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Multiplier Effects of Energy Consumption and CO_2 Emissions by Input-Output Analysis in South Africa

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ABSTRACT

This paper analyzed the energy consumption and CO_2 emission from 18 industrial sectors, and also evaluated the direct and indirect energy consumption and CO_2 emission of changes in the final demand of South Africa's (SA) economy. To accomplish this goal, the input-output linkage and multiplier methods have been applied to investigate the interconnectedness of the 18 sectors' input-output tables for the years 1995, 2000, 2005, 2010 and 2012, and to measure their total impact of energy commodity input coefficients and CO_2 emissions output coefficients for the year 2012. Results revealed that the electricity sector has a weak linkage with others sectors, which means it is mostly independent of other sectors. In another words, it does not induce and enable economic growth. Moreover, two sectors, such as Chemical and Petrochemical Industries and Basic Metals, were found as key sectors in SA's economy in 1995, 2000 and 2012. In 2005 and 2010, only Chemical and Petrochemical Industries was the most important sector in SA. Additionally, Commercial and Public Services was the strongest forward linkage sector in SA. Our findings also showed that the electricity sector was the main direct monetary energy consumer and CO_2 emitter, and therefore the most dominant source in terms of energy and CO_2 intensities among all the 18 sectors in SA. Furthermore, our investigation of the direct and indirect effects on energy consumption and CO_2 emissions indicated that both total of direct energy consumption and CO_2 emissions were higher than both total indirect energy consumption and CO_2 emissions. Finally, some potential suggestions on reducing the energy consumption and CO_2 emissions deduced from this study are discussed.

Keywords: Input-output analysis; Linkage and multiplier effects; Energy consumption; CO_2 emission; Electricity production sector.

INTRODUCTION

Energy plays a critical role in facilitating development in a country. Electricity is a form of energy which is essential in our daily life and is commercialized in other industry sectors. South Africa's industrial sector represented almost 30% of its gross domestic product (GDP, constant 2010) in 2014 (World Bank, 2017). South Africa is the most developed and industrialized country in Africa. Its economy relies heavily on its energy sector, which is dominated by a huge supply of coal. Coal combustion is generally more carbon-intensive than the burning of natural gas or petroleum for electricity. During the period 1990–2014, SA' s GDP, energy consumption and CO_2 emissions increased as shown on Fig. 1. The GDP rose to 412.10 billion USD from 223.04 billion USD, with an average annual growth of 2.61% (World Bank, 2017). The energy consumption and CO_2 emissions increased respectively from 2,137,277.66 Terajoules (TJ) to 3,130,721.57 TJ and 243.8 million tonnes of CO_2 (Mt CO_2) to 437.4 Mt CO_2 with a respective average annual growth of 1.66% and 2.55% (IEA data, 2016).

In 2014, SA's industrial sector had the highest share of energy consumption (37%) of the total energy consumption in the county. The transport, residential, commercial and public services, agriculture and non-specified sectors shared 24%, 23%, 6%, 3% and 2%, respectively (IEA data, 2017). Similarly, the industrial sector also led the consumption of electricity among all the other economic sectors, with 61% of the total, followed by the residential, commercial and public services, with 19% and 14%, respectively (IEA data, 2017). Furthermore, the electricity sector was the largest source of SA's CO_2 emissions, accounting for about 66% of SA's total, followed by the transportation sector with 13%, then, the industrial sector with 12%, next, the residential and commercial and public service sectors with 6%, and finally, the other sectors with 3%.

South Africa has an energy intensive economy with a high dependence on coal, as mentioned above. The country also

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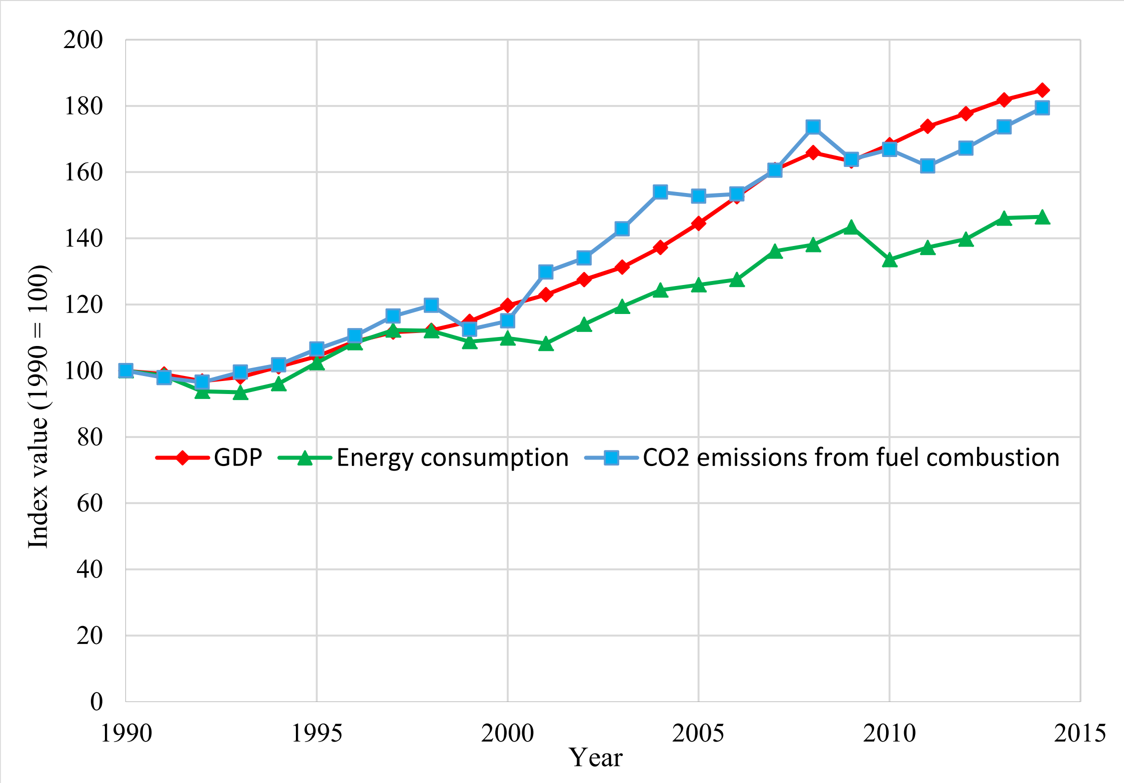

Fig. 1. Trend of GDP, Total Final Energy Consumption and CO_2 emissions (Source: consolidation from data of IEA (2017) and World bank (2017)).

has one of the cheapest sources of energy, as this is viewed as a comparative advantage for economic development. South Africa committed to reduce its GHG emissions by 34% by 2020 and 42% by 2025 under the business-as-usual (BAU) levels. In 2015, South Africa (SA) also submitted its Intended Nationally Determined Contribution (INDC) report that included a goal for reducing its national emissions to 398 and 614 million tonnes of carbon dioxide equivalent in the years 2025 and 2030 (Department of Environmental Affairs, 2015). Therefore, South Africa is confronted with the impasse of simultaneously growing its economy and responding to international pressure to reduce GHG emissions. Policy makers need to promote options that benefit the environment without being harmful to economic growth and the path of development adopted. Different methods have been used to determine the strength of the causal link between energy consumption/CO_2 emission and economic growth (Climent and Pardo, 2007). For illustration, 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. The results indicated a coupling case between energy consumption and CO_2 emissions during 2000–2005, while a relative decoupling was observed for 2006–2011. Additionally, the economic effect was the main factor leading to increased CO_2 emissions from Thailand's thermal power generation, whereas electricity intensity played a major role in decreasing CO_2 emissions. Liou *et al.* (2015) modified conventional two-stage data envelopment analysis (DEA) to analyze the energy use efficiency and the economic efficiency of 28 Organization for Economic Co-operation and Development (OECD) countries from 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 quantities of CO_2. Lin *et al.* (2015) evaluated the decoupling of CO_2 emissions from GDP in South Africa using OECD and Tapio during the period 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. Li *et al.* (2016) looked over challenges and perspectives of 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. Beidari *et al.* (2017) applied the Log Mean Divisia Index (LMDI) to investigate the influence of the factors which governed electricity generation-related CO_2 emission in SA over the period 1990–2013. The results showed that the electricity generation intensity effect was the most important contributor in decreasing CO_2 emissions. However, the effect of economic activity was the major factor that contributed to increasing CO_2 emissions.

The reasons for climate change are many and various.

Among them, these are the combustion of fossil fuels and also emission from the linkages between economic and industrial sectors. The objective of this paper is to analyze the energy consumption and energy emission from a number of economic industries, and also to evaluate the direct and indirect energy consumption and CO_2 emission of changes in the final demand in an economy. The application of Input-Output Analysis (IOA) is one of the tools widely used in the world. Many studies have applied IOA to environmental concerns related to the energy sector. Leontief (1970) was the first to introduce input-output analysis for calculating pollutant emission and assessing control approaches for major industries in the U.S.A. Lin *et al.* (2012) focused on the modeling of economic-based linkage effects of CO_2 emissions and the CO_2 multipliers from the electricity industry in Taiwan by using Input-Output Analysis. Results showed that the electricity sector had important influences on other industrial sectors in Taiwan. Liu *et al.* (2012) used Input-Output Life Cycle Assessment (I-O LCA) to assess the environmental impact of Taiwan's electricity sector during the period 2001–2006. The results pointed out that the environmental impacts of Taiwan's electricity sector increased from 2001 to 2006, and 85% of these were concentrated on eight linked sectors. Recently, Muangthai *et al.* (2016) examined the Inter-Industry Linkages, Energy and CO_2 Multipliers of the Electric Power Industry in Thailand. The results indicated 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.

Most of the previous studies in SA only focused on the linkage effects between economic sectors. They barely investigated the environmental impacts related to the interdependency of those sectors. For example, Stilwell *et al.* (2000) applied input-output methods to investigate the impacts of gold, coal, and other mining activities upon the South African economy during the period 1971–1993. The results pointed out that the linkages between mining and the rest of the economy were insufficient. Tregenna (2008) focused on the manufacturing sector by applying input-output tables to analyze inter-sectoral linkages in the South African economy. Her results demonstrated that the strong backward linkages from manufacturing to services showed that cost and quality of services inputs are critical for the competitiveness of manufacturing. Botha (2013) used IOA method to quantify and explain the total impact of South African Economy Industries in order to understand the interdependence of industries and how changes in one industry might affect other industries. Zhao *et al.* (2015) applied the environmental input-output model with the modified hypothetical extraction method to analyze the carbon linkage among sectors. The results indicated that the total carbon linkage of industrial systems in South Africa in 2005 was 171.32 million tonnes (Mt), which accounts for 81.58 Mt total backward carbon linkage and 89.71 Mt total forward carbon linkage. The results also revealed that the largest total carbon linkage and internal and net forward effect was attributed to the electricity sector.

The purpose of this study is to examine the interconnectedness of the electricity generation sectors for 18 sectors' input-output tables for the years 1995, 2000, 2005, 2010 and 2012, and to measure their total impact of energy commodity input coefficients and CO_2 emissions output coefficients for the year 2012. The electricity sector is the most prevailing source in terms of energy consumption and CO_2 emissions in SA, and also, one of the main sectors that influences its economic development. Since IOA is an effective approach that continues to grow in popularity as a method for assessing the relationship between economic activities of industrial sectors and embodied environmental impacts, this paper adopts the economic-based linkage effects of energy consumption and CO_2 emission of electricity production in SA. First, the linkage effects of the 18 aggregated sectors will be evaluated; then, their energy and CO_2 multipliers will be quantified; and finally the total ratio of direct and indirect effects energy consumption and CO_2 emissions will be carried out for the base year of 2005.

METHODOLOGY

Input-Output Analysis

As mentioned by Lin *et al.* (2012) Leontief was the first to present the input-output model and its application to significant economic problems. The industries, households, and government entities are represented in the IO model in which the output of an industry can be considered as the input of other industries. Furthermore, due to the interdependence of sectors, the balances between the total input and the aggregate output of each product and service in a given economic system can be expressed by linear equations (Leontief, 1970). Based on Lin and Chang (1997), the basic equations of the IO can be expressed as following:

$$\sum_{j=1}^{n} x_{ij} + F_i = X_i \tag{1}$$

$$\sum_{i=1}^{n} x_{ij} + V_j = X_j \tag{2}$$

$$\sum_{j=1}^{n} a_{ij} X_j + F_i = X_i \tag{3}$$

where

X_i is the total gross output produced in sector *i*,

X_j is the total gross input required in sector *j*,

F_i is the product of sector *i* delivered to the final demand,

V_j is the final payment (value added) by sector *j*,

x_{ij} is the amount of the product sector *i* used by per unit of output of sector *j*

$a_{ij} = x_{ij}/X_j$ is the direct input or technical coefficients from product sector *i* used by per unit of output sector *j*.

For example, input of aluminum (i) bought by car producers (j) in 2012 and total car production 2012 will give us the ratio of aluminum input to car output, x_{ij}/X_j [the units are (\$/\$)], and indicated it by a_{ij}:

$$a_{ij} = \frac{x_{ij}}{X_j}$$

$$= \frac{\text{value of aluminum bought by car producers in 2012}}{\text{value of car production in 2012}}$$

This ratio is called a technical coefficient. So, if x_{12} = \$500 and X_2 = \$20, 000 (sector 2 used \$500 of goods from sector 1 in producing \$20, 000 of sector 2 output), $a_{12} = x_{12} / X_2$ = \$500 / \$20,000 = 0.25. Since a_{12} is actually \$0.25/\$1, the 0.25 is represented as the "dollars' worth of inputs from sector 1 per dollars' worth of output of sector 2."

Namely that the technical coefficient represents each unit of the output value for the sector *j* that involved some amount of money to buy directly from sector *i*. Consequently, the technical structure of the entire system can be represented by the matrix of technical IO coefficients of all its sectors. In order to obtain the Leontief inverse matrix, Eq. (3) can be modified in the following matrix (Lin and Chang, 1997; Lin *et al.*, 2012):

$$AX + F = X$$

$$(I - A)\,X = F$$

or

$$X = (I - A)^{-1}F \tag{4}$$

$$X = [b_{ij}]F$$

$$X = BF$$

where
A is the direct input coefficient matrix of a_{ij},
I is the identity matrix,
B is the Leontief inverse matrix, and
b_{ij} are the elements of the Leontief inverse matrix which represent the total direct and indirect requirement of sector *i* by per unit of output sector *j* to final demand.

Linkage Effect Analysis

The idea of linkage effect was developed by Hirschman (1958). It is based on the assumption that the economy could be promoted by adopting an imbalanced investment policy to generate an equilibrium growth among the related industries. In other words, economy in related industries can be boosted through linking input/output activities.

In general, linkages have been categorized into two types: "backward linkage effect" and "forward linkage effect". Backward linkage effect refers to the demand-side connections an industrial sector has with other existing industrial sectors. From an input-output point of view, this linkage is the intermediate demand that an industrial sector makes on other industrial sectors. While forward linkage refers to the supply-side links an industrial sector has with other existing industrial sectors. For instance, many industrial sectors produce for inter-industry demand instead of final consumption. The calculation of the inter-industry linkage effect can be presented as following (Lin and Chang, 1997):

$$U_i^f = \frac{\sum_{j=1}^{n} b_{ij}}{\frac{1}{n}\sum_{i=1}^{n} b_{ij} \sum_{j=1}^{n} b_{ij}} \tag{5}$$

$$U_j^b = \frac{\sum_{i=1}^{n} b_{ij}}{\frac{1}{n}\sum_{i=1}^{n} b_{ij} \sum_{j=1}^{n} b_{ij}} \tag{6}$$

where
U_i^f is the sensibility index of dispersion, representing the forward linkage effect,
U_j^b is the power index of dispersion, representing the backward linkage effect,
b_{ij} are the elements of the Leontief inverse matrix,
$\sum_{i=1}^{n} b_{ij}$ is the sum of elements in column *j* of the Leontief inverse matrix, and
$\sum_{j=1}^{n} b_{ij}$ is the sum of elements in row *i* of the Leontief inverse matrix.

According to Miller and Blair (2009), from the normalized form of the linkages, sectors can be classified in four ways as following:
(1) mostly independent of (not strongly connected to) other sectors (both linkage measures less than 1),
(2) mostly dependent on (linked to) other sectors (both linkage measures greater than 1),
(3) dependent on inter-industry supply (only backward linkage greater than 1) and,
(4) dependent on inter-industry demand (only forward linkage greater than 1).

Multiplier Analysis

The concept of multiplier was first applied by Wright (1974) to describe the energy commodity in input-output analysis. Lin and Chang (1997) stated that various types of pollutants can be associated with a measurable way to energy consumption or processes in the sense that pollution is assimilated to the "externalities" of steady economic activities. In this paper, the "externalities" are integrated into the formal input-output analysis. Also, Miller and Blair (1985) designed the energy and environmental input-output analysis to quantify the total impact of energy commodity input coefficients and pollutant output coefficients. In this study, the multipliers were calculated by the following equations:

$$M = m(I - A)^{-1} \tag{7}$$

$$Q = q(I - A)^{-1} \tag{8}$$

where
$M = [M_j]_{1\times n}$ is the Energy Multiplier, total impact of energy coefficient, which specifies the amount of energy consumption required directly and indirectly caused by per

$10^6 worth of output of industry j, (TJ/Million USD),
$m = [m_j]_{1\times n}$, is the energy consumption coefficient from industry j, (TJ / Million USD),
$(I - A)^{-1}$ is the Leontief inverse matrix,
$Q = [Q_j]_{1\times n}$, is the CO_2 Multiplier, the total impact of CO_2 emissions, which specifies the amount of CO_2 emitted directly and indirectly caused by per $10^6 worth of output of industry j, (kt CO_2/Million USD), and
$q = [q_j]_{1\times n}$, CO_2 emissions coefficient from industry j, (kt CO_2/Million USD).

DATA CONSOLIDATION

The purpose of this study is to examine the interconnectedness of the electricity generation sectors for 18 sectors of SA based upon input-output tables for the years 1995, 2000, 2005, 2010 and 2012, and to measure their total impact of energy commodity input coefficients and CO_2 emissions output coefficients for the year 2012.

Input-output data for 1995, 2000, 2005 and 2010 (which include 34 sectors) was obtained from the Organization for Economic Cooperation and Development (OECD) input-output database (with 2011 being the latest one). In that regard, the 2012 I-O database, with 50 sectors was downloaded from Statistics South Africa (SSA, 2017) website database. Statistics South Africa database provides input-output tables from 2009 to 2012 (the most recent one). The energy consumption in (TJ) and CO_2 emissions from fuel combustion in (kt CO_2) data of Fig. 1 were collected from the International Energy Agency (IEA, 2017) statistics website. The GDP (constant 2010) was measured in USD, and the total population was from the World Bank (2017) website. The statistical energy consumption data in (TJ) for years 1995, 2000, 2005, 2010 and 2012 was collected from Energy Balance Sheets of SA Department of Energy (DOE, 2017) statistics website; the CO_2 emissions in (kt) from energy consumption of each sector were calculated following the revised guidelines 2006 IPPC (IPCC, 2006). Finally, as the sector classifications of the IO table from OECD, Statistics South Africa and those from the Energy Balance Sheets of DOE are not homogenous, we combined all the IO economic tables and energy balance tables into 18 sectors to ease the calculation and interpretation of results, as defined in Table 1.

RESULTS AND DISCUSSION

Inter-Industry Linkages

Tables 2 and 3 show the normalized values of backward and forward linkages of the 18 sectors. According to the results of these two tables, the key sectors (both linkage measures greater than 1) in SA's economy in 1995, 2000 and 2012 were Chemical and Petrochemical Industries and Basic Metals. In 2005 and 2010, only Chemical and Petrochemical Industries was the most important sector in SA. Food and Tobacco, Transport Equipment, Construction, Machinery, Chemical and Petrochemical Industries, Textile and Leather, Wood and Wood Products, Paper Products and Printing, Basic Metals, Non-Metallic Products and, Other Industries were the strong backward sectors (only backward linkage greater than 1) in 2000, 2005, 2010 and 2012. In 1995 only Other Industries sector was missing from the list. The strong forward sectors (only forward linkage greater than 1) were Commercial and Public Services, Mining and Quarrying, Chemical and Petrochemical Industries, Transport, Non-specified (Other sectors) in 1995, 2000, 2005, 2010 and 2012. In 1995, 2000 and 2012, the Basic Metals sector was also a strong forward sector, as was the

Table 1. Sectors classification.

Sectors	Energy balance sheet (DOE)[*]	34- sector I-O tables (OECD)[**]	50- sector I-O tables (SSA)[***]
1. Electricity, Gas and Water Supply	9–10, 17	19	33–34
2. Basic Metals	26, 29	11–12	25–27
3. Chemical and Petrochemical Industries	27	7–8	16–18
4. Non-Metallic Products	30	9–10	19–22
5. Transport Equipment	31	16–17	32
6. Machinery	32	13–15	28–31
7. Mining and Quarrying	33	2	4–6
8. Food and Tobacco	34	3	7–8
9. Paper Products and Printing	35	6	14–15
10. Wood and Wood Products	36	5	12–13
11. Construction	37	20	35
12. Textile and Leather	38	4	9–11
13. Transport	41–47	23	38
14. Agriculture, Forestry and Fishing	49	1	1–3
15. Commercial and Public Services	50	21–22, 24–26	36–37, 39–43, 47, 50
16. Residential	51	32–33	49
17. Other Industries	39	18	23–24
18. Non-specified (other sectors)	52	27–31	44–46, 48

Source: [*] Department of Energy (1995, 2000, 2005, 2010, 2012); [**] Economic Cooperation and Development (1995, 2000, 2005, 2010); [***] Statistics South Africa (2012).

Table 2. Sectoral backward linkage effect for 1995, 2000, 2005, 2010 and 2012.

Sector	Power index of dispersion (PIOD)									
	1995		2000		2005		2010		2012	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
1. Electricity, Gas and Water Supply	0.77	17	0.84	14	0.91	13	0.83	14	0.75	18
2. Basic Metals	1.09	9	1.11	8	1.06	8	1.09	8	1.16	2
3. Chemical and Petrochemical Industries	1.14	5	1.09	9	1.08	7	1.09	9	1.12	5
4. Non-Metallic Products	1.07	10	1.05	11	1.02	11	1.02	11	1.04	9
5. Transport Equipment	1.17	2	1.15	2	1.21	1	1.17	2	1.29	1
6. Machinery	1.15	4	1.16	1	1.16	2	1.10	4	1.16	3
7. Mining and Quarrying	0.86	13	0.83	16	0.79	16	0.79	17	0.78	16
8. Food and Tobacco	1.17	1	1.12	7	1.12	5	1.09	7	1.05	8
9. Paper Products and Printing	1.11	8	1.12	5	1.12	4	1.14	3	1.06	7
10. Wood and Wood Products	1.12	7	1.06	10	1.06	9	1.09	6	0.98	11
11. Construction	1.16	3	1.14	4	1.14	3	1.08	10	1.08	6
12. Textile and Leather	1.13	6	1.14	3	1.11	6	1.24	1	1.13	4
13. Transport	0.80	15	0.86	13	0.86	14	0.83	13	0.81	15
14. Agriculture, Forestry and Fishing	0.92	12	0.92	12	0.94	12	0.97	12	0.96	12
15. Commercial and Public Services	0.80	16	0.77	17	0.77	17	0.81	16	0.76	17
16. Residential	0.74	18	0.70	18	0.76	18	0.76	18	0.93	13
17. Other Industries	0.99	11	1.12	6	1.05	10	1.09	5	1.03	10
18. Non-specified (other sectors)	0.81	14	0.84	15	0.84	15	0.81	15	0.90	14

Table 3. Sectoral forward linkage effect for 1995, 2000, 2005, 2010 and 2012.

Sector	Sensibility index of dispersion (SIOD)									
	1995		2000		2005		2010		2012	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
1. Electricity, Gas and Water Supply	0.81	12	0.75	12	0.69	12	0.79	9	0.85	8
2. Basic Metals	1.17	4	1.10	6	0.79	9	0.81	8	1.23	4
3. Chemical and Petrochemical Industries	1.29	3	1.45	3	1.32	5	1.09	5	1.53	2
4. Non-Metallic Products	0.90	9	0.80	10	0.83	8	0.73	12	0.68	12
5. Transport Equipment	0.79	13	0.73	13	0.73	11	0.59	17	0.75	10
6. Machinery	0.92	8	0.92	7	0.98	6	0.73	11	0.93	7
7. Mining and Quarrying	1.46	2	1.59	2	1.57	2	1.73	2	1.49	3
8. Food and Tobacco	0.66	16	0.61	16	0.66	13	0.70	13	0.67	13
9. Paper Products and Printing	0.89	10	0.87	8	0.79	10	0.77	10	0.71	11
10. Wood and Wood Products	0.58	17	0.51	18	0.45	18	0.54	18	0.62	15
11. Construction	0.72	14	0.62	15	0.65	15	0.60	16	0.43	18
12. Textile and Leather	0.69	15	0.67	14	0.61	16	0.68	14	0.65	14
13. Transport	1.08	6	1.15	5	1.41	3	1.44	3	1.16	5
14. Agriculture, Forestry and Fishing	0.83	11	0.80	9	0.66	14	0.85	7	0.83	9
15. Commercial and Public Services	2.55	1	2.75	1	3.00	1	3.07	1	3.40	1
16. Residential	1.08	5	0.79	11	0.87	7	1.07	6	0.50	17
17. Other Industries	0.58	18	0.60	17	0.61	17	0.62	15	0.55	16
18. Non-specified (other sectors)	1.02	7	1.29	4	1.38	4	1.18	4	1.03	6

Residential sector in 1995 and 2010. The remaining sectors were those with weak linkages (both linkage measures less than 1) which include the Electricity sector.

An increase in the final demand of the key sectors' output will have a huge impact on sectors that supply inputs in the production of these key sectors' output. In other words, the key sectors can induce and support other sectors in economic development. The strong backward sectors generate supplementary demand for the output of upstream sectors, leading to increased upstream output, capacity utilization and upstream technological advancement. On the other hand, the strong forward sectors provide the needs for downstream sectors, comprising downstream investment or technological advancement. In other words, the strong backward sectors influence economic development while the strong forward sectors support economic development (Hirschman, 1959). The weak linkage sectors are mostly independent of other sectors; that means they do not induce nor enable economic growth. The top 5 backward and forward linkage sectors are presented in Tables 4 and 5. Commercial and Public Services was the sector with the highest forward linkage for each year of this study. It has

Table 4. Top 5 backward linkage sectors for 1995, 2000, 2005, 2010 and 2012.

Rank	Backward linkage effect				
	1995	2000	2005	2010	2012
1	Food and Tobacco	Machinery	Transport Equipment	Textile and Leather	Transport Equipment
2	Transport Equipment	Transport Equipment	Machinery	Transport Equipment	Basic Metals
3	Construction	Textile and Leather	Construction	Paper Products and Printing	Machinery
4	Machinery	Construction	Paper Products and Printing	Machinery	Textile and Leather
5	Chemical and Petrochemical Industries	Paper Products and Printing	Food and Tobacco	Other Industries	Chemical and Petrochemical Industries

Table 5. Top 5 forward linkage sectors for 1995, 2000, 2005, 2010 and 2012.

Rank	Forward linkage effect				
	1995	2000	2005	2010	2012
1	Commercial and Public Services	Commercial and Public Services	Commercial and Public Services	Commercial and Public Services	Commercial and Public Services
2	Mining and Quarrying	Mining and Quarrying	Mining and Quarrying	Mining and Quarrying	Chemical and Petrochemical Industries
3	Chemical and Petrochemical Industries	Chemical and Petrochemical Industries	Transport	Transport	Mining and Quarrying
4	Basic Metals	Non-specified (Other sectors)	Non-specified (Other sectors)	Non-specified (Other sectors)	Basic Metals
5	Residential	Transport	Chemical and Petrochemical Industries	Chemical and Petrochemical Industries	Transport

proved to be the major support of the country's economic growth (over 60% of SA's GDP) over the years (World Bank, 2017). This sector boasts other sectors by providing a full range of services such as commercial, retail and merchant banking, mortgage lending, insurance, investment, etc….

It is noticeable that electricity sector has a weak linkage and neither influences nor supports the economic development in South Africa according to the IOA results. In fact, as mentioned by Beidari *et al.* (2017), the electricity sector in SA is facing many challenges due to the increase of the price of electricity, which can be related to the aging of most power stations as they approach the end of their lifespan, causing substantial operational inefficiencies. Furthermore, since the initial electricity blackouts in 2008, Eskom (SA's national electricity distributer) is struggling to meet the country's electricity demand. That will inevitably induce a decrease in total output of the industrial sector (largest electricity consuming sector) followed by the residential, and commercial and public service (second and third largest electricity consuming sectors). The inter-industry linkages of the Electricity sector were illustrated in Table 6, where the Power Index of Dispersion (PIOD) increases from 0.77 in 1995 to 0.91 in 2005, and then decreases to 0.75 in 2012. On the other hand, the Sensibility Index of Dispersion (SIOD) drops from 0.81 in 1995 to 0.69 in 2005, and then rises to 0.85 in 2012. The increase of the PIOD from 1995 to 2005 shows that the Electricity sector in SA was taking steps to bring about the growth of the supply of other economic sectors. Likewise, the rise of the SIOD from 2005 to 2012 indicates that the Electricity sector in SA was taking to enable the growth of the demand of other economic sectors.

Energy Multiplier

The results of energy consumption, monetary energy consumption and energy multiplier of the 18 industrial sectors in 2012 are shown in Table 7. Electricity production, Gas and Water Supply, Other industries, Transport, Basic Metals and Residential are the top 5 sectors in terms of energy consumption and monetary energy consumption in 2012 in SA. Regarding the energy multiplier in 2012, the top 5 sectors are Electricity, Gas and Water Supply; Other Industries; Transport; Basic Metals; and Chemical and Petrochemical Industries. Electricity, Gas and Water Supply is the sector with the highest value of energy consumption (56% of the total), monetary energy consumption and energy multiplier in 2012. However, its gross output is very low (3% of the total). That can explain why its energy intensity and energy multiplier are the highest among other sectors. Apart from the energy multiplier values of Electricity, Gas and Water Supply; Other Industries; Transport; and Residential, the results reveal that each value of all other sectors energy multiplier is more than double their monetary energy consumption respectively. It indicates that those sectors have large indirect energy consumption.

This paper also compares the sectors' gross output and their energy intensity related rankings. The highest gross output sectors such as Commercial and Public Services, Non-specified (other sectors), Mining and Quarrying, Chemical and Petrochemical Industries, Food and Tobacco and Construction with a lower energy intensity are those industries which deserve a continuous growth of the economy. On the other hand, those with less economy such as Electricity, Gas and Water Supply, Residential and Other Industries, which demand more energy and are ranked the highest in energy intensity deserve attention for industries structure and/or the fuel structure shifting.

CO_2 Multiplier

From Table 8, we can see the results of CO_2 emissions, monetary CO_2 emissions factor and CO_2 multiplier in 2012 of the 18 industrial sectors in 2012. Similarly, Electricity, Gas and Water Supply; Other Industries; Transport; Basic Metals; and Residential sectors are the highest CO_2 emissions and monetary CO_2 emissions factors. This is quite logical insofar as if a sector consumes a huge amount of fossil fuel energy, it will probably emit a huge amount of CO_2 as well. The major sectors with the highest values of CO_2 multiplier in 2012 are Electricity, Gas and Water Supply; Other industries; Transport; Basic Metals; and Non-Metallic Products. The Electricity, Gas and Water Supply sector still remains is the dominant direct CO_2 emitter. The reason being that more than 90% of the energy consumed to generate electricity comes from coal. As in energy multiplier section, except for Electricity, Gas and Water Supply; Other Industries; Transport; and Residential, the results reveal that other sectors' CO_2 emission multipliers are more than double their monetary CO_2 emissions. This indicates that the indirect CO_2 emissions of the related sectors are larger than the direct ones. Similarly, the highest gross output sectors such as Commercial and Public Services, Non-specified (other sectors), Mining and Quarrying, Chemical and Petrochemical Industries, Food and Tobacco and Construction with a lower CO_2 emissions intensity are those industries which deserve a continued growth of the economy. On the other hand, sectors such as Electricity, Gas and Water Supply; Residential; and Other industries, which are ranked the highest in CO_2 emissions intensity deserve attention for industries structure and/or the fuel structure shifting.

Table 6. Electricity sector inter-industry linkages for 1995, 2000, 2005, 2010 and 2012.

Year	Power Index Of Dispersion	Rank	Sensibility Index Of Dispersion	Rank
1995	0.77	17	0.81	12
2000	0.84	14	0.75	12
2005	0.91	13	0.69	12
2010	0.83	14	0.79	9
2012	0.76	17	0.85	8

Table 7. Energy consumption, monetary energy consumption and energy multiplier for 2012.

Sector	Gross output (Million USD)	R*	Energy Consumption (TJ)	Monetary Energy Consumption (Tj/Million USD)	R**	Energy Consumption Multiplier (Tj/Million USD)
1. Electricity production, Gas and Water Supply	13257.14	10	3380857.31	255.02	1	304.19
2. Basic Metals	18885.29	8	265636.92	14.07	5	55.80
3. Chemical and Petrochemical Industries	24156.81	5	86343.15	3.57	9	39.12
4. Non-Metallic Products	7082.79	15	62850.32	8.87	6	36.13
5. Transport Equipment	13846.75	9	1851.80	0.13	17	27.16
6. Machinery	10447.17	12	398.20	0.04	18	25.90
7. Mining and Quarrying	34280.55	2	169921.97	4.96	7	33.49
8. Food and Tobacco	23454.52	6	7442.40	0.32	15	20.63
9. Paper Products and Printing	7894.64	14	5871.60	0.74	13	21.44
10. Wood and Wood Products	3570.23	18	1026.00	0.29	16	19.11
11. Construction	22967.53	7	8660.39	0.38	14	23.51
12. Textile and Leather	3830.38	17	10784.60	2.82	10	25.71
13. Transport	27611.47	3	760567.17	27.55	4	41.59
14. Agriculture, Forestry and Fishing	12925.08	11	60565.73	4.69	8	30.46
15. Commerce, Public Services	198851.32	1	179942.70	0.90	12	12.25
16. Residential	9947.83	13	673926.76	67.75	3	83.74
17. Other Industries	4478.86	16	305500.28	68.21	2	99.39
18. Non-specified (other sectors)	26417.48	4	52902.55	2.00	11	22.19

R* = Sectors 'gross output ranking; R** = Sectors' energy intensity ranking.

Table 8. CO_2 emissions, monetary CO_2 emissions factor and CO_2 multiplier for 2012.

Sector	Gross output (Million USD)	R*	Total CO_2 emissions (kt CO_2)	Monetary CO_2 emissions (kt CO_2/Million USD)	R**	CO_2 emissions multiplier (kt CO_2/Million USD)
1. Electricity production, Gas and Water Supply	13257.14	10	230538.28	17.3897	1	20.69
2. Basic Metals	18885.29	8	17016.12	0.9010	5	3.61
3. Chemical and Petrochemical Industries	24156.81	5	2521.43	0.1044	10	2.39
4. Non-Metallic Products	7082.79	15	5829.90	0.8231	6	2.59
5. Transport Equipment	13846.75	9	41.23	0.0030	16	1.76
6. Machinery	10447.17	12	89.66	0.0086	14	1.69
7. Mining and Quarrying	34280.55	2	4326.30	0.1262	8	2.04
8. Food and Tobacco	23454.52	6	164.19	0.0070	15	1.34
9. Paper Products and Printing	7894.64	14	225.96	0.0286	12	1.37
10. Wood and Wood Products	3570.23	18	0.00	0.0000	18	1.22
11. Construction	22967.53	7	611.55	0.0266	13	1.56
12. Textile and Leather	3830.38	17	0.56	0.0001	17	1.43
13. Transport	27611.47	3	53340.76	1.9318	4	2.85
14. Agriculture, Forestry and Fishing	12925.08	11	2961.66	0.2291	7	1.93
15. Commerce, Public Services	198851.32	1	7296.59	0.0367	11	0.79
16. Residential	9947.83	13	51266.13	5.1535	2	6.20
17. Other Industries	4478.86	16	20208.36	4.5119	3	6.55
18. Non-specified (other sectors)	26417.48	4	2986.52	0.1131	9	1.48

R* = Sectors 'gross output ranking; R** = Sectors' CO_2 emissions intensity ranking.

Direct and Indirect Effects of Energy Consumption

The calculated results of the direct and indirect effects of energy consumption of the 18 sectors are presented in Table 9. The majority of sectors have a higher indirect effect of energy consumption except for four sectors which are Electricity, Gas and Water Supply; Transport; Other Industries; and Residential. This shows that most of their energy consumption comes from the Energy sector. Electricity, Gas and Water Supply has the highest direct effect on energy consumption (83.84%) and the lowest indirect effect (16.16%). This clearly indicates that the electricity generation sector relies less on other sectors for its fuel inputs for electricity generation. Finally, the total direct effect of energy consumption of the 18 aggregated sectors accounts for 50.15%, while 49.85% is attributed to the total indirect effect of energy consumption. This can be explained by the fact that the majority of the energy consumption is directly consumed by the electricity sector. In fact, according to the result in Table 7, electricity sector totals of energy consumption and monetary energy consumption (direct energy consumption) account respectively 56% and 55% of the totals of energy consumption and monetary energy consumption, respectively.

Direct and Indirect effects of CO_2 Emissions

Table 10 presents the results related to the direct and indirect effects of CO_2 emissions of the 18 sectors in SA for the year 2012. It is quite similar to the results of direct and indirect energy consumption. As we know, the volume of CO_2 released from fossil fuel combustion depends

Table 9. Direct and indirect effects of energy consumption for the 18 aggregated sectors in 2012.

Sector	Direct effect (%)	Indirect effect (%)
1. Electricity, Gas and Water Supply	83.84	16.16
2. Basic Metals	25.21	74.79
3. Chemical and Petrochemical Industries	9.14	90.86
4. Non-Metallic Products	24.56	75.44
5. Transport Equipment	0.49	99.51
6. Machinery	0.15	99.85
7. Mining and Quarrying	14.80	85.20
8. Food and Tobacco	1.54	98.46
9. Paper Products and Printing	3.47	96.53
10. Wood and Wood Products	1.50	98.50
11. Construction	1.60	98.40
12. Textile and Leather	10.95	89.05
13. Transport	66.24	33.76
14. Agriculture, Forestry and Fishing	15.38	84.62
15. Commercial and Public Services	7.39	92.61
16. Residential	80.90	19.10
17. Other Industries	68.63	31.37
18. Non-specified (other sectors)	9.02	90.98

Table 10. Direct and indirect effects of CO_2 emissions for the 18 aggregated sectors in 2012.

Sector	Direct effect (%)	Indirect effect (%)
1. Electricity, Gas and Water Supply	84.06	15.94
2. Basic Metals	24.93	75.07
3. Chemical and Petrochemical Industries	4.37	95.63
4. Non-Metallic Products	31.80	68.20
5. Transport Equipment	0.17	99.83
6. Machinery	0.51	99.49
7. Mining and Quarrying	6.18	93.82
8. Food and Tobacco	0.52	99.48
9. Paper Products and Printing	2.09	97.91
10. Wood and Wood Products	0.00	100.00
11. Construction	1.71	98.29
12. Textile and Leather	0.01	99.99
13. Transport	67.68	32.32
14. Agriculture, Forestry and Fishing	11.85	88.15
15. Commercial and Public Services	4.65	95.35
16. Residential	83.09	16.91
17. Other industries	68.91	31.09
18. Non-specified (other sectors)	7.66	92.34

principally on the type and quantity of fuels used. Therefore, the sectors with direct effects of energy consumption that are higher than their indirect effects of energy consumption also have greater direct effects of CO_2 emissions and vice versa. Electricity, Gas and Water Supply; Transport; Other Industries; and Residential are the sectors with greater direct effects of CO_2 emissions, and the other sectors come with higher indirect effects of CO_2 emissions. Moreover, the total direct effect of CO_2 emissions intensity of the aggregated 18 sectors accounts for 51.05%, while the total indirect effect of CO_2 emissions intensity accounts for 48.95%, which is quite reasonable. The main reason might be that among all the 18 sectors, the electricity sector has the highest direct effect (84.06%) and the lowest indirect effect (15.94%), as presented in Table 10; and also, according to the result in Table 8, electricity sector totals of CO_2 emissions and monetary CO2 emissions (direct CO_2 emissions) account respectively 58% and 55% of the totals of CO_2 emissions and monetary CO_2 emissions, respectively. This is well correlated with the introduction section and the previous study of Beidari *et al.* (2017) where it is stated that the electricity sector was the largest source of SA's CO_2 emissions, accounting for about 66% of the SA total and more than 90% of the electricity generated in South Africa comes from coal. Those sectors with a large indirect effects need more attention. If we only count the direct emissions of those sectors with a large indirect CO_2 emission, the total CO_2 emissions will be underestimated. If also the total indirect CO_2 emissions was higher than the total direct CO_2 emissions, the total CO_2 emissions could be underestimated. Nonetheless, some enhancements can be made through policy adjustment to reduce high amounts of indirect energy consumption for related sectors, which will reduce their indirect CO_2 emissions.

Policy Implications

Based on the results of this study, the following propositions can be useful to enhance the electricity sector's linkage effects in order to become a key sector for SA, and reduce its direct energy consumption and CO_2 emissions, SA's government should:

(1) invest more in the electricity sector in order to expand electricity capacity. That means they will need to build some new electric power stations.
(2) encourage public investment in order to maintain and expand electricity capacity. That would help to relieve Eskom (the national electricity distributer, which produces 95% of SA's electricity), because Eskom's plant is under severe stretch due to factors such as poor quality of coal, staff deficiencies and a high load on its capacity (Bayliss, 2008).
(3) shift the fuel structure especially in the electricity sector by developing more the renewable energy sector.
(4) increase the quality of coal and provide new technologies such as Carbon Capture and Storage as mentioned by Beidari *et al.* (2017) for the main power plants. That could inevitably increase the efficiency of power plants. That means less coal could be used to produce the same amount of energy or more.
(5) reduce the amount of its oil imports by expanding its renewable energy capacity.

CONCLUSIONS

This paper has applied input-output analysis to investigate the interconnectedness of 18 aggregated sectors for the years 1995, 2000, 2005, 2010 and 2012, and adopted multiplier analysis to quantify the total environmental impacts related to the inter-industry linkages for the year 2012 in South Africa, with a focus on the relationship between the electricity sector and the rest of the economy.

First, the linkage effects were calculated using the PIOD, which stands for backward linkage, and SIOD, which stands for the forward linkage. Results point out that the electricity sector has a weak linkage (both backward and forward linkages are less than 1) with others sectors, which means it is mostly independent of other sectors. In another words, it does not induce and enable economic growth by IOA. Moreover, two sectors such as Chemical and Petrochemical Industries and Basic Metals were found as key sectors in SA's economy in 1995, 2000 and 2012. In 2005 and 2010, only Chemical and Petrochemical Industries was the most important sector in SA. Additionally, Commercial and Public Services was the strongest forward linkage sector in SA, which means it creates a large impact on downstream sectors, comprising downstream investment or technological advancement. In other words, it is the sector which supports the most economic development in SA.

The multiplier analysis was applied to map out the 18 sectors' energy and CO_2 emissions intensities for the year 2012. The results clearly showed that Electricity, Gas and Water Supply; Other Industries; Transport; Basic Metals; and Residential were the top five energy consuming sectors and CO_2 emitters in 2012 in SA. However, the electricity sector was the main direct monetary energy consumer and CO_2 emitter, and therefore it is the most dominant source in terms of energy and CO_2 intensities among all the 18 sectors in SA.

Furthermore, the results of multipliers analysis indicated that most total of indirect energy consumption and CO_2 emissions were higher than direct energy consumption and CO_2 emissions. This means that both indirect energy consumption and CO_2 emissions has large impacts on SA's energy consumption and CO_2 emissions, which cannot be ignored. Therefore, the SA government should plan to implement practical strategies to reduce the indirect energy consumption intensity as well as the indirect CO_2 emissions intensity.

Based on the results of this paper, a variety of propositions which can be useful to improve the electricity sector's linkage effects in order to become a key sector for SA, and reduce its direct energy consumption and CO_2 emissions, have been recommended in the section of policy implications as suggestions.

Finally, this study showed that input-output analysis can be a very useful tool for governments, as it provides valuable information about the functioning and structure of the linkages among sectors in the national level economy, as well as access to both direct and indirect effects related to energy consumption and CO_2 emissions. The multipliers analysis applied in this study gives a good understanding of the interconnectedness among industries for a government to further evaluate the profiles of the direct and indirect effects among industries regarding their energy consumption and CO_2 emissions. Therefore, it can be a worthwhile tool to assist policymakers in elaborating appropriate economic policy as well as improving energy policy makings.

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