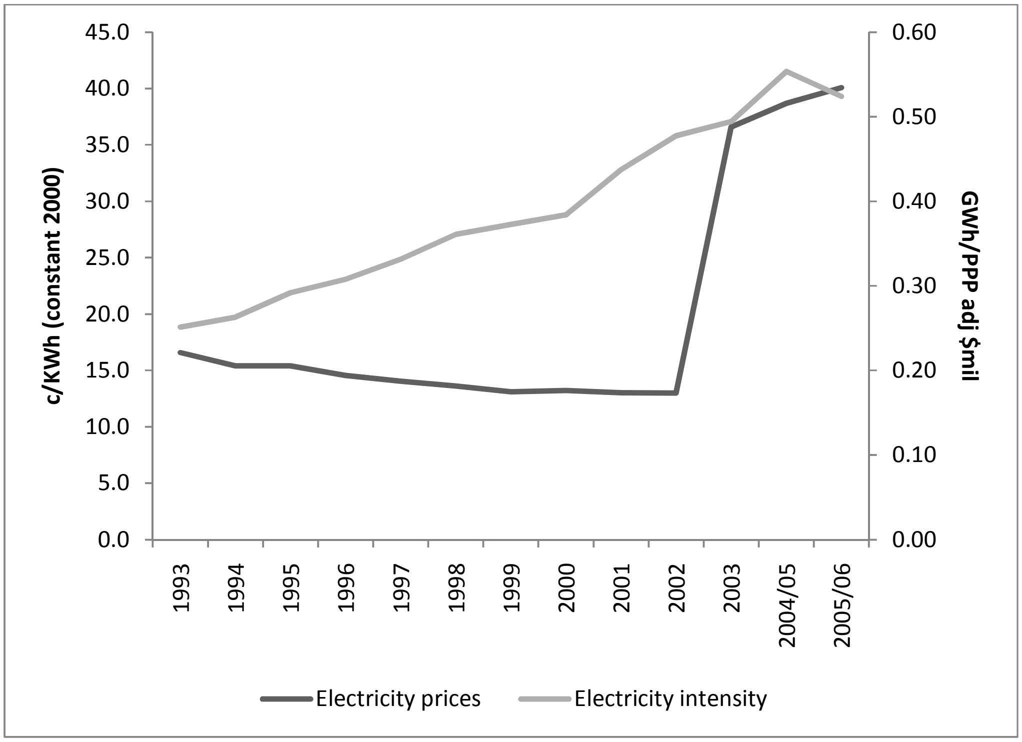


Figure 3.12 Electricity intensity and electricity prices in South Africa: 1993–2005

Source: DME (2009) and authors' calculations based on IMF (2010) and OECD (2009a and 2009b)

There are two possible reasons for this change. First, the electricity prices increased by 182% in 2003 and the drop in electricity intensity (caused by a decrease in electricity consumption) might be considered the lagged impact of the high increase in electricity prices. Second, the South African Department of Minerals and Energy released its first *Energy Efficiency Strategy* in 2005 (DME, 2005a). The purpose of this strategy was to provide a policy framework toward affordable energy for all and diminish the negative consequences of the extensive energy use in the country. Its national target for electricity efficiency was to improve efficiency by 12% by 2015. From a policy perspective, this document might also be the cause of the decrease in 2005–2006. However, it did not have the desired effects to date and is currently being revised.

3.4.6 Conclusion

The study of the efficiency of electricity use has recently become an important topic owing to the linkage of high electricity consumption with the negative consequences of greenhouse gas emissions. The energy policy-makers should take into account the electricity efficiency of the economy because it is a measure that combines the electricity consumption with the economic output (Liddle, 2009).

South Africa’s electricity intensity more than doubled from 1990 to 2007 (from 0.329 to 0.713) and the country’s weighted growth was higher than the majority of the OECD members by a considerable margin. In addition, nine of the thirteen South African economic sectors are more electricity intensive than their OECD counterparts.

It therefore became apparent that for South Africa to reduce its electricity intensity it has to either reduce its electricity consumption or increase its production while keeping its electricity consumption stable. This can be done through a concerted industrial policy to enhance the use and development of electricity efficient appliances. Electricity price reform, as was recently announced, whereby the electricity price level is significantly increased in conjunction with block rate tariffs which charges a higher rate to those that consume more, is also vital. A nation-wide demand-side management programme is also essential in the wake of these results in order to improve efficiencies.

3.5 Summary of empirical evidence

The main purpose of Chapter 3 was to examine the electricity efficiency and consumption in South Africa over the last three decades. The main results can be summarised as follows:

- The electricity consumption was not highly affected by electricity prices during the years before the recent price restructure because the prices were relatively low and stable. On the contrary, in the 1980s when the real prices were higher, the price elasticity was close to negative unity.
- The situation in the disaggregated analysis was not dissimilar. Only the industrial sector (as a whole) presented a significant negative price elasticity while all the rest of the sectors presented a lack of behavioural response with regards to changes in electricity prices.
- Trying to determine what the contributing factors of the period were, the decomposition analysis showed that output and structural changes intensified the electricity consumption; while efficiency improvement is the only contributing factor on the decreasing side of consumption.
- Finally, the comparative analysis concluded that South Africa not only presented a higher electricity intensity than the majority of the OECD members but the gap has been continuously increasing.

This analysis has shown that there is a need for new methods targeting the improvement of the electricity efficiency of the country that will result in lower electricity usage and hence, reduction of the GHG emissions. The next chapter presents the solution proposed in this thesis.

4 PROPOSED SOLUTION: BENCHMARK-AND-TRADE MODEL

4.1 Introduction

The previous chapters evaluate the situation of the electricity demand and efficiency in South Africa. Although the picture presented is rather dismal, there is scope for improvement at the economy-wide level as well as the sectoral level. This chapter presents the thesis' proposed solution to the problem of the high and increasing electricity intensity of the country: a sectoral benchmark-and-trade system.

Benchmark-and-trade systems aspire to steadily improve the participants' environmental performance by targeting certain indicators such as the greenhouse gas emissions (GHG) or particularly CO_2-emissions. They do so by awarding the successful participants with monetary incentives through trading with the less successful ones. As Fell, Mackenzie & Prizer (2008) state, from an economic viewpoint, these systems aim to internalise the externality of emissions by creating a market.

In the application of the proposed benchmark-and-trade system, the target indicator is the electricity intensity and the participants in the trading are various important sectors from both an environmental and an economic viewpoint. The purpose of this chapter is to present the theoretical system, discuss its characteristics in comparison with past international applications and illustrate, with examples, how the system would operate as well as its possible benefits or losses comparing it to the alternative of carbon tax.

The chapter proceeds as follows: Section 4.2 discusses the proposed theoretical mechanisms while Section 4.3 presents a few scenarios based on the implementation of different benchmarks for the initial phase of the programme under different price assumptions. Section 4.4 discusses the advantages of a benchmark-and-trade system to carbon tax; while Section 4.5 analyses whether or not the proposed system has all the desired characteristics to be successful. The final section summarises and concludes.

4.2 Theoretical system

Firstly, it is imperative to comprehend how a benchmark-and-trade system operates theoretically as well as to analyse its main elements, in order to be able to propose it for the South African case. Choosing the target indicator is the most essential decision for the future successful implementation of the system. As was discussed in the Chapter 2: Literature review, the majority of the previously used or proposed cap-and-trade systems, whether they are still in effect or not, aim at the reduction of different types of greenhouse gas emissions, such as CO_2 and SO_2.

With these indicators targeted, the systems deal with the harmful results of a specific action, that is to consume energy. Looking at the picture holistically however, it might prove more beneficial to target the cause behind the problematic conditions and not the results. In South Africa where the generation of electricity is in its majority dependent on coal burning, the main reason for the high emission levels is considered to be the consumption of electricity.

Taking this into account, the proposed system aspires towards the reduction of electricity consumption without ignoring the decisions regarding the participants' economic output. Hence, the system's main objective is the reduction of electricity intensity of the South African industrial sectors where electricity intensity has been defined as the ratio between the electricity consumption of the sector and its output.

Apart from the targeted indicator, the success of a benchmark-and-trade system is highly dependent on its good design and on three other essential decisions (Shammin &Bullard, 2009):

- The determination of the level of the benchmark.
- The definition and allocation of tradable credits/allowances.
- The formula for the initial distribution and trading of the credits/allowances.

In the proposed model, the benchmark is chosen to be subject to the average of the OECD members for each sector. The group of OECD countries is selected because South Africa needs to be compared with international 'best practice' in order to have the chance to learn and improve. Moreover, the South African electricity sector resembles that of advanced economies' and hence, needs to be compared against their industrialisation levels and sophistication.

However, the majority of the South African sectors' electricity intensity is substantially worse off than their OECD counterparts. Given the fact that the difference is immense, the proposed standards should initially reach lower goals.

Next, it is important to discuss the definition and allocation of credits/allowances in the system. As Braun (2009) points out, in some systems the members receive allowances depending on their historical performance adjusted for the programme's benchmark. The benchmark usually decreased through the consecutive phases (APX Power Markets, 2008).

Taking into account the important and desirable principles of administration ease and transparency, the proposed system suggests a straightforward method to determine the credits/allowances to be traded. Using a *grand-fathering* method, the regulator allocates credits/allowances to each sector per phase based on their performance during the previous phase. For every percentage of difference between the South African and the benchmark's electricity intensity, one credit/allowance is assigned (either to be supplied or demanded by the sector).

Evaluating the benchmark and targets recursively in the beginning of every phase shows that it will be not enough for the sectors and the country in its entirety to reach a specific target in the first period only. The increasing efficiencies of the OECD members due to their choices of newer and more efficient technologies will motivate the South African sectors to always keep up with these improvements.

This approach ensures, firstly, that each sector is being assessed based on its comparative performance to a standard benchmark, and secondly, that at any given time the participants are aware of the levels of their targets.

Following the traditional decision-making tree for benchmark-and-trade systems, Figure 4.1 presents a picture of the decisions of a participant in the proposed system. The first question to be answered is of strategic importance because it classifies the sector as a 'buyer' or 'seller' of credits/allowances. In case the electricity intensity is above (below) target, which means that South Africa is worse (better) off, the sector will act as a buyer (seller) in the trade.

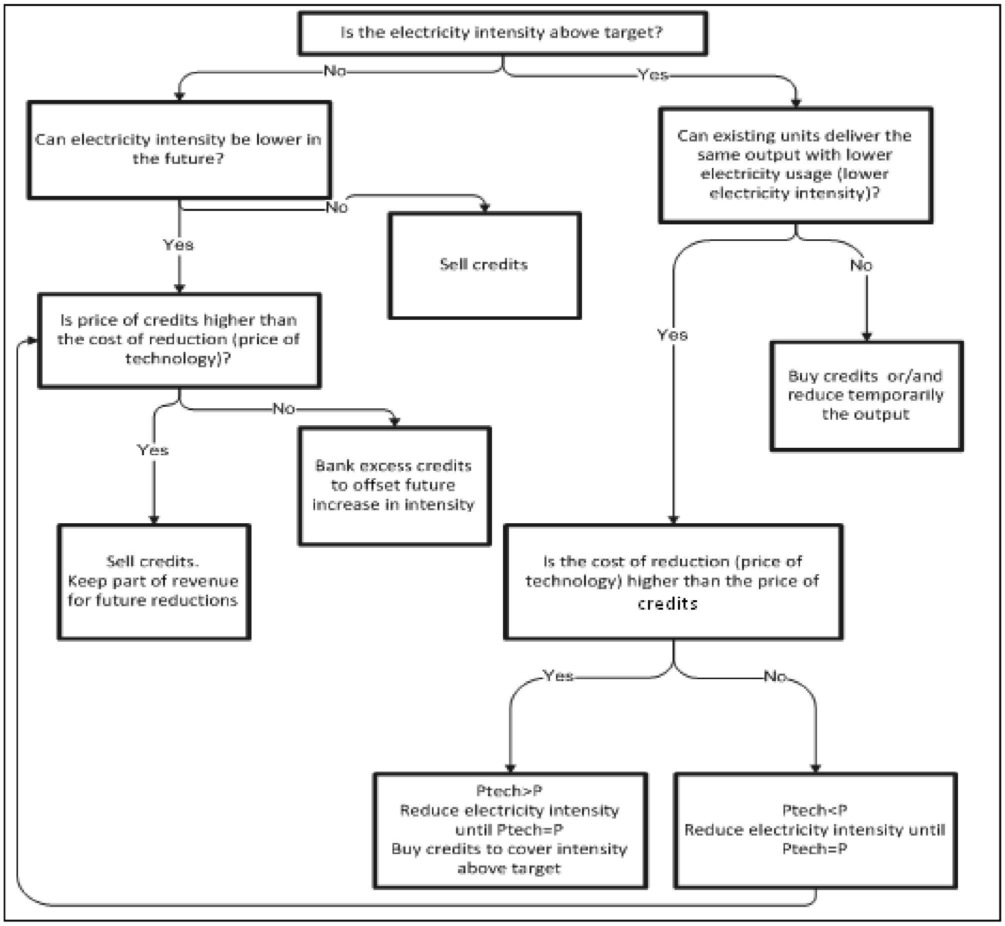


Figure 4.1 Participants' decision-tree in the proposed benchmark-and-trade system

Note: Firstly the participants need to answer the question of whether their intensity is above or below the set target. That defines them as sellers or buyers in the market. In case they are sellers (intensity lower than benchmark), they should evaluate if their intensity can lower in the future: if no, then they sell credits; if yes, the price of credits should be higher than the price of technology in order to sell; otherwise they bank the excess credits. Similar events occur in the case of a buyer of credits. If the electricity intensity can lower in the future then, depending on the comparison between the price of technology and the price of credits, the participant either buys credits or reduces its electricity intensity. If, on the other side, the electricity intensity cannot be reduced, the sector is obliged to buy credits.

Next, the participant, either a buyer or a seller, faces a question about its potential of reducing its electricity intensity further in the future or not. This question's significance lies with the fact that this system aims to improve the sectors' electricity efficiency levels without affecting their economic output.

Finally, the third question posed to the participants is concerned with the cost of reduction or the price of technology needed to decrease the levels of electricity intensity.

All-in-all, Figure 4.1 introduces important new elements to the discussion: a) the opportunity of banking credits/allowances, and b) the concept of the cost of reduction or the price of technology.

With regards to banking, Stavins (2008) states that it is imperative for the participants to be allowed to bank and/or borrow credits between different (consecutive) time periods, within the same phase. This can decrease the uncertainty and allow the sectors to make informed choices before deciding to reduce their intensity depending on the costs of the specific time period. To avoid injustice however, banking and borrowing are only allowed within a single phase. This way, the sectors are evaluated based on their performance in the previous phase in comparison with the OECD performance without taking into consideration strategic decisions within the market and exogenous factors affecting the decisions in the short-run.

The second concept introduced by Figure 4.1 is the price of technology. It can be explained as the cost to a sector or a company to replace its current production methods with newer, more advanced and more efficient technologies. This cost can vary from one time period to another depending on various factors such as the openness of the economy that will allow the transfer of new technologies.

Moreover, in high levels of efficiency, even better technologies become scarce and hence, more expensive. The price of technology is a contributing and key factor to the representation of the total supply curve of credits/allowances.

The International Energy Agency (IEA) has developed an energy efficiency database, entitled INDEEP, under the IEA DSM agreement (http://dsm.iea.org) in 1994. This database includes and evaluates the quality of 229 programmes from 14 countries aiming at the improvement of energy efficiency.

The most common technologies employed are presented in Figure 4.2.

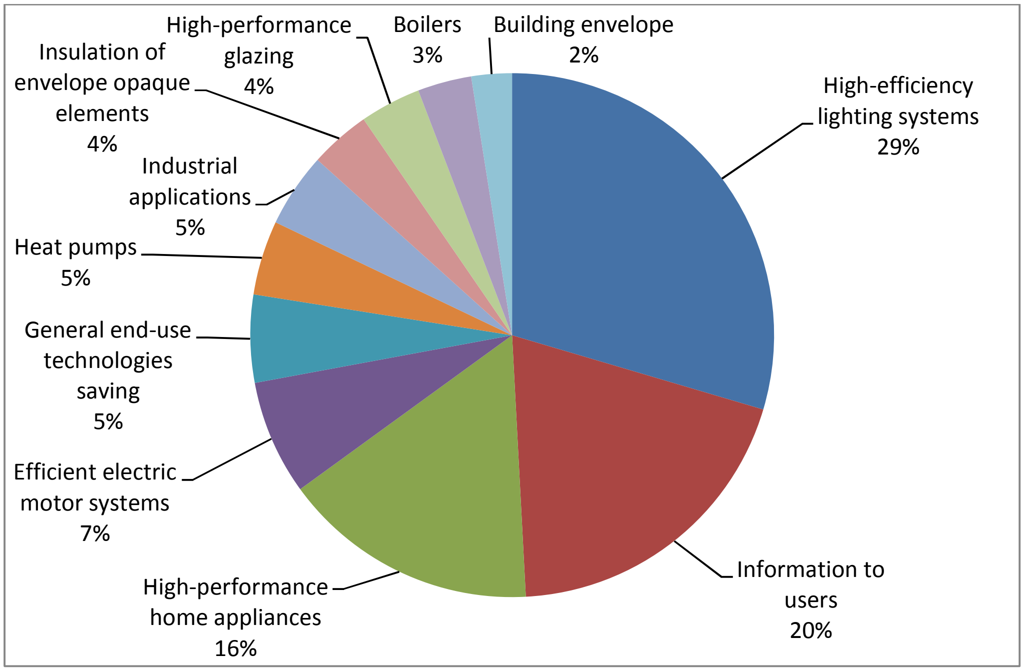


Figure 4.2 Number of programmes by type of technology used
Source: International Energy Agency (2004a)

Figure 4.2 shows that 29% of the programmes produce energy savings by using more efficient lighting, while immaterial techniques such as improved information to the users are preferred by 17% of the programmes (International Energy Agency, 2004a).

The costs of these technologies, according to INDEEP (2004), include utility costs and non-utility costs. Only 94% of the programmes included in the database had cost data available: 60% annual cost data and 40% cumulative cost data. The majority of the programmes cost between 100,000 and 1 million Euros but depending on the specific characteristics, they can cost up to 100 million Euros (Figure 4.3).

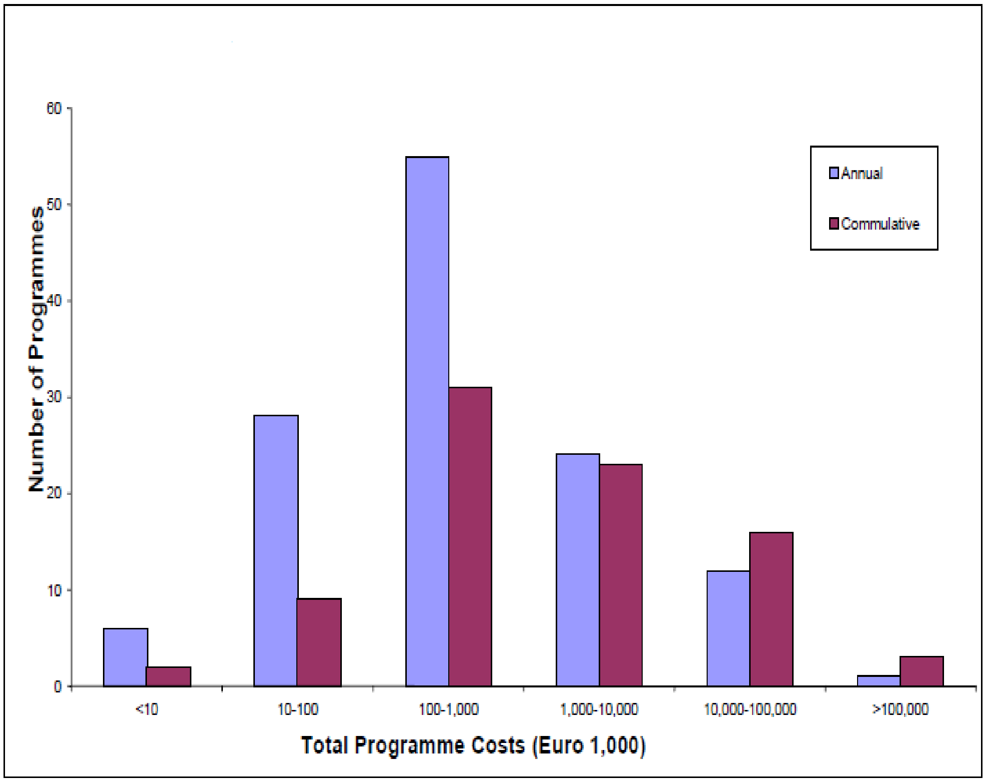


Figure 4.3 Number of programmes vs. total programme costs
Source: INDEEP database (2004)
Note: The costs are shown in Euros (exchange rate date 1/1/2000) and are spread out over the period 1993 to 1999.

The results depicted in Figure 4.3 confirm the fact that the cost of technologies aspiring to improve energy efficiency varies broadly and hence, it is not possible to be quantified per sector and per time period.

Eventually, the market created will have numerous similarities with an oligopoly. Firstly, under an oligopoly there are few suppliers (sectors) and each of them is influenced by the actions of the others. In the proposed model, only sectors that are better off than the standard can be suppliers in the trade.

Another similarity is the existence of barriers to entry. In this case, the market's rules and regulations create the barriers by defining which sectors are suppliers and which are consumers of the credits based on their comparative performance. Hence, a sector cannot become a supplier later in a particular phase.

The overall relationship of the price and the quantity of credits/allowances supplied follows basic economic theory: the higher the price, the higher the quantity supplied. However, the behaviour of the sellers (suppliers) changes depending on price of the technology compared to the price of the credits/allowances.

For as long as the price of the credits/allowances is lower than the price of technology, the supply curve is relatively inelastic (Figure 4.4). That is for every given increase in price, the increase of quantity supplied is smaller ($-1<e<0$). When this inequality holds, the suppliers lack incentives to sell credits because the revenue from the sales cannot cover the potentially desirable change in technology.

Conversely, if the price of credit becomes higher than the price of technology, the suppliers react with higher increases of the quantity supplied for the same percentage increases of price (supply curve relatively elastic, $-\infty<e<-1$). If this inequality holds the suppliers have additional motivation to sell credits in order to achieve profits.

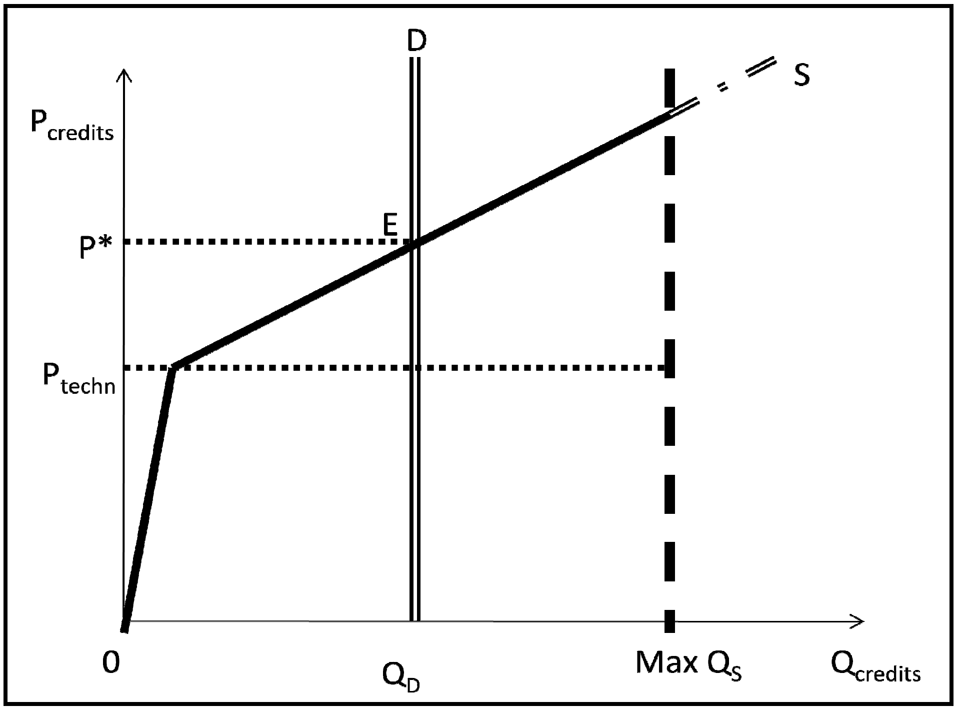


Figure 4.4 Total demand and supply of credits/allowances
Note: The equilibrium price (P*) of a hypothetical market of credits/allowances is presented here, showing the interaction between the demand curve (D) and supply curve (S) for credits. The supply curve (S) is presented to be relatively inelastic for prices lower than the price of technology (P_{techn}): no motivation for the suppliers to sell credits. For prices higher than the price of technology, the supply curve becomes relatively elastic: the increase of quantity demanded is higher than the increase of price that caused it. The dotted line (max Q_s) shows the maximum quantity of credits that can be supplied. Hence, any quantity higher than this cannot be provided by the suppliers; then the regulator should intervene in the market. On the other side, the demand curve is not dependent on price since the sectors to demand and the amount of credits is determined by the design of the system. Point E shows the equilibrium position of the market where price is equal to P* and the traded quantity is Q_D.

It can also be seen that the supply cannot increase indefinitely. This is due to the method of determining the credits/allowances based on their difference to the

OECD industrial sectors' electricity intensity: there are a specific number of credits to be traded in the market.

In order to be able to determine the price of the credits/allowances, the total demand curve is also required. Contrary to the supply, the total demand of credits/allowances is constant and independent of the price. The sectors whose electricity intensity is higher than the benchmark are obliged to buy the necessary credits/allowances as a form of a fine for their performance. Hence, the quantity demanded in the market is constant (Figure 4.4).

Figure 4.4 presents the market including both total supply and demand curves to show how the price of the electricity intensity credits/allowances is determined. The equilibrium price (P*) is depicted at point E where the total demand and supply curves cross each other. In other words, that is the maximum price that the consumers (buyers) are prepared to pay per credit.

The system applies first-degree price discrimination, which is defined as the situation "when each consumer is charged the maximum price he or she is prepared to pay for each unit of the product" (Fourie and Mohr. 2007). Hence, the price in this simple equilibrium is P* for each credit.

The situation presented in Figure 4.4 is not the only possible setup in such a benchmark-and-trade system. Depending on the standard chosen, the constant demand curve might cross the supply curve before the point where elasticity changes. That would mean that the equilibrium price (maximum price consumers are prepared to pay) would be lower than the price of technology.

It is also likely that the total demand curve (also representing the maximum quantity of credits/allowances demanded) is on the right side of the line showing the maximum quantity supplied. In that situation, a shortage of credits/allowances will exist since the amount of credits/allowances that can be supplied in the market cannot cover the demand for credits/allowances from sectors whose electricity intensity is higher than the standard chosen (both scenarios are presented in the following section in detail).

In circumstances like these, the role of the regulator is significant not only for the smooth implementation of the system but also for its interference in the trade. As mentioned before, the sectors whose intensity is above the target are obliged to buy credits/allowances from other sectors. However, in this case, the rest of the sectors are not in possession of more credits/allowances to supply; hence, the consumers will need to purchase credits/allowances from the regulator. The lowest price charged by the regulator would be P* but a higher price might be charged in order to motivate the sectors to improve their electricity intensity levels.

Next, an application of the theoretical system is presented and discussed by showing different possible standards.

4.3 Results

In this section, South African and the OECD electricity intensity data are employed assuming that 2006 is the starting year of the first phase. Before describing the analysis, it is significant to mention that the model is presented for a better understanding of how a system such as the one proposed would operate in real life. However, it can only be hypothetical because with the information available, the price of credits/allowances cannot be determined numerically. The price can only be identified comparatively with the price of technology, which is also difficult to be estimated for two reasons:

- The cost of production technology the participants use is difficult to be estimated and/or changes in the short-run.
- The cost of technology that will enhance the electricity efficiency of the participants varies.

Therefore, the price elasticities presented are all hypothetical and subject to alterations in reality and three different scenarios for the price of the credits are discussed.[7] The main scenario assumes that the price of the credits is equal to the carbon tax on electricity generated imposed by the South African government of R0.02 per kWh consumed; while the other two scenarios assume conditions where the price is lower and higher than the carbon tax by R0.01/kWh, respectively.

The difference between the sectoral intensities of South Africa and the OECD is substantial and could possibly not be covered in one phase. Hence, different scenarios for Phase I of the system are proposed. The benchmarks after the implementation of Phase I will have to be re-estimated taking into account the progress both the South African and the OECD sectors made during Phase I.

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[7] The reason why the sectoral price elasticities of section 3.2 were not used is that, with the exception of the overall industrial sector, the elasticities were not statistically significant and hence, not accurate for being used any further.

Each standard is a proposition on how the trade will be in Phase I. The standards to be discussed are as follows:

- Standard 1: 20 times the OECD electricity intensity
- Standard 2: 10 times the OECD electricity intensity
- Standard 3: OECD electricity intensity

In Table 4.1, the difference between the South African industrial sectors' electricity intensity levels and their OECD counterparts is presented, according to the standard chosen. As discussed in the theoretical representation, one percentage is equivalent to one credit. Also, a negative (positive) sign shows that the South African sector is more (less) intensive than the standard chosen, hence it will become a supplier (consumer) of credits/allowances in the trade.

It can be seen that a number of sectors ('construction', 'food and tobacco', 'machinery' and 'transport equipment') remain suppliers in the trade regardless of the benchmark chosen. However, sectors such as 'mining and quarrying' and 'non-metallic minerals' are worse off for all the proposed selected benchmarks and hence, they are the consumers of the market. However, the rest of the sectors change roles according to how strict the chosen benchmark is. For instance, 'agriculture' would have to act as a supplier under Standard 1.

Table 4.1 Difference of electricity intensities (South Africa- Standards) in 2006*

	Standards		
Sectors	1	2	3
Agriculture and forestry	***1%***	-97%	-1871%
Basic metals**	***51%***	***1%***	-887%
Chemical and petrochemical	***70%***	***41%***	-495%
Construction	***100%***	***100%***	***98%***
Food and tobacco	***96%***	***91%***	***11%***
Machinery	***99%***	***98%***	***81%***
Mining and quarrying	-20%	-141%	-2306%
Non-metallic minerals	-31%	-162%	-2518%
Paper, pulp and printing	***50%***	***1%***	-891%
Textile and leather	***68%***	***35%***	-549%
Transport equipment	***96%***	***92%***	***20%***
Transport sector	***67%***	***34%***	-563%
Wood and wood products	***87%***	***75%***	-154%

Notes: *Number in bold (positive sign) show that the sector is better off than the benchmark chosen and hence they are suppliers of credits and the non-bold (negative sign) indicate the sector's intensity is higher than the benchmark's and therefore, the sector is a consumer of credits.
** 'Iron and steel' and 'non-ferrous metals'

Under Standards 2 and 3, however, it is more electricity intensive than the selected benchmarks and hence, it plays the role of a consumer in the market.

It should be noted here that in a benchmark-and-trade system, the participants are free to decide whether they prefer to trade in the market or rather reduce or increase their electricity consumption in order to meet the benchmark proposed. However, in the next phase even the sectors that preferred to participate fully in the trade have an economic incentive to do so. Also, a number of sectors will combine the two options, trading some credits and adjusting their electricity consumption accordingly.

Next, the first case is presented where all the sectors participate willingly in the market without changing their electricity consumption behaviour. Subsequently, the results of the situation where all the sectors decide to alter their consumption in order to meet the benchmark chosen will be presented.

After translating these differences into credits/allowances, one can calculate the total demand of electricity intensity credits/allowances and the maximum credits/allowances to be supplied in the benchmark-and-trade market. Table 4.2 summarises the total supply and demand of credits/allowances for each of the standards.

Table 4.2 Total demand and supply of credits/allowances in 2006 for different standards implemented

	1	2	3
Total demand (TD)	51	399	10 233
Total supply (TS)	785	567	211
Difference (TS-TD)	734 surplus	168 surplus	-10 022 shortage

It can be seen that the stricter the benchmark is (Standard 3), the less sectors are able to supply the market with credits/allowances; while for more lenient benchmarks (Standard 1), the majority of the South African industrial sectors are better off than the benchmark. The opposite holds for the total supply: the stricter the benchmark is, the lower the total supply for credits/allowances.

To provide a general picture on how the market would look, each of the three different standards are presented next. Standard 1 shows a market where the total demand is very low; Standard 2 presents a market where total demand and total supply do not differ substantially, and finally Standard 3 shows a market where total demand is by far higher than the total supply.

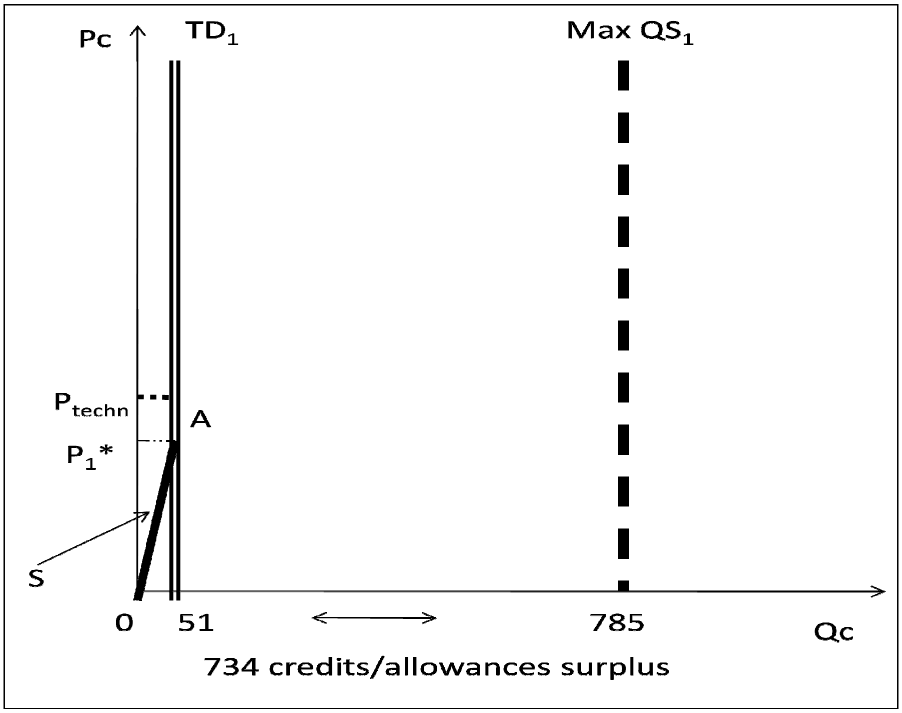

Figure 4.5 Equilibrium at Standard 1

Note: The equilibrium point (A) is where the total demand curve (TD1) crosses the total supply curve (S). So the equilibrium price of the market is P_1* and the equilibrium quantity is equal to the total quantity demanded (51 units). The suppliers, however, are able to provide more credits (max QS_1) and hence, there is a surplus in the market of 734 credits. The equilibrium price is lower than the price of technology so the supply curve has not reached the turning point of its slope.

When choosing Standard 1, the total demand for credits/allowances (TD) is significantly lower (51 credits/allowances) than the maximum quantity that can be potentially supplied (785 credits/allowances). This is because Standard 1 is a highly lenient benchmark and the majority of sectors are below the set target. Only ‘mining and quarrying’ and ‘non-metallic minerals’ are still more intensive than the standard and hence, they constitute the total demand in the market.

Figure 4.5 presents the equilibrium under Standard 1. In this example, due to the limited quantity demanded, the supply curve crosses the demand curve at a price level lower than the price of technology (point A). In this benchmark, the consumers buy all their credits/allowances from the suppliers of the market; hence there is no interference by the regulator. So, the consumers’ expenses will be equal to the suppliers’ revenue which is equal to P_1^* x TD_1(= 51 credits/allowances).

The difference between Standard 1 and Standard 2 is that the total demand is not so small in comparison with the total supply. Standard 2 is stricter than Standard 1 (100% of the OECD sectoral electricity intensities). In Figure 4.6, the equilibrium under this targeted benchmark is presented.

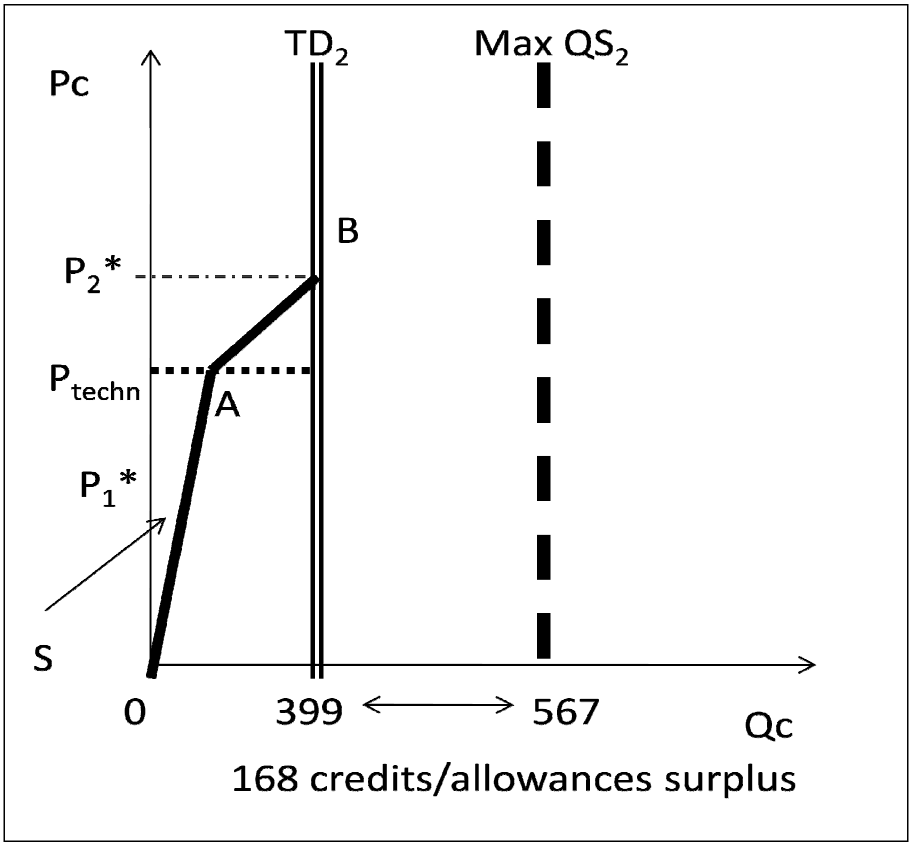

Figure 4.6 Equilibrium at Standard 2

Note: The equilibrium point (B) is where the total demand curve (TD2) crosses the total supply curve (S). So the equilibrium price of the market is P_2* and the equilibrium quantity is equal to the total quantity demanded (399 units). The suppliers, however, are able to provide more credits (max QS_2) and hence, there is a surplus in the market of 168 credits. The equilibrium price is higher than the price of technology so the equilibrium point B is higher than the supply curve's turning point (A).

It is seen in Figure 4.6 that the equilibrium price in this standard is higher than the price of technology since the supply curve becomes more elastic before it crosses the total demand. As in the previous example, the consumers' expenses are equal to the producers' revenue (no regulator interference), P_2* x TD_2 (= 399 credits/allowances).

A completely different picture is depicted if Standard 3 is chosen. Standard 3 is the strictest of all because it aims at reaching exactly the OECD electricity intensity levels. Towards this aim, the total demand for credits/allowances is high (10,233 credits/allowances) because the majority of the South African sectors are worse off than their OECD counterparts, while there will still be industrial sectors whose electricity intensity is lower (‘construction’, ‘food and tobacco’, ‘machinery’ and ‘transport equipment’).

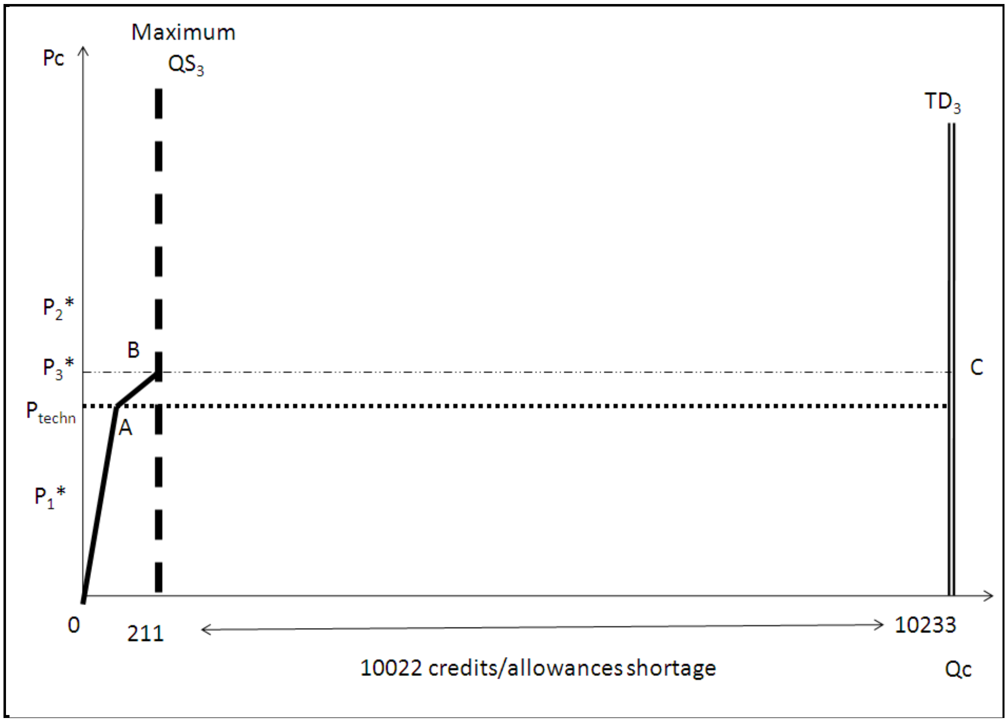

Figure 4.7 Equilibrium at Standard 3

Note: The equilibrium in this case is at point (B), higher than the price of technology (P_{techn}), after the turning point of the supply curve. This is because under a strict benchmark such as Standard 3, the maximum quantity supplied (only 211 credits) is substantially lower than the total demand for credits (TD_3 = 10,233 credits). Owing to this, the market experiences a shortage of credits (10,022 credits) that the regulator is obliged to supply at a certain price equal to or higher than the equilibrium price P_3*.

Also, the equilibrium price is higher than the price of technology; however, it is lower than in Standard 2 because the credits/allowances available to sell are lower (211 credits/allowances).

Hence, the regulator of the system needs to offer the credits/allowances that are in shortage (10,022 credits/allowances) charging at least the equilibrium price per credit. The consumers' expenditure is divided between the suppliers and the regulator. The consumers' expenditure is equal to P_3* x TD_3 (= 10,233 credits/allowances) from which P_3* x $maxQS_3$ (= 211 credits/allowances) is paid to the suppliers and P_3* x shortage (= 10,022 credits/allowances) to the regulator.

In summary, the graphical representation illustrates the fact that the following are crucial factors in determining the credits' price and the system's success:

- Choice of standard
- Price of technology
- Starting point of efficiency for each sector

These aspects of the system determine whether a sector is a supplier or a consumer of credits, the amount of credits offered and demanded in the market and the need for intervention by the regulator.

Presenting these three possible scenarios on how this market would operate by selecting different benchmarks raises questions on how the South African economy will be affected, whether the output will be reduced to meet the targets, and how much the various sectors will gain or lose by the implementation of the system. Before we extend the analysis with numerical examples, it is useful to summarise the two separate roles the sectors might have to play (Table 4.3).

Table 4.3 The meaning of a sector being a consumer or a supplier in the benchmark-and-trade system

Consumer	Supplier
Worse off than the benchmark	Better off than the benchmark
More electricity intensive or less electricity efficient	Less electricity intensive or more electricity efficient
It will have to cut on its electricity consumption (assuming output remains the same)	It can increase its electricity consumption and still be within the limits set by the benchmark
It will have to buy credits in the market (expenses)	It could sell credits in the market (savings)

To account for possible decreases in production to meet the efficiency requirements of the system, a strong assumption is held for the rest of this chapter: economic output of the sectors remains the same and hence, the sectors can only improve their intensity by reducing their electricity consumption.

In the proposed system, the differences between South Africa and the OECD can be translated into units of energy. Table 4.4 presents the differences per sector converted into GWh.

Table 4.4 Changes in electricity use to be implemented to reach the benchmarks (GWh)*

Sectors	Standard 1	Standard 2	Standard 3
Agriculture and forestry	85.09	-5,668.08	-109,225.09
Basic metals **	11,966.39	300.62	-209,683.27
Chemical and petrochemical	7,085.10	4,087.00	-49,878.90
Construction	58.09	58.03	56.93
Food and tobacco	722.42	688.88	85.26
Machinery	46.08	45.65	37.79
Mining and quarrying	-5,727.07	-39,691.77	-651,056.50
Non-metallic minerals	-804.59	-4,214.29	-65,589.03
Paper, pulp and printing	885.56	14.98	-15,655.33
Textile and leather	353.57	183.8	-2,872.15
Transport equipment	89.32	85.61	18.72
Transport sector	2,261.82	1,139.30	-19,065.97
Wood and wood products	264.04	225.7	-464.37
Economy-wide	*17,285.82*	*-42,744.54*	*-1,123,291.91*

Notes: *The negative sign indicates that the sector will have to save this amount of electricity consumption while the positive sign shows that the sector can increase its electricity use and still be within the set benchmark.
** 'Iron and steel' and 'non-ferrous metals'

For a better understanding of Table 4.4, the 'agricultural' sector is discussed as an example. The electricity consumption of the agricultural sector in 2006 (hypothetical starting year of the system) was 5,838,260GWh and its intensity was 0.320GWh/$millions (PPP adj). In the same year, the OECD average electricity intensity was 0.316GWh/$millions (adjusted PPP); hence, the difference of the two was -1% (see Table 4.1) and the sector will act as a supplier of credits. If the economic output of the sector remained unchanged, then these credits would all be converted into GWh by finding the 1% difference of the total electricity consumption: 1% * 5,838,260GWh= 85,092GWh.

Looking at the overall picture, 'mining and quarrying' and 'non-metallic minerals' are the only consumers of credits/allowances in the market. Employing a stricter standard, such as Standard 2, the 'agriculture' sector also joins the group of consumers while eventually, under Standard 3, the only suppliers in the market are 'construction', 'food and tobacco', 'machinery' and 'transport equipment'.

However, the size of the gain or loss of each sector by its participation in the system is dependent on the price of the credit. Given the fact that the market has not been in effect before, it is difficult to have absolutely realistic price scenarios. However, the baseline scenario can adopt the carbon tax for electricity generation in South Africa that was proposed to be R0.02/kWh (for the other two scenarios, a price lower and a price higher than the tax are selected for a better view of a range of results).

In a benchmark-and-trade system, the sectors are allowed to choose between reducing their electricity usage to reach the benchmark or buy the extra electricity consumption in the form of credits. Also, some of the sectors might decide to combine some form of improvement in their efficiency with purchasing credits. Hence, Table 4.4 illustrates the case where all the sectors decide not to buy or sell credits but increase or decrease their electricity usage to reach the benchmark.

Table 4.5 Savings and expenses of the participating sectors (in ZAR millions)*

	Standard 1			*Standard 2*			*Standard 3*		
Sectors	**R0.01/kWh**	**R0.02/kWh**	**R0.03/kWh**	**R0.01/kWh**	**R0.02/kWh**	**R0.03/kWh**	**R0.01/kWh**	**R0.02/kWh**	**R0.03/kWh**
Agriculture and forestry	0.85	1.7	2.55	-56.68	-113.36	-170.04	-1,092.25	-2,184.50	-3,276.75
Basic metals**	119.66	239.33	358.99	3.01	6.01	9.02	-2,096.83	-4,193.67	-6,290.50
Chemical and petrochemical	70.85	141.7	212.55	40.87	81.74	122.61	-498.79	-997.58	-1,496.37
Construction	0.58	1.16	1.74	0.58	1.16	1.74	0.57	1.14	1.71
Food and tobacco	7.22	14.45	21.67	6.89	13.78	20.67	0.85	1.71	2.56
Machinery	0.46	0.92	1.38	0.46	0.91	1.37	0.38	0.76	1.13
Mining and quarrying	-57.27	-114.54	-171.81	-396.92	-793.84	-1,190.75	-6,510.56	-13,021.13	-19,531.69
Non-metallic minerals	-8.05	-16.09	-24.14	-42.14	-84.29	-126.43	-655.89	-1,311.78	-1,967.67
Paper, pulp and printing	8.86	17.71	26.57	0.15	0.3	0.45	-156.55	-313.11	-469.66
Textile and leather	3.54	7.07	10.61	1.84	3.68	5.51	-28.72	-57.44	-86.16
Transport equipment	0.89	1.79	2.68	0.86	1.71	2.57	0.19	0.37	0.56
Transport sector	22.62	45.24	67.85	11.39	22.79	34.18	-190.66	-381.32	-571.98
Wood and wood products	2.64	5.28	7.92	2.26	4.51	6.77	-4.64	-9.29	-13.93
Economy-wide	*172.85*	*345.72*	*518.56*	*-427.43*	*-854.9*	*-1,282.33*	*-11,232.9*	*-22,465.84*	*-33,698.75*

Notes: *The positive figures indicate the amounts in ZAR millions that the sectors will be able to receive from the participation in the market while the negative figures show the amounts that the sectors will have to spend because they are more intensive than the benchmark chosen.
** 'Iron and steel' and 'non-ferrous metals'

On the other side, Table 4.5 presents the possible savings or expenses in ZAR millions per sector in case the sectors decide not to change their consumption behaviour but purchase or sell credits in the market. The negative (positive) value indicates that the sector is a seller (buyer) in the market and the figure shows its savings (expenses). The signs indicate the reduction or increase of electricity costs of the sectors.

Continuing with the example of the agricultural sector, by being more efficient than the OECD counterpart when selecting Standard 1, it will have savings that will vary from ZAR 0,85–2,55 million (depending on the price). When the price is equal to the carbon tax, then the sector not only would not have to pay any taxes but it would also increase its revenue by ZAR 1.77 million.

However, when Standard 2 is chosen, the agricultural sector is more intensive than the OECD; hence, it is a buyer of credits and eventually it would have to pay in order to acquire the required credits. Its expenses would be ZAR 56,68, ZAR 113,36 or ZAR 170,04 million for each of the price scenarios (ZAR0.01/kWh, ZAR0.02/kWh and ZAR0.03/kWh), respectively.

A similar picture is presented in the case of selecting Standard 3. The agricultural sector is much more intensive than the selected benchmark. Hence, the expenses of the sector to acquire the necessary credits are higher than in Standard 2. Depending on the price of the credit, its expenses would vary between ZAR 1,092 and ZAR 3,276 million.

Although the savings and expenses of the participating sectors as presented in Table 4.5 demonstrate that there will be numerous sectors that will benefit by the system, they cannot really show the importance of the gain or loss of each. Hence, taking the analysis a step further, Table 4.6 presents the savings and expenses as a ratio of the sectors' real output in 2006.

Following the previous example, the agricultural sector will earn 0.001% to 0.003% of its economic output in case of Standard 1; however, it will lose 0.066% to 0.197% (Standard 2) or 1.266% to 3.797% (Standard 3) of each economic output.

The only two sectors that are consumers for all standards ('mining' and 'non-metallic minerals') would have to spend less than 0.1% of their economic output (Standard 1); and less than 0.8% (Standard 2); but much higher at Standard 3: depending on the price from 3.45% to 10.34% for the mining sector and 2.56% to 7.68% for the non-metallic minerals sector.

Table 4.6 Savings and expenses of the participating sectors as a ratio to their total output, 2006*

	Standard 1			*Standard 2*			*Standard 3*		
Sectors	**R0.01/kWh**	**R0.02/kWh**	**R0.03/kWh**	**R0.01/kWh**	**R0.02/kWh**	**R0.03/kWh**	**R0.01/kWh**	**R0.02/kWh**	**R0.03/kWh**
Agriculture and forestry	**0.0010%**	**0.0020%**	**0.0030%**	-0.0660%	-0.1310%	-0.1970%	-1.2660%	-2.5310%	-3.7970%
Basic metals**	**0.1100%**	**0.2200%**	**0.3310%**	**0.0030%**	**0.0060%**	**0.0080%**	-1.9310%	-3.8620%	-5.7940%
Chemical and petrochemical	**0.0270%**	**0.0540%**	**0.0810%**	**0.0160%**	**0.0310%**	**0.0470%**	-0.1890%	-0.3790%	-0.5680%
Construction	**0.0004%**	**0.0010%**	**0.0010%**	**0.0004%**	**0.0010%**	**0.0010%**	**0.0003%**	**0.0010%**	**0.0010%**
Food and tobacco	**0.0040%**	**0.0080%**	**0.0120%**	**0.0040%**	**0.0080%**	**0.0110%**	**0.0005%**	**0.0010%**	**0.0010%**
Machinery	**0.0010%**	**0.0020%**	**0.0030%**	**0.0010%**	**0.0020%**	**0.0030%**	**0.0010%**	**0.0020%**	**0.0020%**
Mining and quarrying	-0.0300%	-0.0610%	-0.0910%	-0.2100%	-0.4200%	-0.6300%	-3.4470%	-6.8940%	-10.3400%
Non-metallic minerals	-0.0310%	-0.0630%	-0.0940%	-0.1640%	-0.3290%	-0.4930%	-2.5590%	-5.1180%	-7.6780%
Paper, pulp and printing	**0.0200%**	**0.0400%**	**0.0590%**	**0.0003%**	**0.0010%**	**0.0010%**	-0.3510%	-0.7010%	-1.0520%
Textile and leather	**0.0090%**	**0.0170%**	**0.0260%**	**0.0040%**	**0.0090%**	**0.0130%**	-0.0700%	-0.1400%	-0.2100%
Transport equipment	**0.0010%**	**0.0010%**	**0.0020%**	**0.0010%**	**0.0010%**	**0.0020%**	**0.0001%**	**0.0002%**	**0.0004%**
Transport sector	**0.0120%**	**0.0230%**	**0.0350%**	**0.0060%**	**0.0120%**	**0.0180%**	-0.0990%	-0.1980%	-0.2970%
Wood and wood products	**0.0120%**	**0.0240%**	**0.0360%**	**0.0100%**	**0.0210%**	**0.0310%**	-0.0210%	-0.0420%	-0.0630%
Economy-wide	**0.136%**	**0.268%**	**0.404%**	-0.394%	-0.788%	-1.185%	9.931%	19.861%	29.795%

Notes: *The positive figures indicate the sectors that are better off than the chosen benchmark and hence, are suppliers in the market, they earn a percentage of their output. The negative percentages show the proportion of their output that the consumers in the market have to spend.
** 'Iron and steel' and 'non-ferrous metals'

4.4 Comparison with carbon tax

Taxation is one of the main proposed alternatives to benchmark-and-trade systems to deal with the increasing trends in CO_2-emissions and energy consumption. More specifically, South African authorities have proposed the implementation of a tax on electricity consumption. The idea behind taxing consumption instead of emissions is relatively simple: the main reason for CO_2-emissions in the country is the production of electricity which is 80% coal-generated.

The proposed benchmark-and-trade system and a *carbon tax* have the exact same objective: the reduction of CO_2-emissions. However, the two systems operate through different channels. The taxation aims to make electricity consumption more expensive so that the users will have to decrease consumption in order to avoid extra taxation. Therefore, with the reduction of electricity consumption, the CO_2-emissions are expected to decrease. A possible drawback of this is the fact that certain users will prefer to decrease their production towards a higher reduction of electricity consumption, with detrimental effects to the economic growth of the country.

In addition, measuring the CO_2 emissions in a disaggregated level, as was discussed in National treasury (2010), can be proven complicated, difficult and time-consuming. Hence, currently, the *carbon* tax is imposed on the electricity usage of the consumers with the assumption that the electricity generation and consumption is highly linked with GHG emissions.

On the other side, the electricity efficiency benchmark-and-trade system is a market-based system that will provide users with economic incentives to improve their efficiency levels while also taking into account their economic output. The channel of this system works through the improvement of electricity efficiency in order to gain in the created market by reducing electricity consumption and hence, CO_2-emissions in a specific period of time (Chameidis & Oppenheimer, 2007).

Table 4.7 Comparison* of economic impact of carbon tax and benchmark-and-trade to various sectors (2006)

	Carbon tax	Standard 1	Standard 2	Standard 3
Sectors	Payments (ZAR mil)*	Savings and expenses (ZAR mil)**	Savings and expenses (ZAR mil)**	Savings and expenses (ZAR mil)**
Agriculture and forestry	-116.47	1.7	***-113.36***	-2,184.50
Basic metals***	-456.43	239.33	6.01	-4,193.67
Chemical and petrochemical	-200.88	141.7	81.74	-997.58
Construction	-10.44	1.16	1.16	1.14
Food and tobacco	-15.11	14.45	13.78	1.71
Machinery	-0.93	0.92	0.91	0.76
Mining and quarrying	-563.57	***-114.54***	-793.84	-13,021.13
Non-metallic minerals	-51.93	***-16.09***	-84.29	-1,311.78
Paper & Wood products	-41.04	22.99	4.81	-322.4
Textile and leather	-10.44	7.07	3.68	-57.44
Transport equipment	-1.85	1.79	1.71	0.37
Transport sector	-67.55	45.24	22.79	-381.32
Economy wide	-1546.32	345.72	-854.9	-22465.84

Notes: *The estimates for the savings in electricity after a carbon tax implementation are from a CGE application. These results and the benchmark-and-trade system's results are time-neutral reflecting results by sector at the end of an undefined period. Also, the benchmark-and-trade system does not include feedback effects from the residential and commercial sectors or from inter-industry relations while the CGE does.

**The negative signs in the "savings and expenses" indicate consumer-sectors that need to spend these specific amounts; while the positive signs indicate supplier-sectors that receive these amounts from their participation in the market. The green cells show that the standard chosen under a benchmark-and-trade system is better off the case of a carbon tax implementation and the pink cells show that the standard chosen is worse off.

***'Iron and steel' and 'non-ferrous metals'

Regarding the economic benefit for the electricity users, Table 4.7 presents the savings and expenses of the various sectors under the scenario of a carbon tax of R0.02/kWh versus the three different standards of the proposed system when the price of the credits is equal to the carbon tax.

In the case of taxation, the economic sectors will have to pay a certain amount of tax for their electricity usage. However, in the case of the benchmark-and-trade system (depending on the benchmark selected), some sectors will gain from the trade and will be able to cover some of their costs during the period of implementation.

For instance, the agricultural sector will have to pay ZAR 116.5 million to the government if taxation is implemented. However, if Standard 1 of the benchmark-and-trade system is chosen, the sector will be considered one of the suppliers of the trade and hence, it will gain ZAR 1.7 million. The situation would change in case Standard 2 is chosen: the sector is now a consumer of credits in the market and hence, it would have to spend ZAR 113.36 million in order to buy the necessary credits to continue consuming the same amount of electricity. The important point here is that although the sector is a consumer of credits and has to spend, the amount is lower than the alternative of taxation.

A similar example is also presented by the two sectors that are consumers of credits in any of the three proposed standards: ‘mining and quarrying’ and ‘non-metallic minerals’. These sectors will have to spend higher amounts during stricter standards, such as Standard 3, but the comparison between the implementation of a tax and Standard 1 leaves these two sectors better off if Standard 1 is chosen (mining: 79.7%

less under Standard 1 compared to tax; non-metallic minerals: 69 % less under Standard 1 compared to tax).

On the other hand, the participants may decide not to buy or sell electricity efficiency credits but rather adjust their electricity consumption accordingly in order to reach the chosen benchmark. Table 4.8 presents the percentage of electricity reductions or increase each sector needs to reach the proposed standards as well as the decreases of electricity after the implementation of a carbon tax.

Table 4.8 Comparison* of impact on electricity savings of carbon tax and benchmark-and-trade to various sectors (2006)

	Carbon tax	Standard 1	Standard 2	Standard 3
Sectors	Savings in electricity (%)*	Savings in electricity (%)**	Savings in electricity (%)**	Savings in electricity (%)**
Agriculture and forestry	-0.25%	0.00%	-0.09%	-1.87%
Basic metals***	-3.43%	0.05%	0.00%	-0.89%
Chemical and petrochemical	-0.39%	0.07%	0.04%	-0.49%
Construction	-0.03%	0.10%	0.10%	0.10%
Food and tobacco	-0.03%	0.10%	0.09%	0.09%
Machinery	-0.41%	0.10%	0.10%	0.08%
Mining and quarrying	-0.21%	-0.02%	-0.14%	-2.31%
Non-metallic minerals	-0.33%	-0.03%	-0.16%	-2.52%
Paper & Wood products*	-0.31%	0.14%	0.08%	0.00%
Textile and leather	-0.25%	0.07%	0.04%	-0.55%
Transport equipment	-0.36%	0.10%	0.09%	0.02%
Transport sector	-0.20%	0.07%	0.03%	-0.56%
Economy-wide	*-6.19%*	*0.73%*	*0.17%*	*-8.90%*

Notes: *The estimates for the savings in electricity after a carbon tax implementation are from a CGE application. These results and the benchmark-and-trade system's results are time-neutral reflecting results by sector at the end of an undefined period. Also the benchmark-and-trade system does not include feedback effects from the residential and commercial sectors or from inter-industry relations while the CGE does.

**The negative signs indicate consumer-sectors that need to reduce their electricity usage; while the positive signs indicate supplier-sectors that can even increase their consumption if they choose too. The green cells show that the standard chosen under a benchmark-and-trade system is better off in the case of a carbon tax implementation and the pink cells show that the standard chosen is worse off.

***'Iron and steel' and 'non-ferrous metals'

Based on these results, when using Standards 1 and 2, all the sectors are worse off compared to the reductions expected from the implementation of a carbon tax of R0.02/kWh. However, under a stricter benchmark, a number of sectors would have to decrease their electricity consumption substantially more than under taxation. The economy-wide electricity usage may be expected to decrease up to 8.9%, higher than the carbon tax case of 6.19%.

Continuing with the 'agriculture' sector example, this sector is expected to reduce its electricity usage by 0.25% after an implementation of a carbon tax. However, under Standard 1, the sector can even increase its usage marginally by 0.0015% since it performs better than the benchmark chosen. Under Standard 2, the sector should decrease its usage by 0.0971% to reach the levels of the benchmark. This decrease is much lower than the carbon tax case. Finally, under Standard 3, the agriculture sector should decrease its usage by 1.8709%, a substantial improvement to the expected decrease due to taxation.

4.5 Conclusion

In summary, this chapter proposed a benchmark-and-trade system. Its main target is to improve electricity efficiency levels in South Africa by using a market-based sectoral approach. In the past, benchmark-and-trade systems aimed to reduce greenhouse gas emissions (GHG) and more specifically CO_2- or SO_2-emissions. The difference of this system is that it aspires to deal with the cause of these emissions: energy consumption, more particularly electricity.

In South Africa, a high proportion of electricity generation is based on coal burning with detrimental effects to the CO_2-emissions of the country. Hence, the initial idea of a benchmark-and-trade system was to reduce the electricity consumption of the country. However, such a target could affect the country's economic output severely and therefore the proposed system aspires to reduce the electricity intensity or, in other words to improve the electricity efficiency of the country.

This chapter presented the theoretical mechanisms of the system and discussed some numerical examples based on three different scenarios or standards. The key finding was that, depending on the chosen benchmark, the price of the credits/allowances traded would be different. Also, an important point is that the price of technology is a crucial factor for the participants' decision to change their production methods to more efficient ones.

Taking this analysis a step further, possible price scenarios were examined. Holding the very strong but highly important assumption that sectors kept their economic output constant, they would be able to reduce their electricity consumption (and hence become more efficient) or sell the *capability* of using the specific units of consumption.

Subsequently, a comparison of this system with the implementation of a carbon tax, its main alternative when aiming to improve a country's environmental performance, showed that a benchmark-and-trade system's success and superiority to the carbon tax proposed in South Africa is highly dependent on the choice of the benchmark. However, with the assumed scenarios, under the benchmark-and-trade system there will always be sectors that profit from it by being the suppliers. Coversely, under taxation, all the sectors will have to increase their expenses. Moreover, if the benchmark-and-trade system is well-designed, a number of sectors such as ‘mining and quarrying’, ‘non-metallic minerals’ and ‘agriculture’ will have to pay vastly less to buy credits/allowances than paying the equivalent tax.

Finally, if the participants of the proposed system decide not to buy or sell credits but rather adjust their electricity consumption to match the chosen benchmark, then there would be no financial gains but only an influence in the electricity consumption of the country. In this case, a strict benchmark can achieve higher electricity savings than the implementation of a carbon tax system.

5 GENERAL CONCLUSION

5.1 Restating the main purpose and objectives

The main purpose of this study was to propose a market-based solution promoting demand-side management towards the improvement of electricity efficiency in South Africa. Before doing so, the electricity consumption and efficiency status quo of the country was examined at aggregate and sectoral levels. This thorough analysis showed what the main factors are that determine the trends of electricity consumption in the country; how important electricity efficiency is; which economic sectors are the most and least electricity intensive and why; and finally, how the country performed compared to other countries.

The following specific objectives guided the study:

- To conduct an extensive local and international literature review on electricity efficiency related matters
- To examine and analyse the South African electricity sector and its unique characteristics
- To estimate the price elasticity of electricity both at aggregate and sectoral levels, as well its evolution through time
- To examine the role of electricity efficiency in the evolution of the country's electricity consumption, and investigate how significant the role of the structure of the economy is

- To compare the country's total and sectoral electricity intensity with a group of developing and developed economies and conclude if South Africa is following international standards
- To design the proposed electricity efficiency benchmark-and-trade system and make recommendations on how this market should function and what the limits of the intervention should be in order for this market to be considered successful

5.2 Outline of the study

After the general introduction, the second section of the study reviewed the necessary introductory literature on the case of South Africa, energy (electricity) efficiency matters and cap-and-trade models. More specifically, the presentation of the South African case included an analysis of the key players and their role as well as policies and regulations implemented in the country. Also, it provided a graphical representation of indicative data and information to illustrate the overall picture of the country.

Next, the study proceeded to the definition of energy efficiency as well as its main measuring methods. In addition, it discussed a number of international and local policies towards the improvement of energy efficiency.

Subsequently a brief presentation of the cap-and-trade system was provided followed by a discussion on international applications and an evaluation of the system. The next section provided empirical evidence and aimed to fulfil all the requirements of a complete understanding of the electricity sector in order to proceed with a proposed solution.

First the aggregate price elasticity of electricity demand in South Africa was discussed. An econometric technique known as the Kalman filter was employed in order to estimate the evolution of the sensitivity of electricity consumption to changes in price and output. Next, by using panel data techniques, different behavioural responses of a number of economic sectors to changes in the sector-specific prices and output were examined; while the following section employed decomposition analysis to analyse the role of the structure of the economy, electricity intensity and output to the country's increasing trend of electricity consumption both at an aggregate and a sectoral level. Finally, a comparative analysis of the South African total and sectoral electricity intensities to the OECD countries was presented in the last section.

The fourth part of the study presents the proposed benchmark-and-trade system in order to change the picture of electricity efficiency in South Africa. It explains in detail the mechanisms as well as the policy implications of the model. Finally, the last section provides a general conclusion of the study.

5.3 Important findings

The study's major concluding points can be summarised as follows.

From the first econometric exercise, the Kalman filter, it was found that the price elasticity of aggregate electricity demand has been changing over the years. It was also shown that the higher the electricity price, the higher the sensitivity of consumers to price fluctuations. These results can explain the lack of reaction to price changes in the past and maybe assist the policy-makers in ‘predicting’ future behaviour after the recent and future price hikes.

Next, focus was given to the price elasticity at a sectoral level and the question of whether or not all the sectors’ price sensitivity is the same was answered. Over the study period, only the industrial sector (in total) behaved as expected by economic theory; the price coefficient was shown to be negative and statistically significant. Also, economic output was a positive contributing factor to electricity consumption only for the industrial and commercial sectors (positive and statistically significant coefficients); while for the other three sectors (‘agriculture’, ‘transport’ and ‘mining’) the production was not a statistically significant factor.

Having established that in the past South African consumers were not sensitive to price fluctuations (the situation that might change in the future due to the price reform) the analysis turns to identify other reasons that contributed to the increase in electricity consumption. The changes in production were the main factor that increased electricity consumption, while efficiency improvements during the period were a driver in decreasing consumption. Not surprisingly, the examined sectors presented a different picture regarding its contributing factors. According to the results, the electricity efficiency was the only contributing factor to the decreasing side of electricity consumption at an economy-wide level. Hence, its improvement might prove to be the desired solution towards the decrease of electricity consumption without neglecting the importance of the country’s economic growth.

Taking the significance of efficiency into account, the analysis proceeds to indicate whether there is scope for improvement on a national level from a South African perspective and also do so at a disaggregated sectoral level. The country's total electricity intensity more than doubled in the study period and its weighted growth was higher than the majority of the OECD member countries by a considerable margin. In addition, the vast majority (nine of the thirteen) of the South African industrial sectors were more intensive than their OECD counterparts.

Given these results, a benchmark-and-trade system was proposed to improve the electricity efficiency of the country. This market-based approach promotes the trading of credits among sectors after comparing their electricity efficiencies with the benchmark chosen for each phase. The benchmarks are subject to the equivalent sectors of the OECD countries. An important finding was that depending on the chosen benchmark, the price of the credits differs. Also, the price or cost of technology plays an important role in the decisions the participants make on whether they should trade or change their technology (and hence, efficiency) in order to reduce their electricity consumption.

Finally, the proposed system and a carbon tax both aspire to reduce the GHG emissions but employ different methods. The carbon tax 'penalises' the consumption of energy and aims to thus decrease the electricity (energy) consumption; while the benchmark-and-trade system gives financial incentives to the successful performers to improve their electricity (energy) efficiency. A comparison showed that the benchmark-and-trade system's superiority is highly dependent on the choice of the appropriate benchmark. However, under the proposed system, some sectors will make profits by being better off than the benchmark and supplying the market with credits. However, all the sectors will have to increase their expenses after a carbon tax is imposed.

5.4 Recommendations for further research

The international interest on the consequences of climate change resulting from extensive energy use and GHG emissions as well as the local crisis at the beginning of 2008 have made energy research imperative for the South African policy environment. As Pouris (2008) states, the South African publications on energy have been increasing substantially but from a low basis and focus more on research specialties such as chemical engineering, mechanics and mechanical engineering. However, the severe economic consequences of the 2008 crisis show that energy should also be examined from an economic and environmental point of view. Thus, this study provides the foundation for further research on electricity/energy efficiency in the country.

The main predicament in energy research is the quality and availability of data. Although steps have recently been made, data is still a major problem. Additional work should be undertaken in order to improve the accuracy of the collection of energy data. More importantly, data on a more disaggregated level will be useful in better understanding the way in which companies and households make decisions on consumption and efficiency of energy (electricity).

Moreover, baseline studies of different types of energy at both an economy-wide and a sectoral level should be conducted for two reasons. First, that the South African policy authorities can then be aware of the current situation and second, that the efforts for improvement can have certain targets based on the business-as-usual.

This study also opens new paths for advanced energy research in combination with economic analysis and econometric techniques. Employing panel data and Kalman filter techniques allows researchers to acquire constructive and valuable results with regards to behaviour of sectors and the economy when different factors change. This study sets a precedent for future econometric analysis on different energy types at various levels of disaggregation.

Also, the benchmark-and-trade system can be examined in a *game theory* framework to investigate the participants’ decisions on the demand and supply of credits as well as the electricity reductions and economic benefits from the market. Also, a system dynamics model may be of assistance in order to better understand the mechanics of the system.

Finally, the proposition of a benchmark-and-trade electricity efficiency system extends the horizons on future demand-side management policies both for South Africa and other countries. It would be interesting to apply a similar system to other developed and developing economies and compare the results with that of the South African application. Also, more detailed disaggregation as well as inclusion of different types of energy in the system could improve it further.

APPENDIX

A) Unit root testing

In time series and panel data econometrics, one of the concepts that have attracted increasing attention is the characteristic of stationarity.

“A stochastic process is said to be stationary if its mean and variance are constant over time and the value of covariance between the two time periods depends only on the distance or gap or lag between the two time periods and not the actual time at which the covariance is computed” (Gujarati, 2003:797).

It is highly significant to specify whether a series is stationary or not before continuing. Although there are various tests which have been used to test for stationarity, it was decided to use the most commonly used test in panel data analysis: the Levin, Lin and Chu (2002) test.

The null hypothesis is as follows:

Eq. 0.1

$$\Delta y_{it} = \rho y_{i,t-1} + \sum_{L=1}^{P_i} \theta_{iL} \Delta y_{i,t-L} + \alpha_{mi} d_{mt} + \varepsilon_{it}\ , m = 123$$

Where dmt is the vector of deterministic variables and αmt the corresponding vector of coefficients for model m =1,2,3.

Step 1: Individual augmented Dickey-Fuller (ADF) regressions for each cross-section

Eq. 0.2

$$\Delta y_{it} = \rho_i y_{i,t-1} + \sum_{L=1}^{P_i} \theta_{iL} \Delta y_{i,t-L} + \alpha_{mi} d_{mt} + \varepsilon_{it}\ , m = 123$$

For a given T, choose the maximum lag order pmax and then use the t-statistic of $\widehat{\theta_{\imath L}}$ to determine if a smaller lag can be chosen instead. Once the lag is determined, two auxiliary regressions should be run:

Eq. 0.3

$$\Delta y_{it}\ on\ \Delta y_{i,t-L}\ (L = 1, \ldots .p_i) and\ d_{mt} to\ get\ the\ residual\ \widehat{e_{\imath t}}$$

And

Eq. 0.4

$$\mathrm{y_{i,t-1}\ on\ \Delta y_{i,t-L}\ (L = 1, \ldots .p_i) and\ d_{mt} to\ get\ the\ residual\ \widehat{v_{\imath,t-1}})}$$

Then, standardise these residuals to account for different variances where $\widehat{\sigma_{e\imath}}$ is the standard error for each ADF regression (2).

Eq. 0.5

$$\widetilde{\mathrm{e_{\imath t}}} = \widehat{\mathrm{e_{\imath t}}}/\widehat{\sigma_{\varepsilon\imath}}\ \mathrm{and}\ \tilde{\mathrm{v}}_{\mathrm{i,t-1}} = \hat{\mathrm{v}}_{\mathrm{it}}/\hat{\sigma}_{\varepsilon\mathrm{i}}$$

Step 2: Estimation of the ratio of long-run to short-run standard deviations

Under the null hypothesis (1), the long-run variance can be estimated as follows:

Eq. 0.6

$$\hat{\sigma}_{yi}^2 = \frac{1}{T-1}\sum_{t=2}^{T}\Delta y_{it}^2 + 2\sum_{L=1}^{\overline{K}} w_{\overline{K}L}\left[\frac{1}{T-1}\sum_{t=2+L}^{T}\Delta y_{it}\Delta y_{i,t-L}\right]$$

Where $\overline{K}$ is a truncation lag that can be dependent on the data.

For each cross-section, the ratio of long-run to short-run deviation is $\hat{s}_i = \hat{\sigma}_{yi}/\hat{\sigma}_{\varepsilon i}$ and the average standard deviation is estimated by $\hat{S}_N = \frac{1}{N}\sum_{i=1}^{N}\hat{s}_i$.

Step 3: Computation of the panel test statistics

Run the pooled regression:

Eq. 0.7

$$\tilde{e}_{it} = \rho\tilde{v}_{i,t-1} + \tilde{\varepsilon}_{it}$$

The conventional t-statistic is $t_\rho = \frac{\hat{\rho}}{\hat{\sigma}(\hat{\rho})}$ where

Eq. 0.8

$$\hat{\rho} = \sum_{i=1}^{N}\sum_{t=2+p_i}^{T}\tilde{v}_{i,t-1}\tilde{e}_{it} \Big/ \sum_{i=1}^{N}\sum_{t=2+p_i}^{T}\tilde{v}_{i,t-1}^2$$

Eq. 0.9

$$\hat{\sigma}(\hat{\rho}) = \hat{\sigma}_{\tilde{\varepsilon}} \Big/ \left[\sum_{i=1}^{N}\sum_{t=2+p_i}^{T_i}\tilde{v}_{i,t-1}^2\right]^{1/2}$$

And the estimated variance of $\tilde{\varepsilon}_{it}$ is

Eq. 0.10

$$\hat{\boldsymbol{\sigma}}_{\tilde{\varepsilon}}^2 = \frac{1}{N\tilde{T}} \sum_{i=1}^{N} \sum_{t=2+p_i}^{T} (\tilde{e}_{it} - \hat{\rho}\tilde{v}_{i,t-1})^2$$

The adjusted t-statistic is computed as follows:

Eq. 0.11

$$t_{\rho}^{*} = \frac{t_{\rho} - N\tilde{T}\hat{S}_N \hat{\sigma}_{\tilde{\varepsilon}}^{-2} \hat{\sigma}(\hat{\rho}) \mu_{m\tilde{T}}^{*}}{\sigma_{m\tilde{T}}^{*}}$$

Where $\mu_{m\tilde{T}}^{*}$ and $\sigma_{m\tilde{T}}^{*}$ are the mean and standard deviations given in Levin, Lin and Chu (2002).

B) Hausman test for misspecification

In general, it is assumed that there is exogeneity of the regressors ($E(u_{it}|X_{it})=0$) in panel data models. But the residuals may include individual and time effects possibly correlated with X_{it} ($E(u_{it}|X_{it})\neq 0$). Therefore Hausman (1978) proposed and constructed a test to identify this endogeneity or misspecification.

Null hypothesis H_0: No misspecification or $E(u_{it}|X_{it})=0$

Alternative hypothesis H_1: Misspecification or $E(u_{it}|X_{it})\neq 0$

The test is based on two estimators ($\hat{\beta}_{GLS}$ *and* $\tilde{\beta}_{within}$) that are both consistent with H_0 but have a different distribution under H_1.

Eq. 0.12

$$\hat{q}_1 = \hat{\beta}_{GLS} - \tilde{\beta}_{within}$$

The Hausman test is defined as

Eq. 0.13

$$\mathbf{m_1} = \hat{\mathbf{q}}_\mathbf{1}[\mathbf{var}(\hat{\mathbf{q}}_\mathbf{1})]^{-\mathbf{1}}\hat{\mathbf{q}}_\mathbf{1} \sim \boldsymbol{\chi}^\mathbf{2}_\mathbf{K}$$

Where K is the dimension of $\hat{q}$ (the number of regressors or slope coefficients). However, Hausman and Taylor (1981) mentioned that there are other equivalent tests that are asymptotically distributed χ^2_K under H_0.

Eq. 0.14

$$\hat{\mathbf{q}}_\mathbf{1} = \hat{\boldsymbol{\beta}}_\mathbf{GLS} - \tilde{\boldsymbol{\beta}}_\mathbf{w}$$

Eq. 0.15

$$\hat{\mathbf{q}}_\mathbf{2} = \hat{\boldsymbol{\beta}}_\mathbf{GLS} - \tilde{\boldsymbol{\beta}}_\mathbf{B}$$

Eq. 0.16

$$\hat{\mathbf{q}}_\mathbf{3} = \tilde{\boldsymbol{\beta}}_\mathbf{w} - \hat{\boldsymbol{\beta}}_\mathbf{B}$$

Where the vector of slope coefficients is $m_i = \hat{q}_i V_i^{-1} \hat{q}_i$ where $V_i = var(\hat{q}_i)$ for i=1,2,3.

To avoid the estimation of the GLS estimator for simplicity purposes, we prefer the computation of m_3:

Eq. 0.17

$$\hat{\mathbf{q}}_\mathbf{3} = \tilde{\boldsymbol{\beta}}_\mathbf{w} - \hat{\boldsymbol{\beta}}_\mathbf{B} \textbf{ and } \mathbf{m_3} = \hat{\mathbf{q}}_\mathbf{3}\mathbf{V}_\mathbf{3}^{-\mathbf{1}}\hat{\mathbf{q}}_\mathbf{3} \text{ where } \mathbf{V_3} = \mathbf{var}(\hat{\mathbf{q}}_\mathbf{3})$$

The comparison of m_3 to $\chi^2(2)$ will provide us with the information to know whether we should accept the null hypothesis of heterogeneity of the X regressors or not: if $m_3 > \chi^2(2)$, we reject the null hypothesis.

C) Testing for heteroskedasticity

A correct panel data regression assumes homoskedastic disturbances with similar variances across time and individuals. However, when cross-sectional units are of varying size and different variances then this assumption may not hold and the standards errors will be biased.

The general test for heteroskedasticity is adopted from Greene (econometric analysis).

Null hypothesis: H_0: $\sigma_i^2 = \sigma^2$ for all i or homoskedasticity

Alternative hypothesis: H1: $\sigma_i^2 \neq \sigma^2$ for all i or heteroskedasticity

The LM test statistic is defined as follows:

Eq. 0.18

$$\mathbf{LM} = \frac{\mathbf{T}}{\mathbf{2}}\sum_{\mathbf{i=1}}^{\mathbf{N}}[\frac{\hat{\boldsymbol{\sigma}}_{\mathbf{i}}^{\mathbf{2}}}{\hat{\boldsymbol{\sigma}}} - \mathbf{1}]^{\wedge}\mathbf{2} \sim \boldsymbol{\chi}_{\mathbf{N-1}}^{\mathbf{2}}$$

Where $\hat{\sigma}_i^2$ is the individual regression's RSS/NT while $\hat{\sigma}$ is the pooled regression's RSS/NT. If the LM $> \chi_{N-1}^2$ then the null hypothesis can be rejected and it can be concluded that the model suffers from heteroskedasticity.

D) Testing for serial correlation

In a panel data analysis context, the classical error component disturbances $(\mathrm{u_{it}} = \mathrm{\mu_{it}} + \mathrm{v_{it}})$ assume correlation within a cross-section due to individual effects. The correlation coefficient then becomes:

Eq. 0.19

$$\mathbf{Correl(u_{it}, u_{is}) = \frac{\sigma_{\mu}^2}{(\sigma_{\mu}^2+\sigma_{v}^2)}, for\ t \neq s}$$

However, we might observe serial correlation where the unobserved shock in a given period will affect the relationship for a few periods. To test for serial correlation, we assume the following: $y_{it} = Z_{it}' \, \delta + u_{it}$ where δ is (K+1) x1 and $\mathrm{u_{it}} = \mathrm{\mu_{it}} + \mathrm{v_{it}}$ for i=1,...N and t=1,....N, and $\mu_i \sim IIN(0, \sigma_\mu^2), v_{it}$ is either AR(1) or MA(1). The proposed test checks for serial correlation together with individual effects.

Null hypothesis: H_0: $\sigma_\mu^2 = 0;\ \lambda = 0$ (No random effects and No serial correlation)

$v_{it} = \varepsilon_{it} - \lambda \varepsilon_{i,t-1}$

Alternative hypothesis H_1: $\sigma_\mu^2 = 0;\ \rho = 0$ (Random effects and serial correlation)

$v_{it} = \ \rho v_{i,t-1} + \varepsilon_{it}$

If the LM $> \chi_2^2$ then the null hypothesis can be rejected and it can be concluded that the model suffers from serial correlation.

REFERENCES

Al-Faris, A. (2002). The demand for electricity in GCC countries. *Energy Policy,* 30, 117–124.

Alvarez, L.J., Burriel, P. & Hernando, I. (2010). Price-setting behaviour in Spain: evidence from micro PPI data. *Managerial and decision economics,* 31(2–3), 105–121.

Amarawickrama, H.A. & Hunt, L.C. (2008). Electricity demand for Sri Lanka: A time series analysis. *Energy,* 31(2–3), 724–739.

Amusa, H., Amusa, K. & Mabugu, R. (2010). Aggregate demand for electricity in South Africa: An analysis using bound testing approach to cointegration. *Energy Policy,* 33(5), 724–739.

Anderson, R. (1997). *The US Experience with economic incentives in environmental pollution control policy.* Washington D.C.: Environmental Law Institute.

Andrade-Silva, F.I. & Guerra, S.M. (2009). Analysis of the energy intensity evolution in the Brazilian industrial sector – 1995 to 2005. *Renewable and Sustainable Energy Reviews,* 13(9), 2589–2596.

Andrews, D. (1993). Tests for parameter instability and structural change with unknown change point. *Econometrica,* 61(4), 821–856.

Ang, B. (2004). Decomposition analysis for policymaking in energy: which is the preferred method? *Energy Policy,* 32(9), 1131–1139.

Ang, B.W. & Choi, K.H. (1997). Decomposition of aggregate energy and gas emission intensities for industry: a refined Divisia index method. *The Energy Journal,* 18(3), 59–73.

Ang, B.W. & Liu, F.L. (2001). A new energy decomposition method: perfect in decomposition and consistent in aggregation. *Energy,* 26(6), 537–548.

Ang, B. & Zhang, F.Q. (2000). A survey of index decomposition analysis in energy and environmental studies. *Energy,* 25(12), 1149–1176.

Apergis, N. & Payne, J.E. (2010). Renewable energy consumption and economic growth: Evidence from a panel of OECD countries. *Energy Policy,* 38, 656–660.

APX Power markets. (2008). *Cap and Trade: From all sides now*. Retrieved 2009, from http://www.apx.com.

Arnberg, S. & Bjorner, T.B. (2007). Substitution between energy, capital and labour within industrial compaines: A micro panel data analysis. *Resource and Energy Economics,* 29(2), 122–136.

Atakhanova, Z.H. & Howie, P. (2007). Electricity demand in Kazakhstan. *Energy Policy,* 35, 3729–3743.

Avi-Yonah, R.S. & Uhlmann, D.M. (2009). Combating global climate change: why a carbon tax is a better response to global warming than cap and trade. *Stanford Environmental Law Journal,* 28(3).

Baker, D. (2003). The Environmental Kuznets curve. *The Journal of Economic Perspectives,* 17(1), 226–227.

Bales, C. & Duke, R. (n.d.). *The Debate Zone: Carbon tax vs Cap and Trade.* Retrieved 2010, from http://whatmatters.mckinseydigital.com/the_debate_zone/carbon-tax-vs-cap-and-trade.

Baltagi, B. (2008). *Econometric analysis of Panel data.* West Sussex: John Wiley.

BBC News. (2006). *Q&A: The carbon trade.* Retrieved 2010, from http://news.bbc.co.uk/2/hi/business/4919848.stm.

Bekker, B., Eberhard, A. & Marquard, A. (2008). South Africa's rapid electrification programme: Policy, institutional, planning, financing and technical innovations. *Energy Policy,* 36(8), 3125–3137.

Bernard, J. & Cote, B. (2002). *L'intensite energetique du sectur Manufacturier de 1976 a 1996.* Quebec, Canada: Chaire em Economique de l'Energie Electrique GREEN. Departement d'Economique, Universite Laval.

Bianco, V., Manca, O., Nardini, S. & Minea, A.A. (2010). Analysis and forecasting of non-residential electricity consumption in Romania. *Applied Energy,* 87, 3584–3590.

Bitttencourt, M. (2009). Macroeconomic performance and inequality: Brazil, 1983–1994. *The Developing Economies,* 47(1), 30–52.

Blignaut, J.N. (2009). Fixing both the symptoms and causes of degradation: The need for an integrated approach to economic development and restoration. *Journal of Arid Environments,* 73, 696–698.

Blignaut, J.N. & De Wet, T. (2001). Some recommendations towards reducing electricity consumption in the South African manufacturing sector. *South African Journal of Economic and Management Sciences,* 4(2), 359–379.

Blignaut, J.N., Mabugu, R.M. & Chitiga-Mabugu, M.R. (2005). Constructing a greenhouse gas emissions inventory using energy balances: the case of South Africa 1998. *Journal of Energy in Southern Africa,* 16(3), 105–116.

Bor, Y. (2008). Consistent multi-level energy efficiency indicators and their policy implications. *Energy Economics,* 30(5), 2401–2419.

Bosetti, V., Carraro, C., Massetti, E. & Tavoni, M. (2008). International energy R&D spillovers and the economics of greenhouse gas atmospheric stabilization. *Energy Economics,* 30(6), 2912–2929.

Bosseboeuf, D., Chateau, B. & Lapillonne, B. (1997). Cross-country comparison on energy efficiency indicators: the on-going European effort towards a common methodology. *Energy Policy,* 25(7–9), 673–682.

Boyd, G.A., Hanson, D.A. & Sterner, T. (1988). Decomposition of changes in energy intensity *1: A comparison of the Divisia Index and other methods. *Energy Economics,* 10(4), 309–312.

Braun, M. (2009). The evolution of emissions trading in the European Union – The role of policy networks, knowledge and policy entrepreneurs. *Accounting, Organizations and Society,* 34(3–4), 469–487.

Bureau of African Affairs. (2010). *Background note: South Africa.* Retrieved 2011, from http://www.state.gov/r/pa/ei/bgn/2898.htm.

Burtraw, D. (1996). The SO_2 emissions trading program: cost savings without allowance trades. *Contemporary Economic Policy,* 14(2), 79–94.

Burtraw, D. & Mansur, E. (1999). Environmental effects of SO_2 Trading and Banking. *Environmental Science Technology,* 33(20), 3489–3494.

Burtraw, D., Krupnick, A., Mansur, E., Austin, D. & Farrell, D. (1998). Costs and benefits of reducing air pollutants related to acid rain. *Contemporary Economic Policy,* 16(4), 379–400.

Burtraw, D., Palmer, K., Bharvirkar, R. & Paul, A. (2001). *The effect of allowance allocation on the cost of carbon emission trading.* Discussion Paper 01-30 Resources for the future.

Carlson, C., Burtraw, D., Cropper, M. & Parlmer, K.L. (2000). Sulfur Dioxide Control by electric utilities: what are the gains from trade? *The Journal of Political Economy,* 108(6), 1292–1326.

Centre for American Progress (2008). Cap and trade 101. Washington DC: Centre for American Progress.

Chameides, W. & Oppenheimer, M. (2007). *Carbon trading over taxes.* Retrieved 2010, from http://0-mediawiki.mmab.ca.innopac.up.ac.za/images/2/20/CarbonTrade.pdf.

Choi, K. & Ang, B. (2003). Decomposition of aggregate energy intensity changes in two measures: ratio and difference. *Energy Economics,* 25, 615–624.

Chu, C.-S.J. (1989). *New tests for parameter constancy in stationary and non-stationary regression models.* California, US: Unpublished manuscript, Department of Economics, University of California.

Currie, D. & Hall, S. (1994). Expectations, Learning and empirical macro economic models. *International Journal of Systems Science*, 25(5), 849-869.

Cuthbertson, K. (1988). Expectations, learning and the Kalman filter. *The Manchester School,* 56(3), 223–246.

Cuthbertson, K., Hall, S. & Taylor, M. P. (1992). *Applied econometric techniques.* New York, US: Harvester Wheatsheaf.

De Vita, G., Endresen, K. & Hunt, L. C. (2006). An empirical analysis of energy demand in Namibia. *Energy Policy,* 34, 3447–3463.

De Wet, A. & Van Eyden, R. (2005). Capital mobility in sub-saharn Africa: A panel data approach. *South African Journal of Economics,* 73, 23–35.

Department of Government Communications and Information Systems (DCGIS). (1940). South African Yearbook 1940. Pretoria, South Africa: Department of Government Communications and Information Systems

Department of Minerals and Energy (DME). (Various issues). Aggregate Energy Balances. Pretoria, South Africa: Department of Minerals and Energy.

Department of Minerals and Energy (DME). (1998). *White Paper on energy policy.* Pretoria, South Africa: Department of Minerals and Energy.

Department of Minerals and Energy (DME). (2005a). *Energy Efficiency Strategy of the Republic of South Africa.* Pretoria, South Africa: Department of Minerals and Energy.

Department of Minerals and Energy (DME). (2005b). *Energy price report 2005.* Pretoria, South Africa: Department of Minerals and Energy.

Department of Minerals and Energy (DME). (2010a). *Digest of South African energy statistics 2009.* Pretoria, South Africa: Department of Minerals and Energy.

Department of Minerals and Energy (DME). (2010b). *Energy Price Report 2009.* Pretoria, South Africa: Departments of Minerals and Energy.

Dergiades, T. & Tsoulfidis, L. (2008). Estimating residential demand for electricity in the United States, 1965–2006. *Energy Economics,* 30, 2722–2730.

Diabi, A. (1998). The demand for electric energy in Saudi Arabia: an empirical investigation. *OPEC Review, 22,* 23–29.

Dikeman, N. (2010). *Cap-and-trade vs carbon tax: 6 myths busted.* Retrieved 2010, from http://www.cleantechblog.com/2010/02/cap-and-trade-vs-carbon-tax-6-myths.html.

Dilaver, Z. & Hunt, L. (2010). Industrial electricity demand for Turkey: A structural time series analysis. *Energy Economics*, doi:10.1016/j.eneco.2010.10.001.

Durning, A. (2008). *Carbon trade or carbon tax? Both!* Retrieved 2010, from http://www.worldchanging.com/archives/008055.html.

Economic Commission for Europe (ECE). (1996). *Worldwide Energy Conservation Handbook.* Tokyo, Japan: Energy Conservation Center.

Edelston, B., Armstrong, D., Kirsch, L.D. & Morey, M.J. (2009). Electricity price impacts of alternative greenhouse gas emission cap-and-trade programs. *The electricity journal,* 22(6), 37–46.

Egorova, S. & Volchkova, N. (2004). *Sectoral and regional analysis of industrial electricity demand in Russia.* Working Paper New Economic school.

Ellerman, D.A. (2004) *The US SO2 cap-and-trade programme* In: Tradeable permits: policy evaluation, design and reform. Paris: Organisation for Economic Co-operation and Development (OECD).

Ellerman, D.A. (2007). *Forum: US experience with emissions trading.* CESifo DICE Report 4. Munich, Germany: CESifo Group.

Ellerman, D.A. (2009). *The EU's emissions trading scheme: A prototype global system? Report No 170.* Science and Policy Global Change Reports.

Ellerman, D. A., & Buchner, B. K. (2007). The European Union emissions trading scheme: Origins, Allocation and Early results. *Environmental economics and policy , 1* (1), 66-87.

Ellerman, D.A., Joskow, P.L. Schmalensee, R., Montero, J.-P. & Baily, E.M. (2000). *Markets for clean air: The US acid rain program.* New York: Cambridge University Press.

Energy Information Administration. (1999). *Energy Efficiency report: Chapter 2.* Retrieved 2009, from http://www.eia.doe.gov/emeu/efficiency/ee_ch2.htm.

Engle, R.F. & Granger, C.W. (1987). Co-integration and error correction: representation, estimation and testing. *Econometrica,* 55, 251–267.

Environmental Protection Agency (EPA). (2008). *Cap and Trade.* Retrieved 2009, from http://www.epa.gov/airmarkt/cap-trade/index.html

Eskom. (1984). *Electricity Supply Commission Escom/Eskom Annual report 1984.* Pretoria, South Africa: Eskom.

Eskom. (2010). *Generation Business plant mix, Fact Sheet.* Pretoria, South Africa: Eskom.

Eskom (n.d.). Eskom website: www.eskom.co.za.

European Union (EU). (2006). European Union Action plan for energy efficiency. Brussels, Belgium: European Union Comission

Farrell, A., Carter, R. & Raufer, R. (1999). The NO_x budget: market-based control of tropospheric ozone in the northeastern United States. *Resource and Energy economics,* 21(2), 103–124.

Fell, H.G., Mackenzie, I.A. & Prizer, W.A. (2008). *Prices versus quantities versus bankable quantities.* RFF Discussion paper No 08-32-Rev.

Freeman, S.L., Niefer, M.J. & Roop, J.M. (1997). Measuring industrial energy intensity: practical issues and problems. Energy Policy, 25(7–9), 703–714.

Fourie, L., Mohr, P. (2007). *Economics for South African students*. South Africa: Van Schaik Publishers

Gergel, S.E., Bennett, E.M., Greenfield, B.K., King, S., Overdevest, C.A. & Sumborg, B. (2004). A test of the environmental Kuzents curve using long-term watershed inputs. Ecological Applications, 14(2), 555–570.

Ghaderi, F.S., Azade, M.A. & Mhammadzabeh, S. (2006). Electricity demand function for the industries in Iran. *Information Technology Journal,* 5(3), 401–406.

Gorodnichenko, Y. & Schitzer, M. (2010). *Financial constraints and innovation: why poor countries don't catch up.* NBER Working paper No 15792.

Greening, L.A., Davis, W.B. & Khrushch, M. (1997). Comparison of six decomposition methods: application to aggregate energy intensity for manufacturing in 10 OECD countries. *Energy economics,* 19, 375–390.

Gujarati, D.N. (2003). *Basic Econometrics.* Columbus, Ohaio: McGraw-Hill.

Hansen, B. (1992). Tests for parameter instability in regressions with I(1) processes. *Journal of Business and Economic statistics,* 10(3), 321–335.

Harvey, A. (1987). Applications of the Kalman filter in econometrics. In: Cambridge Press *Advances in econometrics: Fifth World Congress Volume I*. New York, US: Econometric Society Monographs Cambridbe University.

Harvey, A. (1997). Trends, cucles and autoregressions. *The Economic Journal*, 107, 192-201.

Hausman, J.A. (1978). Specification tests in econometrics. *Econometrica,*46(6), 1251-1271.

HausmanJ.A. & Taylor, W.E. (1981). Panel data and unobservable individual effects. *Econometrica,* 49 (6), 1377-1398.

Hendry, D. & Juselius, K. (2001). Explaining Cointegration analysis: Part II. *Energy Journal,* 22, 75–120.

Hendry, D. & Juselius, K. (2000). Explaining Cointegration analysis: PartI. *Energy journal,* 21, 1–42.

Hoekstra, R. & Van den Bergh, J.C. (2003). Comparing structural decomposition analysis and index. *Energy Economics,* 25(1), 39–64.

Hondroyiannis, G. (2004). Estimating residential demand for electricity in Greece. *Energy Economics,* 26, 319–334.

Howells, M., Victor, D., Gaunt, T., Elias, R. & Alfstad, T. (2006). Beyond free electricity: the costs of electric cooking in poor households and a market-friendly alternative. *Energy Policy,* 34, 3351–3358.

Hsiao, C. (2003). *Analysis of panel data.* Cambridge, UK: Press Syndicate of the University of Cambridge, Cambridge University Press.

Hübler, M. & Keller, A. (2010). Energy savings via FDI? Empirical evidence from developing countries. *Environment and Development economics,* 15, 59–80.

Hunt, L.C., Judge, G. & Ninomiua, Y. (2003). Underlying trends and seasonality in UK energy demand: a sectoral analysis. *Energy Economics,* 25, 93–118.

Im, K.S., Pesaran, H.M. & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics,* 115(1), 53–74.

Inglesi, R. (2010). Aggregate electricity demand in South Africa: Conditional forecasts to 2030. *Applied Energy,* 87(1), 197–204.

Inglesi, R. & Blignaut, J.N. (2010). Estimating the demand elasticity for electricity by sector in South Africa. In: ERC *Putting a price in carbon: Economic instruments to mitigate climate change in South Africa and other developing countries*. Cape Town, South Africa: Energy Research Centre, University of Cape Town.

Inglesi, R. & Pouris, A. (2010). Forecasting electricity demand in South Africa: A critique of Eskom's projections. South African Journal of Science, 106(1/2), 50–54.

Inglesi-Lotz, R. (2011). Evolution of price elasticity demand in South Africa A Kalman filter application. Energy Policy, 39, 3690-3696.

Inglesi-Lotz, R. Blignaut, J.N. South Africa's electricity consumption: A sectoral decomposition analysis. Accepted in Applied Energy, doi:10.1016/j.apenergy.2011.06.018

International Energy Agency (IEA). (2001). *International emission trading from concept to reality.* Paris, France: International Energy Agency (IEA).

International Energy Agency (IEA). (2004a). *INDEEP analysis report 2004.* Paris, France: International Energy Agency (IEA).

International Energy Agency (IEA). (2004b). *Key world energy statistics.* Paris, France: International Energy Agency (IEA).

International Monetary Fund (IMF). (2009a). *World Economic Outlook April 2009.* International Monetary Fund Publications.

International Monetary Fund (IMF). (2009b). *World Economic Outlook October 2009.* Washington DC: International Monetary Fund.

International Monetary Fund (IMF). (2010). *World Economic Outlook April 2010.* Washington DC: International Monetary Fund.

Independent online (IOL). (2010). *Electricity co-generating growing*. Retrieved 2010, from http://www.iol.co.za/business/markets/south-africa/electricity-go-generation-growing-1.837757.

Isaksson, A. (2000). Financial liberalization, foreign aid, and capital mobility:evidence from 90 developing countries. *Journal of international financial markets, institutions and markets,* 11, 309–338.

Japanese government. (2006). New National Energy Strategy. Tokyo: Japanese government.

Kalman, R. (1960). A new approach to linear filtering and prediction problems. *Journal of Basic Engineering,* 82(4), 35–45.

Kalman, R. (1963). New methods in the Wiener filtering theory. In: *Proceedings of the First Symposium of engineering applications of random function theory and probability*, 270.

Kambara, T. (1992). The energy situation in China. *China quarterly,* 131, 608–636.

Kamerschen, D. & Porter, D. (2004). The demand for residential, industrial and total electricity, 1973–1998. *Energy Economics,* 26(1), 87–100.

Kasprzyk, D., Duncan, G., Kalton, G. & Singh, M. (1989). *Panel surveys.* New York, US: John Wiley.

Klepper, G. & Peterson, S.M. (2004). The EU emissions trading scheme allowance prices, trade flows and competitiveness effects. *European Environment,* 14(4), 201–218.

Korppoo, A., Lukkanen, J., Vehmas, J. & Kinnunen, M. (2008). What goes down must come up? Trends of electricity use in the North-West of Russia. *Energy Policy,* 36(9), 3588–3597.

Lawson, T. (1980). Adaptive expectations and uncertainty. *The Review of Economic Studies,* 47(2), 305–320.

Lee, C.-C. & Lee, J.-D. (2009). Income and CO_2 emissions: Evidence from a panel unit root and cointegration tests. *Energy Policy,* 37, 413–423.

Lein, S.M. (2010). When do firms adjust prices? Evidence from micro panel data. *Journal of Monetary Economics,* 57(6), 696–715.

Levin, A., Lin, C. & Chu, C.-S.J. (2002). Unit root tests in panel data: asumptotic and finite-sample properties. *Journal of Econometrics,* 108(1), 1–24.

Liddle, B. (2009). Electricity intensity convergence in IEA/OECD countries: Aggregate and sectoral analysis. *Energy Policy,* 37(4), 1470–1478.

Linn, J. (2010). The effect of cap-and-trade programs on firms' profits: evidence from the Nitrogen Oxide Trading Program. *Journal of Environmental Economics and Management* , 59(1), 1-14.

Liu, N. & Ang, B. (2007). Factors shaping aggregate energy intensity trend for industry: Energy intensity versus product mix. *Energy Economics,* 29(4), 609–635.

Liu, X., Ang, B. & Ong, H. (1992). The application of the Divisia index to the decomposition changes in industrial energy consumption. *The Energy Journal,* 13(4), 161–178.

Lundberg, L. (2009). *An econometric analysis of the Swedish industrial electricity demand.* Masters Thesis, Department of Business Administration and Social Sciences, Lulea University of Technology.

Ma, C. & Stern, D.I. (2008). China's changing energy intensity trend: A decomposition analysis. *Energy Economics,* 30(3), 1037–1053.

Mail & Guardian Online. (2008). *Nersa: power crisis cost South Africa about R50 million*. Retrieved 2009, from http://www.mg.co.za/article/2008-08-26-nersa-power-crisis-costsa-about-r50bn.

Markandya, A., Pedroso-Galinato, S. & Streimikiene, D. (2006). Energy intensity in transition economies: Is there convergence towards the EU average? *Energy Economics,* 28(1), 121–145.

Market Advisory Committee. (2007). Recommendations for designing a green cap-an-trade system for California. US: Market Advisory Committee.

Marquard, A. (2006). *The origins and development of South African energy policy.* PhD Dissertation, Faculty of Engineering and the Built environment, University of Cape Town.

Medlock III, K. & Soligo, R. (2001). Economic Development and end-use energy demand. *The Energy Journal,* 22(2), 77–106.

Mendiluce, M., Perez-Arriaga, I. & Ocana, C. (2010). Comparison of the evolution of energy intensity in Spain and in the EU15. Why is Spain different? *Energy Policy,* 38(1), 639–645.

Metcalf, G. (2008). An empirical analysis of energy intensity and its determinants at the State level. *The Energy Journal,* 29(3), 1–27.

Michel, S. (2009). A cheap and effective CO_2 cap-and-trade for electricity. *The Electricity Journal,* 22(8), 45–54.

Miketa, A. (2001). Analysis of energy intensity developments in manufacturing sectors in industrialised and developing countries. *Energy Policy,* 29(10), 769–775.

Monast, J. (2010). *Climate change and financial markets: Regulating the trade side of cap and trade.* Washington DC: Environmental Law Institute.

Morley, B. & Abdullah, S. (2010). *Environmental taxes and economic growth: Evidence from panel causality tests.* Working paper, Department of Economics, University of Bath.

Morrison, G. & Pike, D. (1977). Kalman fitering applied to statistical forecasting. *Management Sciences,* 23(7), 768–774.

Mukherjee, K. (2008). Energy use efficiency in US manufacturing: A nonparametric analysis. *Energy Economics,* 30(1), 76–96.

Nakajima, T. & Hamori, S. (2010). Change in consumer sensitivity to electricity prices in response to retail deregulation: A panel empirical analysis of the residential demand for electricity in the United States. *Energy Policy,* 38, 2470–2476.

Narayan, P., Smyth, R. & Prasad, A. (2007). Electricity consumption in G7 countries: a panel co-integration analysis of residential demand elasticities. *Energy Policy,* 35, 4485–4494.

National Energy Council (NEC). (1990). *South African energy statistics 1950–1989.* Pretoria, South Africa: National Energy Council.

National Treasury. (2010). Discussion paper for public comment Reducing Greenhouse Gas Emissions : The carbon tax option . Pretoria, South Africa.

Nordhaus, H. (2007). To tax or not to tax: Alternative approaches to slowing global warming. *Review of Environmental Economics and Policy,* 1(1), 26–44.

National Energy Regulator, (n.d.) NERSA website: www.nersa.co.za.

Odhiambo, N. (2009). Electricity consumption and economic growth in South Africa: A trivariate causality test. *Energy Economics,* 31(5), 635–640.

Oikonomou, V., Becchis, F., Steg, L. & Russolillo, D. (2009). Energy saving and energy efficiency concepts for policy making. *Energy Policy,* 37, 4787–4796.

Organisation for Economic Co-operation and Development (OECD). (2009a). *Energy balances for OECD countries.* Paris, France: Organisation for Economic Co-operation and Development.

Organisation for Economic Co-operation and Development (OECD). (2009b). *Energy balances for non-OECD countries.* Paris, France: Organisation for Economic Co-operation and Development.

Oxford advanced learners' dictionary (2005). Oxford advanced learners' dictionary. UK

Ozawa, L., Sheinbaum, C., Martin, N., Worell, E. & Price, L. (2002). Energy use and CO_2 emissions in Mexico's iron and steel industry. *Energy,* 27, 225–239.

Palmer, K., Burtraw, D., Bharvikar, R., Paul, A. (2001). Restructuring and the cost of reducing NOx emissions in electricity generation. Washington DC: Resources for future.

Parry, I. (2007). *Should we abandon cap and trade in favor of a* CO_2 *tax.* Washington DC: Resources for future.

Pouris, A. (1987). The price elasticity of electricity demand in South Africa. *Applied Economics,* 19, 1269–1277.

Pouris, A. (2008). Energy and fuels research in South African universities: A comparative assessment. *The Open Information Science Journal,* 1(9), 1–9.

Profeta, T. & Daniels, B. (2005). Design principles of *Cap and trade system for greenhouse gases.* Duke University: Nicholas institute for environmental policy solutions.

Quantec (n.d). Quantec databases for South Africa. Pretoria, South Africa.

Repetto, R. & Austin, D. (1997). *The costs of climate protection: A guide for the perplexed.* Washington DC: World Resources Institute: Climate Protection Initiative.

Republic of South Africa. (1987). *Electricity Act of Government Gazette.* Pretoria, South Africa: Republic of South Africa.

Republic of South Africa. (2004). *Act 40 of 2004 Government Gazette.* Pretoria, South Africa: Republic of South Africa.

Republic of South Africa. (2006). *Act 4 of 2006 Government Gazette.* Pretoria, South Africa: Republic of South Africa.

Republic of South Africa. 2010. Letter dated 29 January, for the South African national focal point. Pretoria, Department of Environmental Affairs http://unfccc.int/files/meetings/application/pdf/southafricacphaccord_app2.pdf Accessed 8 February 2010

Republic of South Africa. 2011. *Electricity Act of Government Gazette: Integrated Resource Plan for electricity 2010-2030.* Pretoria, South Africa: Republic of South Africa.

Sadorsky, P. (2009). Renewable energy consumption and income in emerging economies. *Energy Policy,* 37, 4021–4028.

Salta, M., Polatidis, H. & Haralambopoulos, D. (2009). Energy use in the Greek manufacturing sector: A methodological framework based on physical indicators with aggregation and decomposition analysis. *Energy,* 34(1), 90–111.

Schipper, L., Ting, M., Khrushch, M. & Golove, W. (1997). The evolution of carbon dioxide emissions from energy use in industrialised countries: an end-use analysis. *Energy Policy,* 25(7–9), 651–672.

Schleich, J., Rogge, K. & Betz, R. (2009). Incentives for energy efficiency in the EU emissions trading scheme. *Energy Efficiency,* 2, 37–67.

Schmalensee, R., Joskow, P.L., Ellerman, D.A., Montero, J.P. & Bailey, E.M. (1998). An interim evaluation of Sulphur Dioxide emissions trading. *Journal of economic perspectives,* 12(3), 53–68.

Sebitosi, A. (2008). Energy efficiency, security of supply and the environment in South Africa: Moving beyond the strategy documents. *Energy,* 33(11), 1591–1596.

Shammin, M.R. & Bullard, C. (2009). Impact of cap-and-trade policies for reducing greenhouse gas emissions on US households. *Ecological Economics,* 68(8–9), 2432–2438.

Sinton, J. & Levine, M. (1994). Changing energy intensity in Chinese industry: the relative importance of structural shift and intensity change. *Energy Policy,* 22(3), 239–255.

Slade, M. (1989). Modelling stochastic and cyclical components of technical change: An application of Kalman filter. *Journal of Econometrics,* 41(3), 363–383.

Smil, V. (1990). *China's energy.* Washington DC: Office of Technology Assessment, US Congress.

South Africa web. (n.d.). *Electricity price in South Africa*. Retrieved 2010, from http://www.southafricaweb.co.za/electricity-price-hike-south-africa.

South African Reserve Bank (SARB). (Various issues). *Quarterly Bulletin.* Pretoria, South Africa: South African Reserve Bank.

South Coastal Air Management District (2006). Annual RECLAIM audit report for the 2004 compliance year US: South Coastal Air Management District.

Statistics South Africa (StatsSA). (2009). *South Africa Energy Statistics 2009.* Pretoria, South Africa: Statistics South Africa.

Statistics South Africa (StatsSA). (2010). *Supply and Use tables 2005.* Pretoria, South Africa: Statistics South Africa.

Stavins, R. (1998). What can we learn from the Grand Policy experiment? Lessons from SO2 allowance trading. *Journal of Economic Perspectives , 12* (3), 69-88.

Stavins, R. (2007). *A US cap-and-trade system to address global climate change: Applications of cap-and-trade mechanisms.* The Hamilton Project: The Brookings Institution.

Stavins, R. (2008). Addressing climate change with a comprehensive US cap-and-trade system. *Oxford Review of Economic Policy,* 24(2), 298–321.

Streimikiene, D., Ciegis R., Grundey, D. (2008). Promotion of energy efficiency in Lithuania. Renewable and Sustainable Energy Reviews, 12, 772-789.

Sun, J. (1998). Changes in energy consumption and energy intensity: a complete decomposition model. *Energy Economics,* 20, 85–100.

Taylor, L.D. (1975). The demand for electricity: a survey. *The Bell Journal of Economics,* 6(1), 74–110.

Tiwari, P. (2000). An analysis of sectoral energy intensity in India. *Energy Policy,* 28(11), 771–778.

UCT. (2003). *Options for a basic electricity support tariff: supplementary report.* Cape Town, South Africa: Research Project 400903, University of Cape Town.

US Congress. (2007). *Energy Independence and Security Act of 2007.* Washington DC: US Congress.

US Department of State (2010). Background Note: South Africa. Retrieved 2010, from http://www.state.gov/r/pa/ei/bgn/2898.htm.

Vamvakidis, A. & Wacziarg, R. (1998). *Developing countries and the Feldstein-Horioka puzzle.* Washington DC: Working paper 98/2 International Monetary Fund.

Van Heerden, J., Blignaut, J.N. & Jordaan, A. (2008). *On the real exchange rate effects of higher electricity prices in South Africa.* Pretoria, South Africa: Working Paper, Department of Economics, University of Pretoria.

Van Heerden, J., Gerlagh, R., Blignaut, J.N., Horridge, M., Hess, S., Mabugu, R., et al. (2006). Searching for triple dividends in South Africa: Fighting CO_2 pollution and poverty while promoting growth. *The Energy Journal,* 27(2), 113–142.

Von Hirschhausen, C. & Andres, M. (2000). Long-term electricity demand in China – From quantitative to qualitative growth? *Energy Policy,* 28(4), 231–241.

Wachsmann, U., Wood, R., Lenzen, M. & Schaeffer, R. (2009). Structural decomposition of energy use in Brazil from 1970 to 1996. *Applied Energy,* 86(4), 578–587.

Waggoner, M. (2010). The House Erred: A carbon tax is better than cap and trade. *Annual meeting for the Law and Society Association* . Chicago, US.

Ward, M., Hagemann, M., Hohne, N., O'Sullivan, R., Streck, C. And Winkler, H. (2008). The role of sector no-lose targets in scaling up finance for climate change mitigation activities in developing countries. International Climate Division, Department of Environment, Food and Rural affairs (DEFRA), UK, Aukland, GrtipleC, Climate Focus, Ecofys. Retrieved from 2011, http://tinyurl.com/4orbvv4

Webber, C. (2009). Measuring structural change and energy use: Decomposition of the US economy from 1997 to 2002. *Energy Policy,* 37(4), 1561–1570.

Wiener, N. (1949). *The extrapolation, the interpolation and smoothing of stationary time series with engineering applications.* Cambridge: MIT Press.

Wing, S. (2008). Explaining the declining energy intensity of the US economy. *Resource and energy economics,* 30, 21–49.

World Energy Council (WEC). (2008). *Review and Evaluation Chapter 1.3 Definition and scope of energy efficiency.* Retrieved 2010, from http://www.worldenergy.org/publications/energy_efficiency_policies_around_the_world_review_and_evaluation/1_introduction/1175.asp.

Yandle, B., Vijayaraghavan, M. & Bhattarai, M. (2002). *The Environmental Kuznets Curve: A primer.* Montana: Research study 02-1 Property and Environment Research Center.

Zhang, Z. (2003). Why did the energy intensity fall in China's industrial sector in the 1990s? The relative importance of structural change and intensity change. *Energy Economics,* 25(6), 625–638.

Zhao, X., Ma, C. & Hong, D. (2010). Why did China's energy intensity increase during 1998–2006: Decomposition and policy analysis. *Energy Policy,* 38(3), 1379–1388.

Zhou, N., Levine, M. & Price, L. (2010). Overview of current energy efficiency policies in China. *Energy Policy*, In Press, Corrected Proof.

Ziramba, E. (2008). The demand for residential electricity in South Africa. *Energy Policy,* 36, 3450–3466.

Websites:

http://psidonline.isr.umich.edu/

http://pwt.econ.upenn.edu/

http://www.imf.org/external/index.htm

http://data.worldbank.org/

http://dsm.iea.org