Aerosol and Air Quality Research, 17: 1043–1051, 2017

ISSN: 1680-8584 print / 2071-1409 online
doi: 10.4209/aaqr.2016.11.0477

Decomposition Analysis of CO_2 Emissions from Coal - Sourced Electricity Production in South Africa

Mohamed Beidari[1], Sue-Jane Lin[1*], Charles Lewis[2]

[1] *Department of Environmental Engineering, National Cheng Kung University, Tainan 701, Taiwan*
[2] *Department of Resources Engineering, National Cheng Kung University, Tainan 701, Taiwan*

ABSTRACT

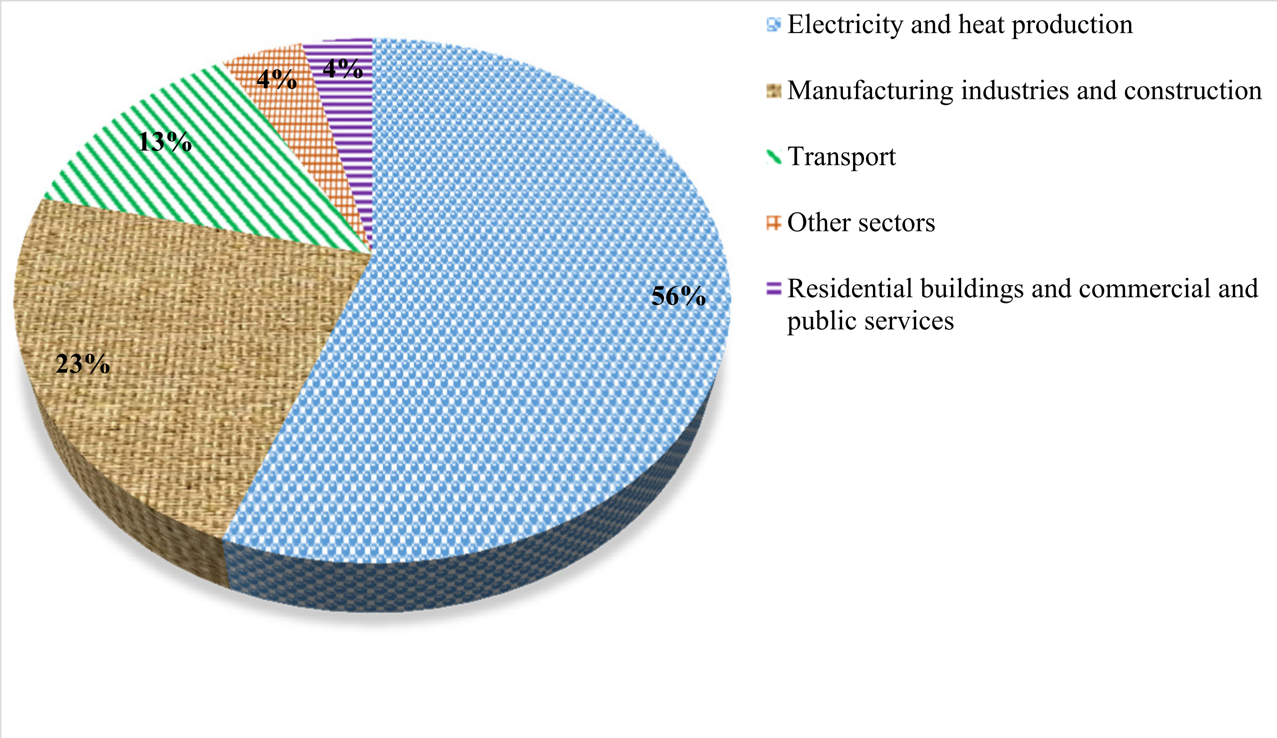
In 2013, the electricity sector was the largest source of South Africa's CO_2 emissions, accounting for about 60% of its total. South Africa (SA) is one of the highest CO_2 emitters on a per capita basis when compared to many developed and developing countries. For a better understanding of the driving forces leading the electricity-related CO_2 emission per person, this paper applies the Log Mean Divisia Index (LMDI) to analyze the influence of the factors which ruled electricity generation-related CO_2 emission in SA over the period 1990–2013. We focused on coal which is the dominant fuel used in SA for electricity generation. The results show that the electricity generation intensity effect plays the dominant role in decreasing CO_2 emissions. However, the effect of economic activity is the major determinant that contributes to increasing CO_2 emissions. In order to reduce its greenhouse gas emissions levels, meet the agreement of the COP21 agreement, and fight against CO_2 emissions per-capita associated with electricity generation, it is recommended that SA's government should improve the efficiency of its existing electricity power generation plants and expand more of its renewable energy sources (nuclear included).

Keywords: Carbon dioxide; Coal consumption; Electricity generation; LMDI method.

INTRODUCTION

South Africa (SA) is the most industrialized and developed country in Africa. According to British Petroleum (BP) Statistical Review of Energy (2014), coal accounted 72% of South Africa's total primary energy consumption, followed by oil (22%), natural gas (3%), nuclear (3%), and renewables (less than 1%) in 2013. This dependency on coal put SA as the leading carbon dioxide emitter in Africa and the 13th largest in the world, according to the latest U.S. Energy Information Administration report (EIA, 2015). Coal combustion is generally more carbon-intensive than the burning natural of gas or petroleum for electricity. Although coal represents more than 90% of the electricity generated in South Africa, which accounts for about 99% of CO_2 emissions from electricity sector and (IEA data, 2015). In 2013, the electricity sector was the largest source of SA's CO_2 emissions, accounting for about 60% of the SA total as shown in Fig. 1. Carbon dioxide emissions from electricity have increased by 64% since 1990 as electricity demand has grown and as coal has remained the dominant source for generation. Therefore, it is clear to see that the challenge of reducing greenhouse gas emissions requires the reduction of coal. To achieve such a reduction in the use of coal, it is imperative to improve the energy efficiency and increase the share of renewable energy in electricity production. For instance, Liou *et al.* (2015) modified conventional two-stage DEA to analyze the energy use efficiency and the economic efficiency of 28 Organization for Economic Co-operation and Development (OECD) countries during 2005 to 2007. Results indicated that OECD countries are only interested in economic development, have little concern for energy use efficiency, and continue to release considerable CO_2. Lin *et al.* (2015) evaluated the decoupling of CO_2 emissions from GDP in South Africa using OECD and Tapio during 1990–2012, and they investigated the primary CO_2 emission drivers with the Kaya identity. Results showed that a strong decoupling occurred during 2010–2012, and the increase in population, GDP per capita, and adverse energy efficiency were the primary driving forces for increased CO_2 emission. Muangthai *et al.* (2016) examined the Inter-Industry Linkages, Energy and CO_2 Multipliers of the Electric Power Industry in Thailand. The results showed that the electricity generation sector has a high forward linkage effect and a fairly low backward linkage effect. The results also revealed that in 2010 the electricity generation sector was the highest energy intensive and CO_2 intensive industry. Li *et al.* (2016) looked over defies and perspectives

* Corresponding author.
Tel.: +886-6-2364488; Fax: +886-6-2364488
E-mail address: t15197@mail.ncku.edu.tw



Source: consolidation from data of IEA (2015).

Fig. 1. Share of South Africa CO_2 emissions by sector in 2013 (IEA data, 2015). Other sectors include industrial waste and non-renewable municipal waste.

on carbon fixation and utilization technologies. Results revealed that CO_2 fixation via fast-growing biomass decreases CO_2 uses for supplying chemicals and energy products, while integrated alkaline waste treatment with CO_2 capture and utilization is a smart approach to accomplishing direct and indirect reduction of GHG discharges from industries.

A better and deeper understanding of the driving forces governing electricity- related CO_2 emission is useful in future policy making. To accomplish this purpose, one of the best approaches is to decompose the evolution of electricity-related CO_2 emission into possible affecting factors. To quantify the impact of different factors on change of energy consumption and CO_2 emissions, two main decomposition methods are popular today: structural decomposition analysis (SDA) and index decomposition analysis (IDA) (Ang, 2004; Wachsmann *et al.*, 2009; Chang, 2010). IDA is built on sector level data, while SDA uses the input-output (I-O) model and data to decompose the changes (Chang and Lin, 2008; Li *et al.*, 2014). IDA applies the index number concept in decomposition, and it has been universally used by scholars. For example, Lin and Chang (1996) applied the Divisia index approach to decompose emission of SO_2, NO_x and CO_2 from major economic sectors in Taiwan during 1980 to 1992. They revealed that economic growth had the leading positive effect on emission changes. Lin *et al.* (2006) also adopted the Divisia index method to determine the key factors and strategies for industrial-related CO_2 emission in Taiwan (1991–2001) by comparing the USA, Japan, Germany, Netherlands and South Korea. They assumed that economic growth was the key factor for increased CO_2 emission for all countries. Lu *et al.* (2007) associated the decoupling index with the Divisia index method to examine CO_2 emissions from highway transportation in Taiwan, Germany, Japan and South Korea during 1990–2003. Results confirmed that economic activity and motor vehicle growth were the main factors for the rise of CO_2 emissions for the four countries. Liu and Lin (2011) identified the key factors causing CO_2 emissions in Taiwan's electricity sector during 1990–2009 using the Divisia index method. The conclusion showed that economic growth is the most significant driving force for the increase of CO_2 emissions. Recently, Muangthai *et al.* (2014) used Divisia index decomposition to evaluate the key influences affecting the evolution of CO_2 emissions from Thailand's thermal power sector during 2000–2011. In order to fill the gap for which there is a lack of any comprehensive literature survey that focuses on emission studies, Xu and Ang (2013) reviewed 80 papers appearing in peer-reviewed journals from 1991 to 2012 in this application area. Among IDA methods, Ang *et al.* (2003) and Ang (2004) concluded that the LMDI method was the preferred method because this technique makes it possible to present decomposition without residuals, a very desirable property in decomposition analysis. Moreover Ang (2015) presented a guide on the implementation issues of the logarithmic mean Divisia index (LMDI) decomposition methods. Therefore, in the current decomposition system, the modified LMDI method has been recognized and widely used. Zhang *et al.* (2013) applied the Logarithmic Mean Divisia Index (LMDI) to the electricity generation in China during 1991–2009. The results showed that the economic activity effect was the most important contributor to increased CO_2 emissions from electricity generation, while the electricity generation efficiency effect played the dominant role in decreasing CO_2 emissions. Wang *et al.* (2014) also utilized the new generalized LMDI method by combining the C-D production function and the LMDI method to analyze the driving factors dominating China's energy consumption over the period 1991–2011. They found that the energy intensity effect was the most important factor for decreased energy consumption during the study period. However, the investment effect and labor effect were the critical factors in the growth of energy consumption. Furthermore, Ren *et al.* (2014) adopted the Log Mean Divisia Index (LMDI) method based on the extended Kaya identity to explore the impacts of industry structure, economic output, energy structure, energy intensity, and emission factors on the total carbon dioxide emissions from China's manufacturing industry during the period 1996–2010. The results showed that the increase in economic output has the largest effect on the increase of CO_2 emissions and that the decrease in energy intensity has produced a considerable decrease in CO_2 emissions. Moreover, Chong *et al.* (2015) analyzed the influencing factors of coal consumption growth in China using the logarithmic mean Divisia index (LMDI) decomposition method based on the physical processes of coal utilization from raw coal to the end-use sectors. The results identified the rapid growth of GDP (gross domestic production) per capita, which heavily relied on the expansion of heavy industry, as the dominant factor driving coal consumption growth. Improvement in the energy efficiency of coal power generation and coal end-use combustion were the primary factors reducing coal consumption. Cansino *et al.* (2015) also used the LMDI I to investigate the driving forces of Spain′ s CO_2 emissions. They found that renewable energy sources acted as a detriment to the drivers of CO_2 emissions. More recently, Lin and Long (2016) employed the LMDI to explore the driving factors of carbon emissions changes in China's chemical industry utilizing time series data and provincial panel data. The results pointed out that energy intensity and energy structure are conducive for a decrease in carbon emissions, while output per worker and industrial economic scale were the aggravating drivers for carbon emissions increase. Shao *et al.* (2016) also extended the previous logarithmic mean Divisia index (LMDI) decomposition model by introducing three factors: R&D intensity, investment intensity, and R&D efficiency. The results showed that among conventional (macroeconomic) factors, expanding the output scale is mainly responsible for the increase in energy-related industrial CO_2 emissions (EICE), and industrial structure adjustment is the most significant factor in mitigating EICE.

Currently, several studies have focused on energy consumption in South Africa. For example, Inglesi-Lotz and Blignaut (2011) conducted a sectoral decomposition analysis of the electricity consumption by applying the LMDI for the period 1993–2006 to determine the main drivers responsible for its increase. Inglesi-Lotz and Pouris (2012) used the LMDI to look at the factors affecting the trends in energy efficiency in South Africa from 1993 to 2006 and particularly focused on the impact of structural changes and consumption efficiency of the country's energy intensity. Recently, Zhang *et al.* (2015) considered five factors (the economic activity effect, the energy intensity effect, the fossil energy structure effect, the renewable energy structure effect and the emission-factor effect) by applying the LMDI method to analyze the contribution of the factors which influence energy-related CO_2 emissions in South Africa over the period 1993–2011. The results revealed that the energy intensity effect played the dominant role in decreasing of CO_2 emission while the economic activity was a critical factor in the growth of energy-related CO_2 emission in SA.

Moreover, Lin *et al.* (2015) mentioned that the high dependence on coal makes the country very highly carbon-intensive and one of the highest per capita emitters of CO_2 emissions when compared to many developed and developing countries. In continuation of the previous work, we focus on the electricity generation-related CO_2 emission per capita in South Africa. In order to better understand the driving forces leading electricity-related CO_2 emission, we chose the LMDI method because it is the preferred and dominant one among IDA methods (see Ang *et al.*, 2003; Ang, 2004) to analyze the influence of the factors which rule electricity generation-related CO_2 emission per capita in South Africa over the period 1990–2013. We consider coal as the main energy consumption source since it is the dominant one between among all the fossil fuels used in South Africa for electricity generation, and also because of the CO_2 emissions related with its usage (IEA data, 2015).

METHODOLOGY

The purpose of this paper is to apply the LMDI to analyze the influence of the factors which rule electricity generation-related CO_2 emission per capita in South Africa over the period 1990–2013.

Calculation of the Total CO_2 Emissions from Electricity Generation

The CO_2 emissions of a given fuel was calculated following the 2006 IPCC guidelines. It can be expressed as the following:

$$Emissions_{CO_2,fuel} = Fuel\,Consumption_{fuel} \times Emissions\,Factor_{CO_2,fuel} \tag{1}$$

where:
$Emissions_{CO_2,fuel}$ = emissions of CO_2 by type of fuel (kg)
$Fuel\,Consumption_{fuel}$ = amount of fuel combusted (TJ)
$Emissions\,Factor_{CO_2,fuel}$ = emission factor of CO_2 by type of fuel (kg TJ^{-1}).

For CO_2, the carbon oxidation factor is assumed to be one.

To calculate the total CO_2 emissions from all the source category, the emissions as calculated in Eq. (1) are summed over all fuels:

$$Emissions_{CO_2} = \sum_{fuels} Emissions_{CO_2,fuel} \tag{2}$$

The default carbon emission factors for different fuel type are listed in Table 1. Only three fuel types are considered in this paper, namely other bituminous coal, gas/diesel oil, and other primary solid biomass because they are the only carbon-based fuels involved in SA's electricity production.

Application of Logarithmic Mean Divisia Index (LMDI)

The IDA method presents several methods, but there is no agreement as to which one is the best. In this paper we followed the method proposed by Ang (2004) who argues that the LMDI should be the preferred methods because of the following reasons:

1. Solid theoretical foundation
2. Perfect decomposition (no unexplained residual term)
3. Congruity in aggregation
4. Flexibility

According to Lin *et al.* (2015), the CO_2 emissions from electricity generation can be expressed as an extended Kaya identity, as given below:

$$\begin{aligned} C = Q/P &= \frac{Q}{CEP}\frac{CEP}{EPC}\frac{EPC}{TEP}\frac{TEP}{GDP}\frac{GDP}{P} \\ &= CC \times H \times CI \times EI \times EA \end{aligned} \quad (3)$$

where
C is the CO_2 emissions per population (kt capita^{-1}) from fuels consumption;
Q is the total CO_2 emissions (kt) from fuels consumption;
CEP is the amount of coal fuel used (TJ) in SA electricity production (EP);
EPC is the coal fuel power generation (GWh) (thermal power generation) in SA;
TEP is the total electricity production (GWh) in SA;
GDP is the SA gross domestic product (constant 2005 USD);
P is the total population in SA;
CC = Q/CEP is the carbon emission coefficient (kt TJ^{-1}) from coal;
H = CEP/EPC is the reciprocal of coal based electricity generation efficiency (TJ GWh^{-1}) in South Africa;
CI = EPC/TEP is the share of electricity production from coal in SA;
EI = TEP/GDP is the electricity intensity (GWh USD^{-1}) of economy output in SA;
EA = GDP/P is the per-capita GDP (USD capita^{-1}).

The purpose of this paper is to use the LMDI to identify the major factors which influence the CO_2 emissions per capita in SA during the period 1990–2013. According to the LMDI method given by Ang (2005), the change of CO_2 emissions between a base year 0 and a target year t, denoted by ΔC_{tot} (additive decomposition), Eq. (3) can be decomposed into the following determinant factors:

$$\Delta C_{tot} = C^T - C^0 = \Delta C_{cemf} + \Delta C_{ht} + \Delta C_{sc} + \Delta C_{eint} + \Delta C_{act} \quad (4)$$

ΔC_{tot}, ΔC_{cemf}, ΔC_{ht}, ΔC_{sc}, ΔC_{eint}, and ΔC_{act}, respectively, denote the total effect, the carbon emission factors effect, the electricity generation efficiency effect, the coal intensity effect, the electricity generation intensity effect and the scale effect due to per-capita GDP growth. The LMDI formulae are summarized in Table 2.

DATA CONSOLIDATION

The data used in this study was collected from various sources. The GDP (constant 2005) is measured in USD, and the total population comes from the World Bank (2015) website. The amount of different fuel types used for electricity production is in kilo tonnes of oil equivalent (ktoe); including coal, oil, gas, biofuels, nuclear, hydro, geothermal and solar obtained from the International Energy Agency (IEA, 2015) statistics website. The amount of each carbon-based fuel (coal, oil, gas and biofuels) was converted to Tera joules (TJ) using the IEA unit conversion system for the purpose of CO_2 emission calculations of each of carbon-based fuel. From the IEA statistics website (2015), we also collected the total electricity production in SA and the total electricity generated from coal consumption. Finally, the CO_2 emissions from the different sectors in SA are from the IEA (2015) annual CO_2 emissions highlights of non-OECD countries, and the total CO_2 emissions in kilo tonnes (kt) are the sum of the CO_2 emissions from each of the carbon-based fuels as mentioned in the methodology.

RESULTS AND DISCUSSION

Trends of Energy Consumption and CO_2 Emissions from SA's Thermal Power Sector

To simplify the analysis of the results, the study period was subdivided into five sub-periods (1990–1995; 1995–2000; 2000–2005; 2005–2010 and 2010–2013). The accumulated amount of fossil fuels and coal used in the production of South Africa's electricity remains almost the same (Fig. 2). That means South Africa is enormously dependent on coal for its electricity production. From 1995 to 2010, the amount of coal used for the production of electricity has increased by 69.33%. The reason for this coal dependence might be because coal is the most abundant source of energy in SA, and its price is relatively cheaper as compared to other fuel sources. However, during the period 2010–2013, the coal

Table 1. Default emissions factors for stationary combustion in the energy industries (kg of greenhouse gas per TJ on a net calorific basis).

Fuel type	Default Emission Factor (CO_2)
Other Bituminous Coal	94 600
Gas/Diesel Oil	74 100
Other Primary Solid Biomass	100 000

Source: 2006 IPCC guidelines for national greenhouse gas inventories.

Table 2. LMDI formulae for decomposing changes in electricity generation-related CO_2 emissions.

Kaya identity $C = Q/P = \frac{Q}{CEP}\frac{CEP}{EPC}\frac{EPC}{TEP}\frac{TEP}{GDP}\frac{GDP}{P} = CC \times H \times CI \times EI \times EA$

Additive decomposition

Change scheme $\Delta C_{tot} = C^T - C^0 = \Delta C_{cemf} + \Delta C_{ht} + \Delta C_{sc} + \Delta C_{eint} + \Delta C_{act}$

LMDI formulas

$$\Delta C_{Cemf} = \frac{C^T - C^0}{lnC^T - lnC^0} ln\left(\frac{CC^T}{CC^0}\right)$$

$$\Delta C_{ht} = \frac{C^T - C^0}{lnC^T - lnC^0} ln\left(\frac{H^T}{H^0}\right)$$

$$\Delta C_{sc} = \frac{C^T - C^0}{lnC^T - lnC^0} ln\left(\frac{CI^T}{CI^0}\right)$$

$$\Delta C_{eint} = \frac{C^T - C^0}{lnC^T - lnC^0} ln\left(\frac{EI^T}{EI^0}\right)$$

$$\Delta C_{act} = \frac{C^T - C^0}{lnC^T - lnC^0} ln\left(\frac{EA^T}{EA^0}\right)$$

where

$$L\left(C^T, C^0\right) = \begin{cases} \frac{C^T - C^0}{lnC^T - lnC^0}, & C^T C^0 \neq 0 \\ C^T, & C^T = C^0 \\ 0, & C^T C^0 = 0 \end{cases}$$

ΔC_{tot}: the total effect,
ΔC_{cemf}: the carbon emission factors effect,
ΔC_{ht}: the electricity generation efficiency effect,
ΔC_{sc}: the coal intensity effect,
ΔC_{eint}: the electricity generation intensity effect,
ΔC_{act}: the scale effect due to per-capita GDP growth.

used for SA's electricity generation has decreased to 3.33%. The nuclear and renewable energy has less influence on the SA's electricity generation (Fig. 2), so the reason for the decrease of the coal usage during the period 2010–2013 is probably due to the fact that most of the power stations are approaching the end of their lifespan, resulting in substantial operational inefficiencies (Letschert *et al.*, 2013).

Fig. 2 also shows that the trends for the total CO_2 emission and CO_2 emission from coal in SA are highly similar. In fact coal accounts for about 99% of CO_2 emissions from electricity generation. That is, the CO_2 emission strongly depends on the coal consumption. The consequence of this is that SA's electricity-related CO_2 emission has increased at a rapid pace of 70% between 1990 and 2010 and decreased about 3% during 2010–2013. From what we mentioned above, it is obvious that the CO_2 emission evolves with the coal consumption.

Decomposition Analysis

The calculated results are presented over six periods (Table 3) to reflect the CO_2 emission changes in SA. The reason for this division is to simplify the analysis of the results.

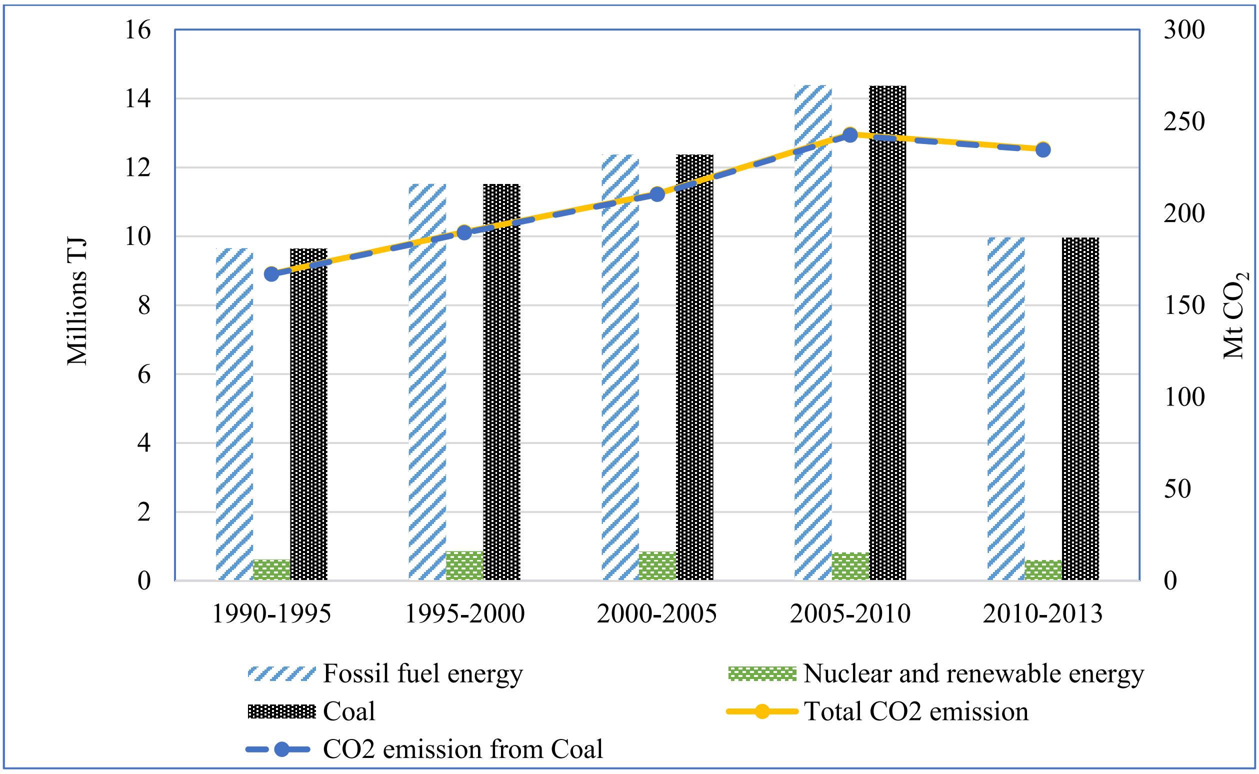
The results obtained from the decomposition analysis by the LMDI method are presented in Table 3 and Fig. 3. The CO_2 emissions reduction is majorly due to the apparent decrease of the coal intensity effect, followed by the electricity generation intensity effect. However, the economic activity and electricity generation efficiency effects are the most important contributors to increase CO_2 emissions from electricity generation in South Africa.

This analysis shows that the emissions coefficient effect (ΔC_{cemf}) plays a minor role in increasing CO_2 emissions from electricity generation except for 2000–2005. The accumulated (period-wise) effect leads to an increase of nearly 0.010 t capita^{-1} of CO_2 emissions, which accounts for 2.94% of the total change (ΔC_{tot}). However, the emissions coefficient effect is relatively small (Table 3) the carbon emission factors of other bituminous coal, gas/diesel and other primary solid biomass are assumed to be constant in the classification of fuel used for electricity generation.

The results also show that the generation efficiency effect (ΔC_{ht}) increased the CO_2 emissions, except for 2000–2005 and 2010–2013. The accumulated (period-wise) effect is a decrease of 0.311 t capita^{-1}, which accounts for 88.47% of the total change (ΔC_{tot}) in absolute value; this shows that the country still generally remains on old inefficient plants rather than switching to combined fuels that would produce a better generating efficiency, such as the switch from coal power plants to high-efficiency combined cycle gas-turbines (CCGT).

During the study period, the coal intensity effect (ΔC_{sc}) in SA's electricity generation decreases CO_2 emissions in most periods except for 2000–2005, as shown in Table 3 and Fig. 3. However, the accumulated (period-wise) effect is a decrease of 0.029 t capita^{-1}, which only accounts for 8.16% of the total CO_2 emissions per-capita change (ΔC_{tot}) in absolute value. This effect plays a minor role in decreasing CO_2 emissions, and it indicates that electricity generated by nuclear energy and renewable energy (such as hydro power and solar power) does not largely change CO_2 emissions.

Over the study period, the electricity generation intensity



Source: consolidation from data of IEA (2015).

Fig. 2. Share of energy consumption structure and the CO_2 emissions from South Africa's electricity power generation.

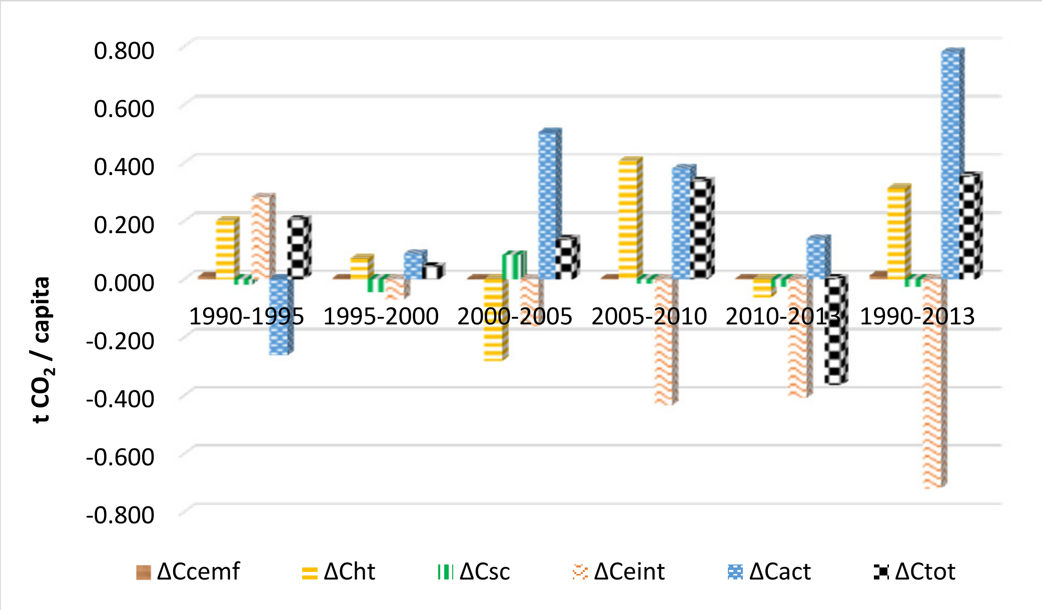
Table 3. Decomposition of the changes in CO_2 emissions in South Africa: 1990–2013.

Period	ΔC_{cemf}*	ΔC_{ht}*	ΔC_{sc}*	ΔC_{eint}*	ΔC_{act}	ΔC_{tot}*
1990–1995	0.008	0.199	–0.021	0.281	–0.263	0.204
	(3.80)	(97.74)	(–10.38)	(137.85)	(–129.00)	(100)
1995–2000	0.002	0.070	–0.045	–0.071	0.086	0.042
	(4.95)	(165.89)	(–106.45)	(–169.94)	(205.55)	(100)
2000–2005	–0.002	–0.283	0.081	–0.164	0.502	0.135
	(–1.72)	(–209.49)	(60.22)	(–121.32)	(372.31)	(100)
2005–2010	0.002	0.406	–0.017	–0.435	0.380	0.336
	(0.68)	(120.81)	(–5.02)	(–129.46)	(112.99)	(100)
2010–2013	0.001	–0.064	–0.029	–0.410	0.138	–0.365
	(0.17)	(–17.67)	(–7.82)	(–112.45)	(37.76)	(100)
1990-2013	0.010	0.311	-0.029	-0.720	0.779	0.352
	(2.94)	(88.47)	(-8.16)	(-204.62)	(221.37)	(100)

(*) means that the unit is in t/capita and the values into the brackets represent the percentage.

effect (ΔC_{eint}) plays the dominant role in decreasing CO_2 emissions except for 1990–1995. The accumulated (period-wise) effect is a decrease of 0.720 t capita^{-1}, which accounts for 204.62% of the total change (ΔC_{tot}) in absolute value. The decreasing trend might be due to new process, new technologies and new equipment, which were accompanied by the extensive application of energy-saving technologies and the advancement of management level as mentioned by Inglesi-Lotz and Pouris (2012). During the period 2010–2013, the absolute value in percentage of the electricity generation intensity effect is very large compare to others in the same period. This may be attributed to the fact that most of the power stations are approaching the end of their lifespan, resulting in substantial operational inefficiencies (Letschert *et al.*, 2013). Moreover, since the initial electricity blackouts in South Africa in 2008, the National Energy Regulator (Nersa) has granted Eskom (the SA national electricity distributer) an annual average increase of 22% a year for seven years (Eskom report; 2015); this has played a major role in decreasing the electricity demand of South Africa.

The results also reveal that the scale effect due to per-capita GDP growth (ΔC_{act}) is the major determinant that contributes positively to increasing CO_2 emissions in SA's electricity generation. The scale effect due to per-capita GDP growth indicates a continual increase of CO_2 emissions



ΔC_{tot}: the total effect,
ΔC_{cemf}: the carbon emission factors effect,
ΔC_{ht}: the electricity generation efficiency effect,
ΔC_{sc}: the coal intensity effect,
ΔC_{eint}: the electricity generation intensity effect and,
ΔC_{act}: the scale effect due to per-capita GDP growth.

Fig. 3. LMDI decomposition results of CO_2 emissions per-capita from electricity generation in SA (1990–2013).

over the study period expect in 1990–1995. The decrease for CO_2 emissions in 1990–1995 was due to the economic sanctions and probably to the effects of political instability as described by Lin *et al.* (2015). It is obvious that during most periods of decrease in electricity generation intensity, (ΔC_{act}) increased, and vice-versa. According to the World Bank data (2015), SA economic growth per-capita has an average increase of 0.83% over the study period; that means the country economy is pretty stable with a slowing growth trend. In addition, the new (post-1994) South African government considered electricity provision as very imperative for the growth and development of the country (Inglesi-Lotz and Blignaut, 2011). Moreover according to Letschert *et al.* (2013) the electricity price in South Africa is one of the lowest in the world. From the above-mentioned, it is, therefore, not surprising that the demand for electricity since then has followed the country's economic growth path very closely. The role of the structure of the economy which is associated to the path of development adopted could be the reasons for the increase of the CO_2 emissions. The accumulated (period-wise) effect of (ΔC_{act}) is an increase of 0.779 t capita^{-1}, which accounts for 221.37% of the total change (ΔC_{tot}) in absolute value.

Policy Implications

Sustainable development is a vital topic in the 21st century. The Working Group II of the Inter-governmental Panel on Climate Change (IPCC) in their Fifth Assessment Report on Climate Change (WGII AR5, 2014) characterized climate change as a challenge in managing and reducing risks, identifying options for low-cost, and high-efficacy solutions that simultaneously address climate change adaptation and sustainable development (Pachauri *et al.*, 2014). In 2009, South Africa committed to reduce its GHG emissions by 34% by 2020 and 42% by 2025 below the business as-usual (BAU) levels. In 2015, South Africa (SA) also submitted its Intended Nationally Determined Contribution (INDC) report that included a target for reducing its national emissions in a range between 398 to 614 million tonnes of carbon dioxide equivalent in the years 2025 and 2030 (Department of Environmental Affairs, 2015). Therefore, South Africa has advanced from an agreement to decrease emissions relative to the BAU, to an authentic emissions range for 2025 and 2030.

According to this study results, for the SA's government to meet the 21st Conference of Parties (COP21) agreement (Aubertin *et al.*, 2015) and fight against CO_2 emissions per-capita associated with electricity generation, the following measures are recommended for sustainable development:

(1) Improve the generation efficiency of electricity power of existing power plants by using advanced technologies or by substituting fuels that combust more efficiently. For example, a conventional coal-powered steam turbine could be converted into an advanced turbine that uses pulverized coal.
(2) Use more renewable energy sources (including nuclear source) rather to generate electricity. That can be done by increasing the share of total electricity generated from wind, solar, hydro, geothermal, biofuel and nuclear sources.

(3) Apply the CCS technique by capturing CO_2 as a by-product of coal combustion before it enters the atmosphere and then transferring the CO_2 to a long-term storage area, such as an underground geologic formation. The CO_2 is captured from the stacks of a coal-fired power plant, and then transferred via pipeline to a nearby abandoned field where the CO_2 is injected underground.
(4) Examine the demand side management (DSM) to employ operative economic approaches to reduce the electricity demand by effective economical tools to increasing efficiency and saving in households, businesses, and industries.
(5) Plan the outlook for the future; the main choice being to reduce the CO_2 emissions from power plants by switching in the fuel mix. Since coal accounts for more than 70% of the primary energy supply in SA, the change in the fuel mix away from coal will be difficult. According to Nkomo (2005) coal with the best quality is exported, while the lower quality coal is retained for domestic use; this contributes to GHG high emission levels and other environmental problems. So for a short term goal, we think SA should increase the quality of coal designated for domestic usage.

CONCLUSION

In this paper, we investigated the factors that impact the changes of CO_2 emissions per person from South Africa's electricity generation. The changes of CO_2 emissions were divided into five factors based on the LMDI method: the carbon emission factors effect, the electricity generation efficiency effect, coal intensity effect, the electricity generation intensity effect, and the scale effect due to per-capita GDP growth. The main conclusions can be expressed as following:

The CO_2 emissions reduction per-capita is majorly due to the electricity generation intensity effect followed by the apparent decreasing of the coal intensity effect which cumulatively (period-wise) account for 204.62% and 8.16% of the total change (ΔC_{tot}) in absolute value, respectively. However, the economic activity and the electricity generation efficiency effects are the most important contributors to increase CO_2 emissions from electricity generation per person in South Africa. Their accumulated (period-wise) effects account respectively for 88.47% and 221.37% of the total change (ΔC_{tot}). The decrease in the change of CO_2 emissions per-capita can be attributed to the application of energy-saving technologies, the end of most power stations' lifespan, the recent increase in electricity price, and therefore a reduction in SA's electricity demand. However, the increase of CO_2 emissions can be explained by the demographic pressure, the role of the structure of the economy which is associated with the path of development adopted in South Africa.

Base on the results of this study, to reduce its greenhouse gas emissions levels in 2025 and in 2030 in a range between 398 to 614 million tonnes of carbon dioxide equivalent, meet the agreement of the COP21 agreement, fight against CO_2 emissions per-capita associated with electricity generation and to enhance the electricity generation efficiency, a variety of opportunities to reduce greenhouse gas emissions have been proposed in the section of policy implications as suggestions to strive for better policy making decisions.

Finally, the method applied in this study can be useful to other countries with comparable cases to identify the factors that impact the changes of CO_2 emissions per capita from electricity generation and as a decision-making tool for evaluating sustainable development.

ACKNOWLEDGEMENTS

The authors would like to express our sincere appreciation to the editors and anonymous reviewers for their valuable comments and suggestions regarding this manuscript.

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Received for review, November 7, 2016
Revised, March 1, 2017
Accepted, March 13, 2017