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

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

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

Eq. 3.4

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

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

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

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.

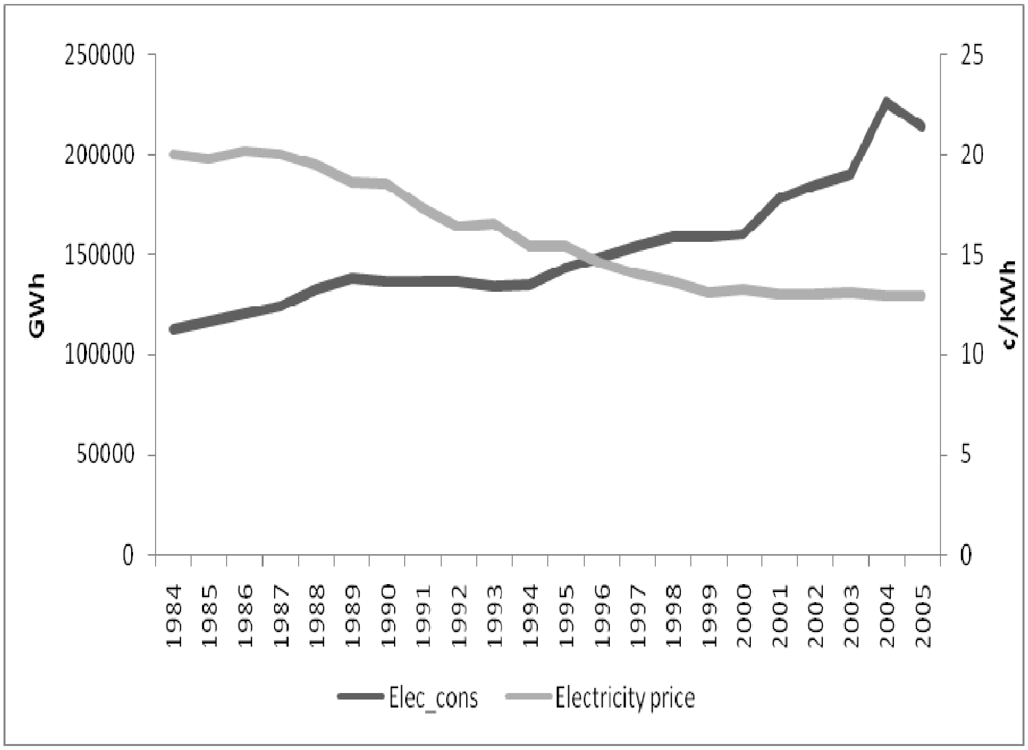


Figure 3.1 Electricity consumption and price in South Africa (1984 to 2005)
Source: DME (2005b); DME (Various issues); National Energy Council (1990)
Note: The black line represents the increasing electricity consumption of the study period in GWh, while the grey line illustrates the declining average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

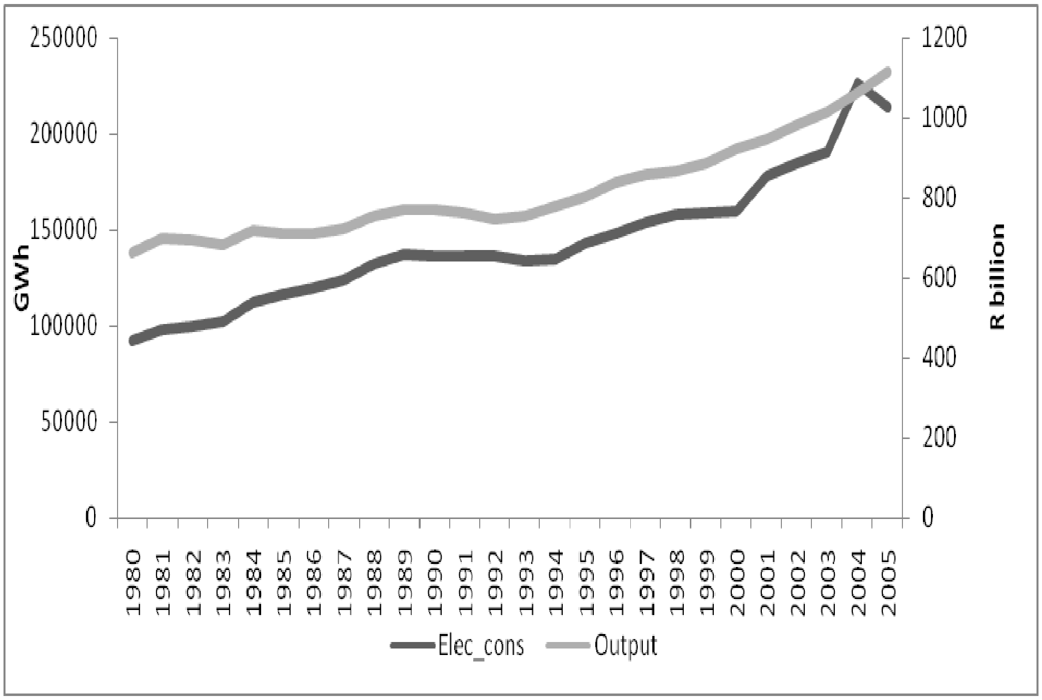


Figure 3.2 Electricity consumption and GDP in South Africa (1980 to 2005)
Source: DME (Various issues); IMF (2009a); National Energy Council (1990)
The black line represents the increasing electricity consumption of the study period in GWh, while the grey line illustrates the country's economic output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

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.

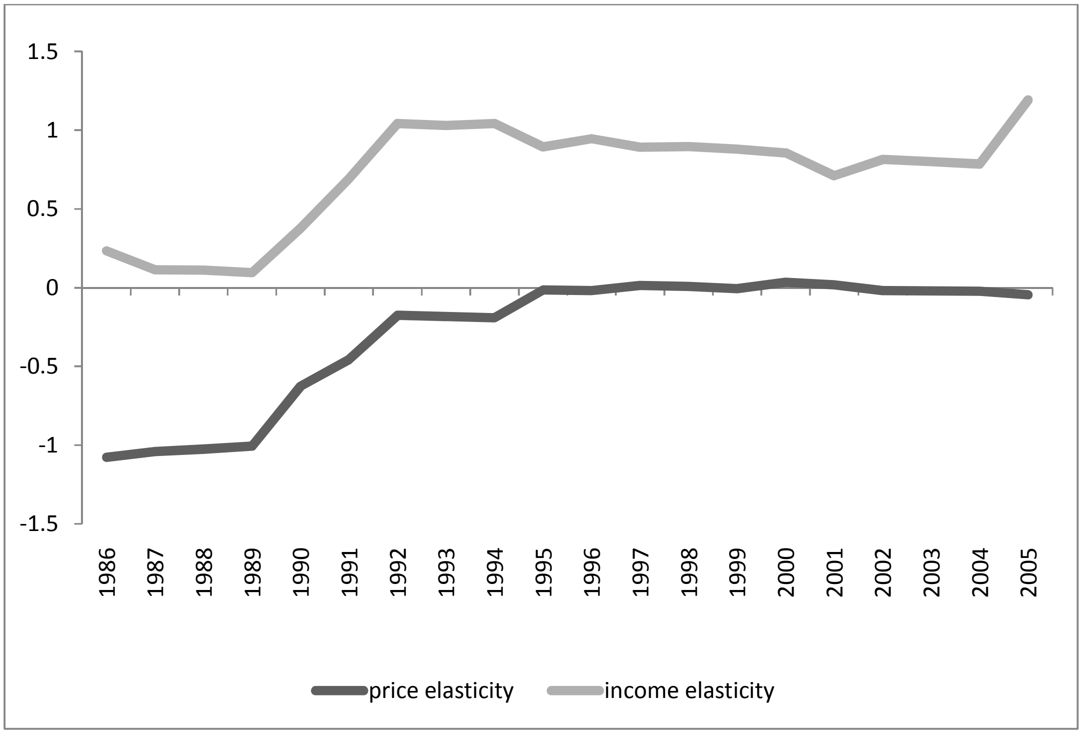


Figure 3.3 Price and income elasticities (1986–2005)
Source: Author's estimation
The black line represents the estimated price elasticity of the model while the grey line shows the estimated income elasticity of the model. It can be seen that the price elasticity was close to -1 for the first part of 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.

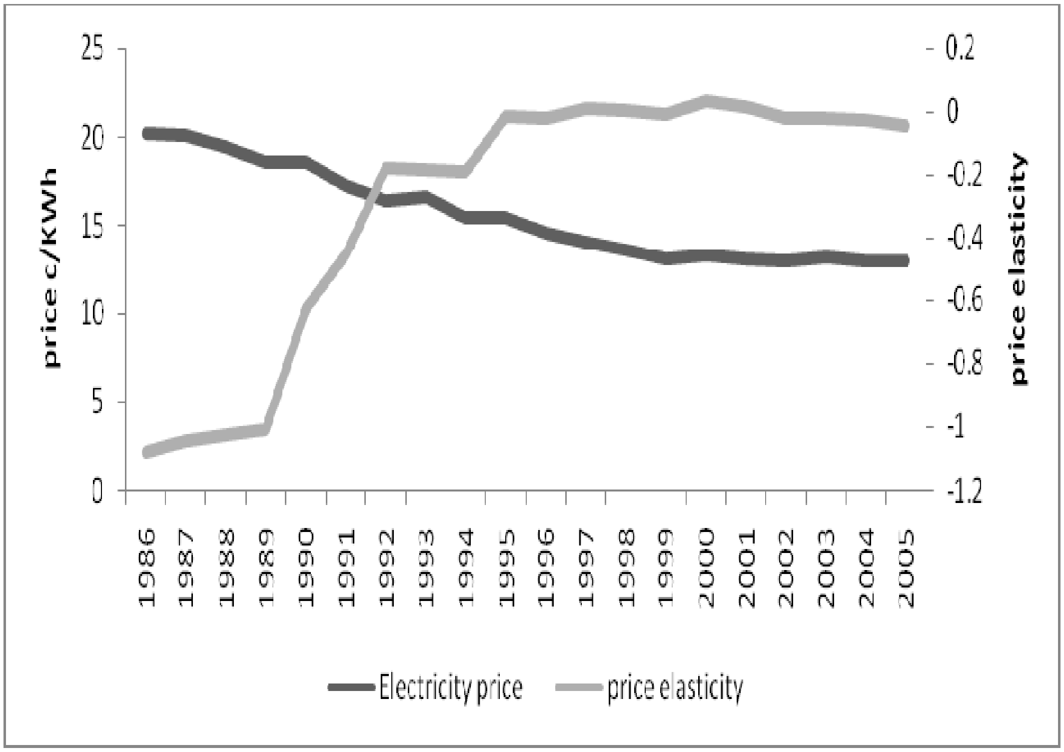


Figure 3.4 Electricity prices and price elasticity 1986-2005

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,

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

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

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

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

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.

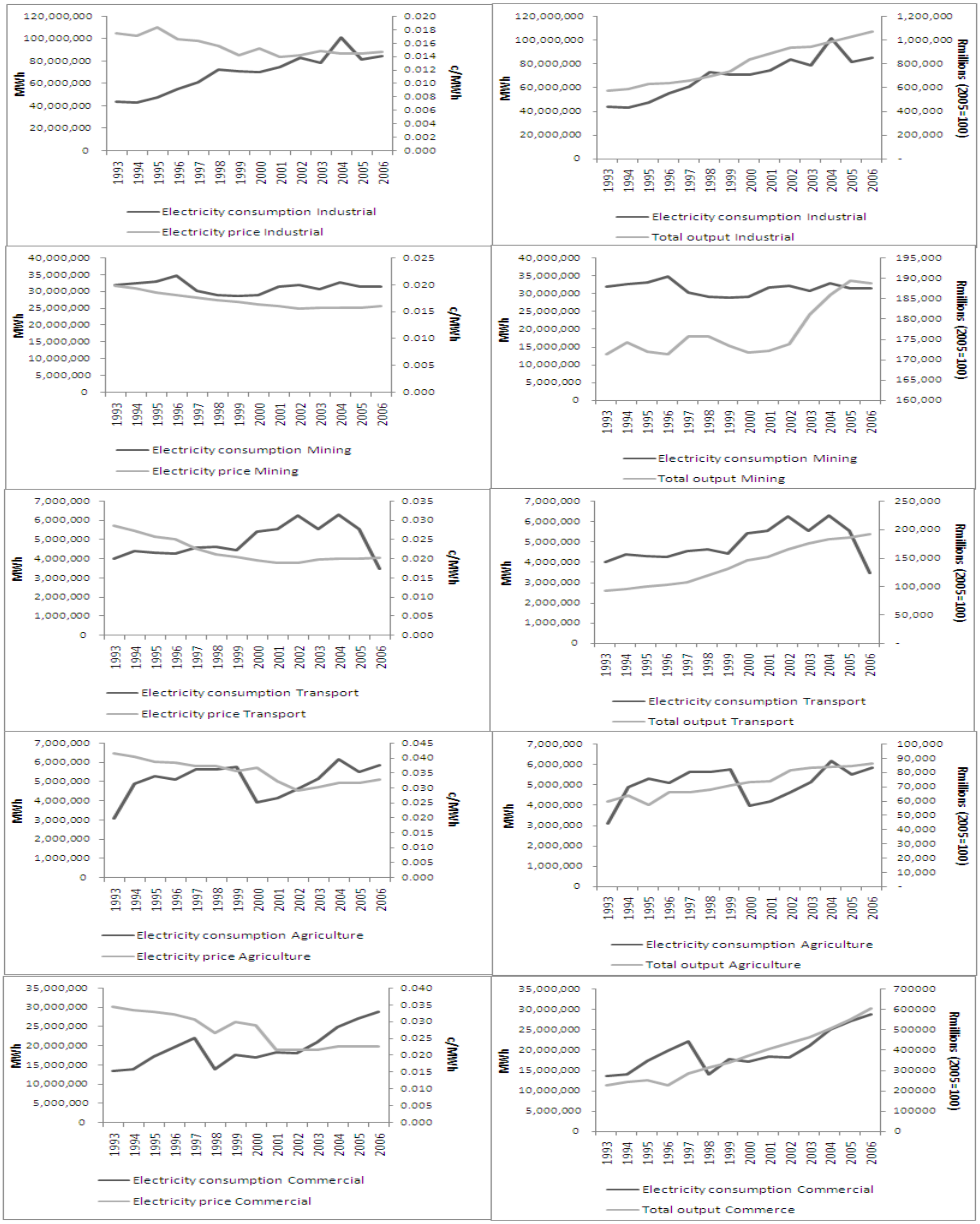


Figure 3.5 Electricity consumption, prices and economic output for the Industrial, Mining, Transport, Agriculture and Commercial sectors, 1993–2006
Source: DME (various issues); DME (2010a) and Quantec (n.d)

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

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

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

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%

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.

[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.

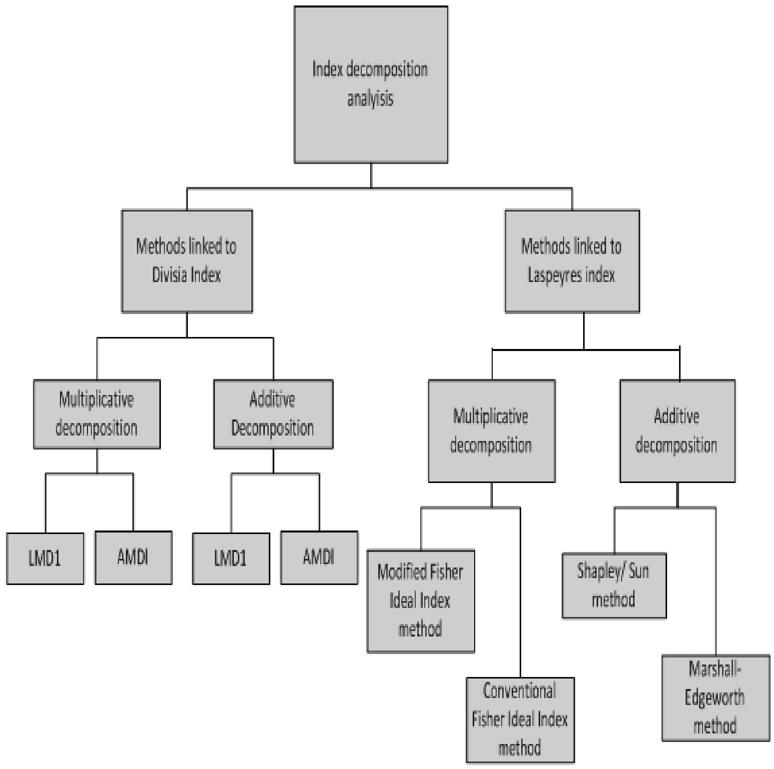


Figure 3.6 Recommended decomposition techniques

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

$$\ln\left(\frac{C_T}{C_0}\right) = \sum_{i=1}^{n}\sum_{j=1}^{m}\int_0^T w_{ij}(t)\left(\frac{dlnY_i(t)}{dt} + \frac{dlnU_{ij}(t)}{dt} + \frac{dlnS_{ij}(t)}{dt} + \frac{dlnI_i(t)}{dt}\right)dt$$

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

$$\frac{C_T}{C_0} = \exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_0^T w_{ij}(t)\frac{dlnY_i(t)}{dt}dt\right) exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_0^T w_{ij}(t)\frac{dlnU_{ij}(t)}{dt}dt\right)$$

$$exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_0^T w_{ij}(t)\frac{dlnS_{ij}(t)}{dt}dt\right) exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_0^T w_{ij}(t)\frac{dlnI_i(t)}{dt}dt\right)$$

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* ϵ [0,T], the following identity is derived:

Eq. 3.24

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

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

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

$$\exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_0^T w_{ij}(t)\frac{d\ln Y_i(t)}{dt}dt\right) \exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_0^T w_{ij}(t)\frac{d\ln U_{ij}(t)}{dt}dt\right) +$$

$$\exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_0^T w_{ij}(t)\frac{d\ln S_{ij}(t)}{dt}dt\right) \exp\left(\sum_{i=1}^{n}\sum_{j=1}^{m}\int_0^T w_{ij}(t)\frac{d\ln I_i(t)}{dt}dt\right)$$

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

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

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

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

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

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

$$\Delta\ \mathbf{E_{tot}} = \mathbf{E_t} - \mathbf{E_0} = \Delta\mathbf{E_{out}} + \Delta\mathbf{E_{str}} + \Delta\mathbf{E_{int}}$$

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

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

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

$$\Delta\mathbf{E_{prod}} = \sum_i \mathbf{w_{it}}\ \mathbf{ln}(\frac{\mathbf{Y_t}}{\mathbf{Y_0}})$$

Eq. 3.30

$$\Delta\mathbf{E_{str}} = \sum_i \mathbf{w_{it}}\ \mathbf{ln}\ (\frac{\mathbf{S_{it}}}{\mathbf{S_0}})$$

Eq. 3.31

$$\Delta\mathbf{E_{int}} = \sum_i \mathbf{w_{it}}\ \mathbf{ln}\ (\frac{\mathbf{I_{it}}}{\mathbf{I_0}})$$

Eq. 3.32

$$\Delta\mathbf{E_{tot}} = \mathbf{E_t} - \mathbf{E_0} = \sum_i \mathbf{w_{it}}\ \mathbf{ln}\ (\frac{\mathbf{Y_t S_t I_{it}}}{\mathbf{Y_0 S_{i0} I_{i0}}})$$

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

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

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.

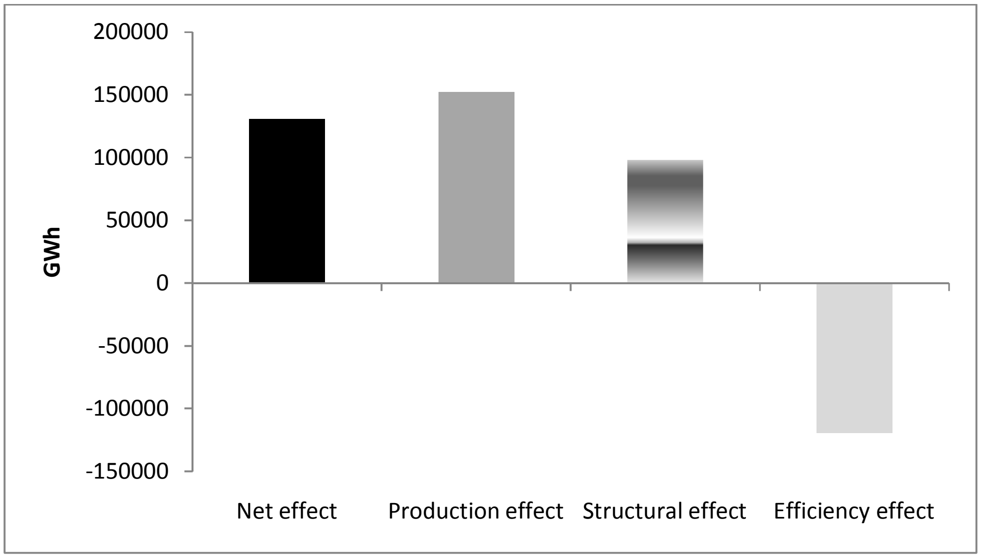


Figure 3.7 Contribution of output, structural and efficiency effects to total electricity consumption for 1993–2006
Source: Author's estimations

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.

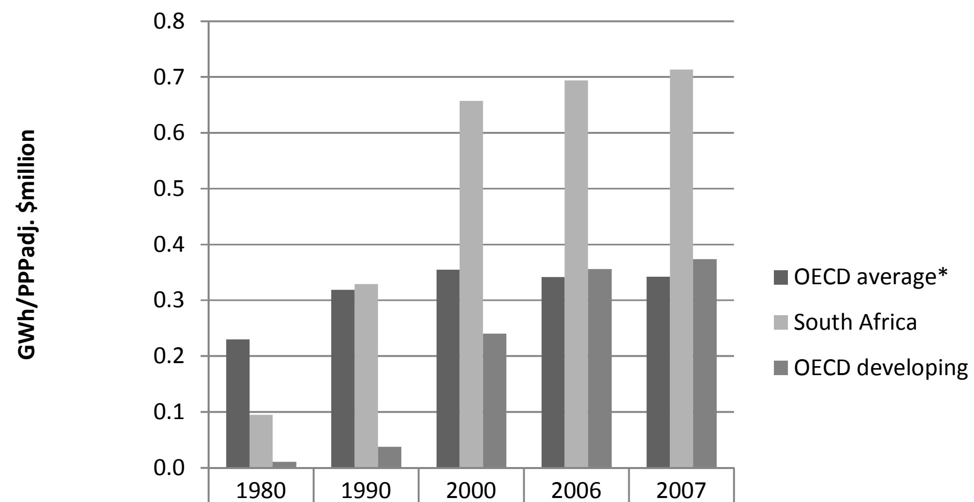
Also, the OECD's data and definitions are consolidated under one umbrella organisation. This limits the risk of data inconsistencies.

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.

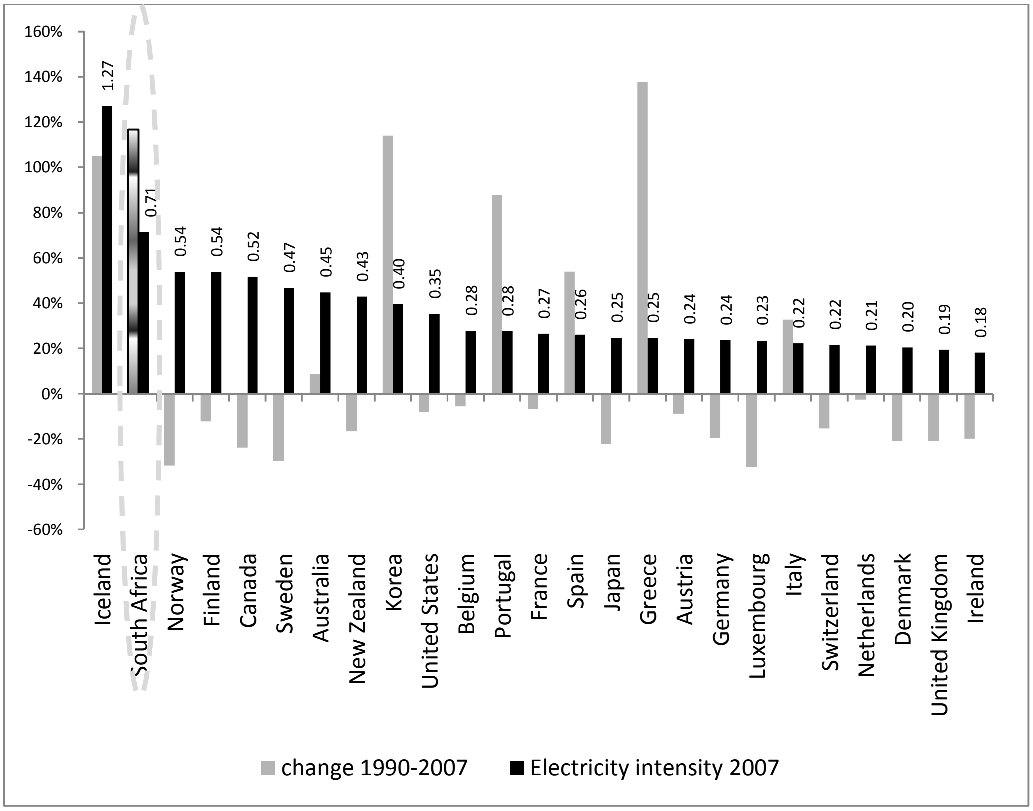


Figure 3.9 Electricity intensity in 2007 (in GWh/$millions (PPP adj)) and its growth: 1990 to 2007 for South Africa and OECD members
Source: Authors' calculations based on IMF (2010) and OECD (2009a and 2009b)

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.

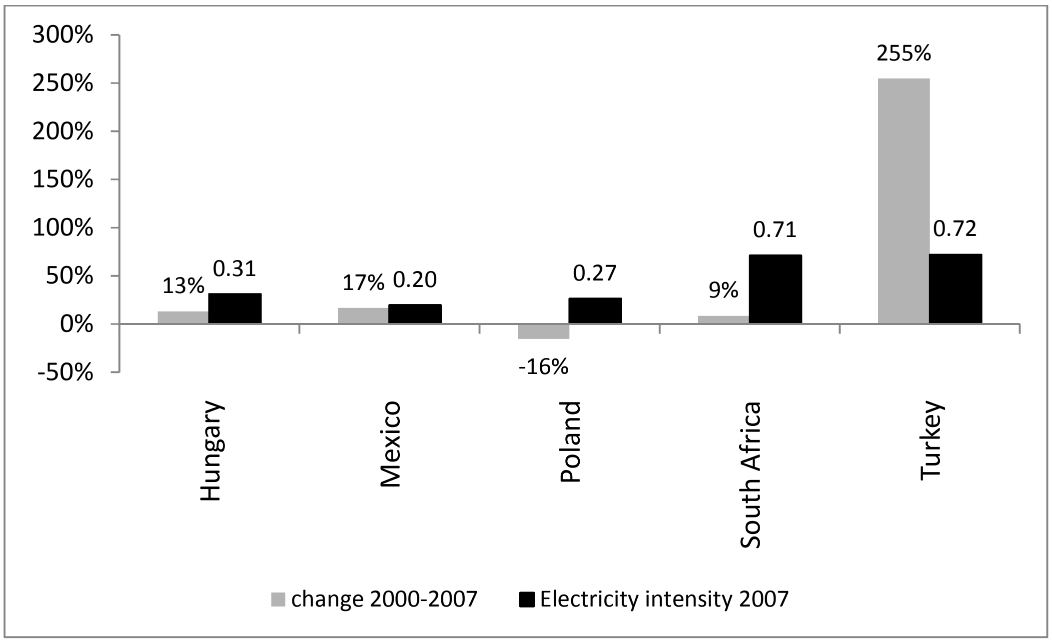


Figure 3.10 Electricity intensity in 2007 (in GWh/$ million (PPP adj)) and its growth: 2000 to 2007 for South Africa and OECD developing countries
Source: Authors' calculations based on IMF (2010) and OECD (2009a and 2009b)

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

$$\mathbf{Weighted\ growth_{\imath}} = \frac{\mathbf{electricity\ intensity_{i,2007}}}{\mathbf{electricity\ intensity_{SA,2007}}} \times \mathbf{real\ growth_{i}}$$

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

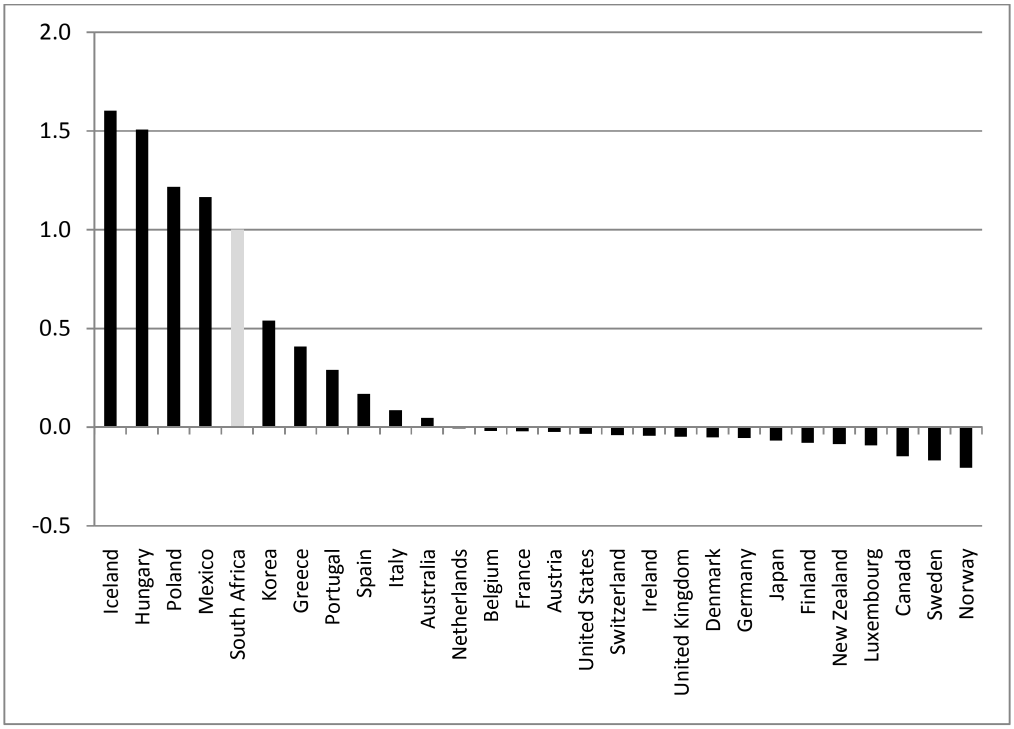


Figure 3.11 Weighted electricity intensity growth relative to South Africa's electricity intensity (where SA (2007) = 1)
Source: Authors' calculations based on IMF (2010) and OECD (2009a and 2009b)

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

$$\textbf{Weighted difference}_{\boldsymbol{i}} = \frac{\textbf{sector's output share}_{\textbf{OECDave}}}{\textbf{sector's output share}_{\textbf{SA}}} \times \textbf{ difference}$$

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.

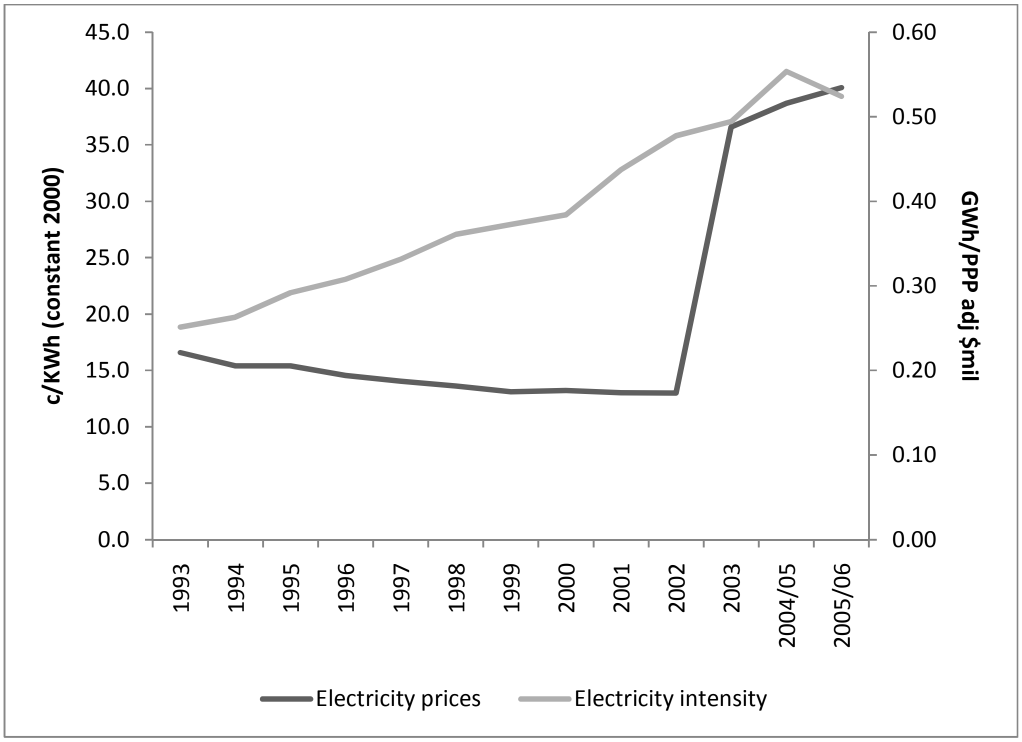


Figure 3.12 Electricity intensity and electricity prices in South Africa: 1993–2005

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.