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Title: South Africa's electricity consumption: A sectoral decomposition analysis

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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 [1]. 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 [2]. 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 [3, 4, 5, 6, 7] have indicated that there are principally three main 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.

In this study, we conduct a decomposition analysis to determine the significance of each of these three factors. We first consider the annual changes of the factors' contribution to total electricity consumption followed by a sectoral decomposition analysis for the period 1993 to 2006. This time period has been 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.

Section 2 of this paper discusses the situation of the South African electricity consumption and economic growth for the period 1993 to 2006. The research method and data characteristics are discussed in Sections 3 and 4, respectively. In Section 5, the results of the decomposition analysis are presented and Section 6 concludes the study.

2 Background

South Africa is the African continent's main producer of electricity, generating 43% of the total electricity in 2007 [8, 9]. Amusa *et al.* [8] show that 92% of electricity produced by Eskom (the national electricity provider) is produced from coal, with the remainder generated from nuclear energy (5%) and other sources (3%). This contributed to the country's high carbon emissions intensity [2] and has to be reduced to meet international commitments made.

Since the beginning of the 1990s and especially from 1994 onwards, after the democratisation of the country, the South African economy and society has undergone major structural changes. Directly as a result of apartheid policies, poor rural areas suffered from, among others, a lack of access to basic services such as electricity. Almost two-thirds of the South African population did not have access to electricity before 1994 [10]. In addition, the new (post-1994) South African government considered electricity provision as very important for the growth and development of the country [11, 12]. It is, therefore, not surprising that the demand for electricity since then has followed the country's economic growth path very closely (see Figure 1).

Take Figure 1

A closer analysis, however, is required to unpack this trend. One way of doing so is by gaining an understanding of the sectoral differences as depicted through the electricity intensities, and to then conduct a decomposition analysis to determine the main factors that has determined this growth in electricity consumption. We turn to this next.

3 Research method

The decomposition techniques as an analytical tool have attracted much interest in the energy literature over the last two decades [3, 5, 13, 14, 15, 16, 17, 18, 19, 20]. 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 [19]. 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 [3, 4, 5, 6, 7].

There are mainly two types of decomposition methodologies, namely the index decomposition analysis (IDA) [20, 21, 16] and the structural decomposition analysis (SDA) [22]. 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 [22] while IDA explains only direct (first-round) effects to the economy. The IDA applies sectoral production and electricity and the SDA requires data-intensive energy input-output analysis [4]. The advantages and constraints of each of these methods are discussed in depth by Hoekstra and Van den Bergh [23] and Ma and Stern [24]. Because of the data constraint concerning SDA, the IDA is generally perceived as the method of choice by a number of studies [25, 26, 27].

Following this tradition we also deploy the IDA method. Among the practitioners of the IDA method there are differences concerning the appropriate indexing method. We, however, concur with Mendiluce *et al.* [19], Ang and Liu [6], Ang [26] and Ang and Zhang [27] that the multiplicative and additive Log Mean Divisia Index method (LMDI) should be the preferred method for the following reasons:

- It has a solid theoretical foundation;
- Its adaptability
- Its ease of use and result interpretation;
- Its perfect decomposition;
- There is no unexplained residual term; and
- Its consistency in aggregation.

Another feature of the LMDI decomposition method is that it presents symmetry between decomposition of changes in terms of ratios or differences [28], which means that decomposition in ratios or differences conclude the same results. Given the above rationale, and the international support for, we also use the LMDI method in the same way as Zhao *et al*. [20]. The variables and terms to be used are defined as follows:

- E_t: total Industrial & Agriculture electricity consumption in year *t*

- $E_{i,t}$: electricity consumption in sector *i* in year *t*
- Y_t: total Industrial & Agriculture output in year *t*
- $Y_{i,t}$: output of sector *i* in year *t*
- $S_{i,t}$: output share of sector *i* in year *t* (=Y*i*,*t*/Y*t*)
- $I_{i,t}$: electricity intensity of sector *i* in year *t* (=E*i*,*t*/Y*i*,*t*)

Total Industrial & Agriculture electricity consumption:

$$\boldsymbol{E_t = \sum_i Y_t \frac{Y_{it}}{Y_t}\frac{E_{it}}{Y_{it}} = \sum_i Y_t\, S_{it}\, I_{it}} \quad (1)$$

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

$$\Delta\, \boldsymbol{E_{tot} = E_t - E_0 = \Delta E_{out} + \Delta E_{str} + \Delta E_{int}} \quad (2)$$

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 holds:

$$\Delta\, \boldsymbol{E_i = E_{i,t} - E_{i,0} = \Delta E_{i,out} + \Delta E_{i,str} + \Delta E_{i,int}} \quad (3)$$

Based on the approach followed by Ang [26] and Zhao *et al.* [20], the above-mentioned changes are defined as follows:

$$\boldsymbol{\Delta E_{out} = \sum_i w_{it} \ln(\frac{Y_t}{Y_0})} \quad (4)$$

$$\boldsymbol{\Delta E_{str} = \sum_i w_{it} \ln(\frac{S_{it}}{S_0})} \quad (5)$$

$$\boldsymbol{\Delta E_{int} = \sum_i w_{it} \ln(\frac{I_{it}}{I_0})} \quad (6)$$

$$\boldsymbol{\Delta E_{tot} = E_t - E_0 = \sum_i w_{it} \ln(\frac{Y_t S_t I_{it}}{Y_0 S_{i0} I_{i0}})} \quad (7)$$

Where *w* is the logarithmic weighting scheme:

$$\boldsymbol{w_{it} = L(E_{it} - E_{i0}) = (E_{it} - E_{i0})/\ln(\frac{E_{it}}{E_{i0}})} \quad (8)$$

and

$$\boldsymbol{L(x, y) = (y - x)/\ln(y/x), x \neq y} \quad (9)$$

The production effect being equal to the “change in production” is self-explanatory and does not require any further explanation. 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. It should be noted though that the structural effect is not a simple summation, but 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 these of less electricity intensive decrease, the structural effect will be positive and hence 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.

4 Data sources and characteristics

African countries suffer from a dearth of energy data and more specifically, South Africa started reporting official energy balances only from 1993 onwards. Therefore, the study period selected is from 1993 to 2006 and the sectoral data on electricity consumption and real output are collected accordingly. The study period was selected based upon data restrictions and also to avoid capturing abnormalities from the period before the country’s democratisation, which happed over the period 1990–1994.

The selection of sector level disaggregation is mainly focussed towards the primary and secondary sectors due to the nature of the economy. We therefore place more emphasis 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 household expenditure, there is not a specific indicator for 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 Quantec databases [29] and the data for the electricity consumption from the Aggregate Energy Balances of the Department of Minerals and Energy [30]. All economic measures are reported as rand millions (constant 2005 prices) and the electricity consumption is measured in GWh.

5 Results

The results of the decomposition analysis are provided in Table 1. It shows, among others, the large increase in the electricity consumption in South Africa from 1993 to 2006, which amounts to a total increase of 131,024 GWh. As expected for an economy that started growing rapidly 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) in the economy also contributed to the increase of the electricity consumption (98,220 or 64%).

Take Table 1

In contrast, the efficiency effect (change in the level of electricity intensity), as expected, was the only contributing factor on the decreasing side of electricity consumption. Although both electricity consumption and total output increased substantially over the study period, making the overall electricity intensity of the country rise, the rate of increased, however, is declining. The declining rate of increase is considered to be efficiency improvements.

The efficiency improvements contributed a decrease of 119,560 GWh to 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 120TWh if it was not for these changes in electricity intensity. This important result of the exercise is particularly useful for policy making as it indicates, firstly, the important role that technological improvements can play, and, secondly, the degree to which efficiency additional improvements are required to offset the production and structural effects. The overall effects of the two factors for the period 1993 to 2006 are diagrammatically illustrated in Figure 2.

Take Figure 2

These results are in accordance with findings for China [20]. Their results showed that efficiency improvements are the only decreasing factor to electricity consumption, however, this effect could not completely offset the high contribution of the production and structural changes on the increasing side. The results are, however, in contrast with a number of other studies. The first group, Sinton and Levine [31] and Zhang [32], conclude that the improvements in electricity efficiency are the most influential factor to the economy-wide trend in electricity consumption among developed countries. The second group, Smil [33] and Kambara [34], who studied emerging and developing economies, indicate that structural changes are the dominant effect driving the increases in electricity consumption. The South African results are therefore unique in that, as a developing country and emerging economy that has seen much political change over the last 2 decades, that the economic structure and the structure of electricity consumption, is not the dominant factor. It is the output or production effect that dominates. To gain further insight into why this might be the case, one has 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 [35].

In Table 2 we present the results of a sectoral decomposition analysis. This is very 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. In the table the sectors are organised according to their efficiency effect with the sector in which efficiency improvements in absolute terms was the highest listed first. In the last column, the sectors' ranking with regards to their aggregate effect to electricity consumption for the period 1993 to 2006 is provided.

Take Table 2

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 the national electricity consumption were ‘non-ferrous metals’ (14,089 GWh), ‘iron and steel’ (13,027 GWh) and ‘chemical and petrochemical’ (8,449 GWh). 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 has played a role in only five out of fourteen sectors in the reduction of electricity consumption (‘transport’, ‘iron and steel’, ‘mining and quarrying’, ‘wood and wood products’ and ‘machinery’). However, ‘non-ferrous metals’ that contributed much to the aggregate effect (i.e. contribution to electricity consumption) is the one that presented the highest positive efficiency effect, i.e. a worsening of efficiency, (3,572 GWh). From this it is clear that even though the national, economy-wide, effects shown in Table 1 indicates a slowdown in the rate of increase in electricity intensity, and hence efficiency improvements, that this effect is not a country-wide phenomena. It is highly sector specific. The efficiency effect is dominated by the transport sector and it therefore justifies special attention. One of the major electricity users in the transport sector is freight rail. This sector all but collapsed over 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 efficiency effect reported here therefore is not necessarily that of improved use of electricity-based transport, but a change in transport modus, or technology change. It is therefore not a bona fide efficiency improvement.

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

6 Conclusion

This study examines the situation of electricity consumption in South Africa for the period 1993 to 2006. The purpose of the analysis is to identify factors that led to the increasing levels of electricity consumption for the period. To do so, decomposition techniques were applied in order to break down the consumption into three main factors: the changes in production, structural changes of the economy and finally, efficiency improvements.

Our findings show that electricity consumption is mostly affected by output changes followed by efficiency improvements and lastly, by structural changes. Also, their contribution to electricity consumption trends increased through the years. From the period 1993-94 to 1996-97 (see Table 1), changes in the structure of the economy considerably influenced the increase in electricity consumption. From the year after, the efficiency improvements contributed more towards the decreasing side of the consumption. Until the end of the period, intensity has shown its decreasing influence (lower than production effects) to the electricity consumption trend.

Although these findings present an important trend, examination of the factors that affected each economic sector separately would provide useful information for the South African energy policy makers. Firstly, through a sectoral decomposition exercise, dominant electricity consumer sectors can be identified. The top three contributors to the national electricity consumption were 'non-ferrous metals' (14,089 GWh), 'iron and steel' (13,027 GWh) and 'chemical and petrochemical' (8,449 GWh). 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 of the effect.

On the decreasing side of electricity consumption, however, only five out of 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 one that presented the highest positive efficiency effect (3,572 GWh).

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 sum, 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 to decrease the electricity consumption. However this increase has been dominated by positive scale effect (income or production increase) and hence, it was not able to offset the influence of the output changes. This important result of the exercise is particularly useful for policy making as further improvements on efficiency are needed to intensify its decreasing influence on electricity usage.

Macroeconomic policies aim towards the increase of the country’s production outcome. Our results have shown that this would prove unfavourable to the electricity consumption of all the sectors of the South African economy. Energy authorities would have to oppose the growth of the economy if they seek only the decrease of production in order to control the consumption increases.

On the contrary, improving the electricity efficiency on a national level would become the solution towards the decrease of electricity consumption. Unfortunately, for the studied period, its negative effects to electricity consumption have been outweighed by the high positive effects of changes in production. However, although the policy makers should focus on improving electricity efficiency, the implementation of sector-specific strategies, taking into consideration the differences between sectors’ electricity and economic profiles, will be more appropriate.

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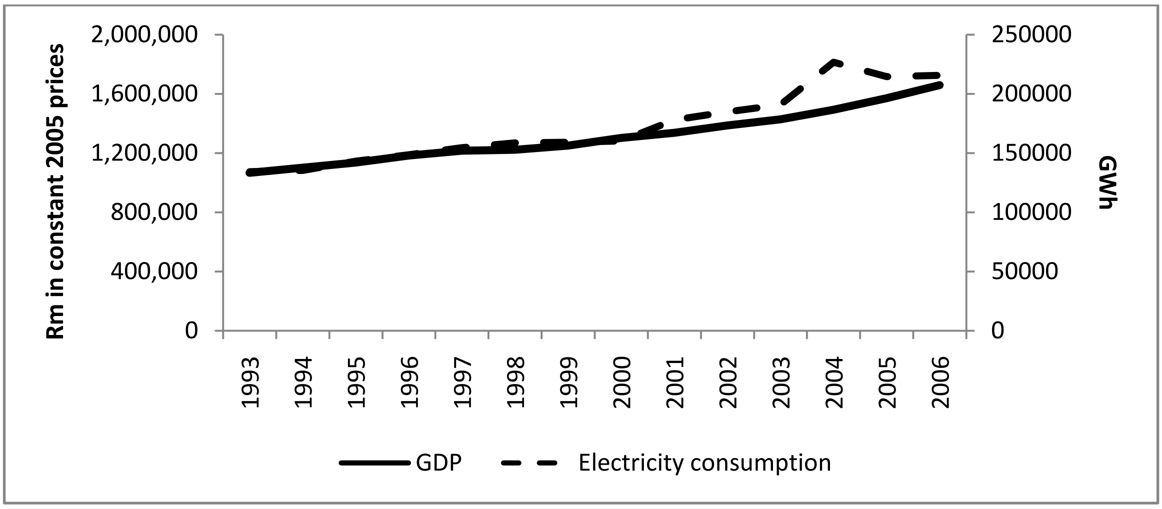
Figure 1

Figure 1: Electricity consumption and gross domestic product (GDP) in South Africa 1993 to 2006



Source: South African Reserve Bank [36] and the Department of Minerals and Energy [30].

Figure 2

Figure 1: Contribution of output, structural and efficiency effect to total electricity consumption for the period 1993 to 2006

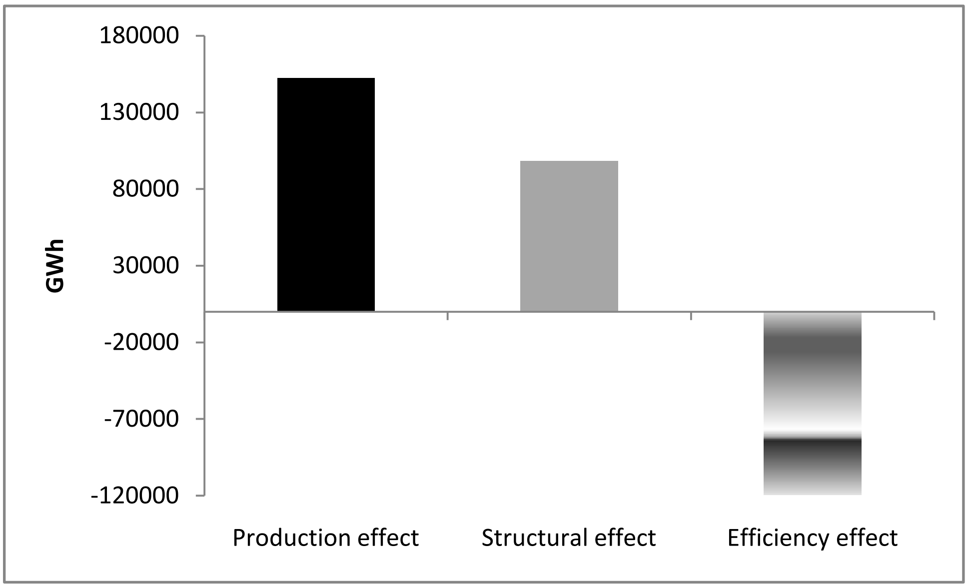


Table 1

Table 1: 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%

Table 2

Table 2: Decomposition of South Africa's electricity consumption by sector 1993 to 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	

* 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'.