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# Linkage analysis of sectoral $CO_2$ emissions based on the hypothetical extraction method in South Africa

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ABSTRACT

As one of the top carbon emitters in Africa, South Africa has received tremendous pressure to reduce carbon emissions. Issues related to energy consumption and greenhouse gas emissions in South Africa have thus far been widely studied. However, the carbon linkage caused by the intermediate trade among industrial sectors has typically been ignored. This study integrates the environmental input–output model with modified hypothetical extraction method to investigate the carbon linkage among sectors. Based on the data of South Africa in 2005, this study empirically estimates the linkages of $CO_2$ emissions involved in the industrial sectors and the carbon effects of inter-sector linkages. Results show that the total carbon linkage of industrial systems in South Africa in 2005 is 171.32 million tons (Mt), which accounts for 81.58 Mt total backward carbon linkage and 89.71 Mt total forward carbon linkage. The industrial block of electricity, gas, and water has the largest total carbon linkage and internal and net forward effect, and the block of basic metal, coke, and refined petroleum products has the largest net backward effect. The potential policy implications on energy consumption and reduction of $CO_2$ emissions deduced from this numerical study are also discussed.



## 1. Introduction

Global warming and energy use have been the focus of attention worldwide over the past two decades. However, debates on international climate negotiations and the adjustment of $CO_2$ abatements seem intense but lack effective progress. As a high-speed growing economy that is part of Brazil, Russia, India, China, and South Africa Association (BRICs) and as one of the top $CO_2$ emitters in Africa, South Africa has actively participated in exploring energy conservation policies domestically and pursuing energy cooperation within the BRICs and Annex A.

South Africa has experienced rapid industrialization since the 1990s. The rapid development of the economy and the extensive consumption of non-renewable fossil resources, which lead to $CO_2$ emissions, have attracted attention across the world. South Africa is the 14th highest $CO_2$ emitter globally, having emitted more than 367 million tons (Mt) of $CO_2$ in 2011 (IEA, 2013), and its per capita of $CO_2$ emissions is twice the world average (Arndt et al., 2013). Therefore, South Africa has been trapped in the development pattern of high $CO_2$ emission because of the superiority of coal resources and high subsidies from the government to the energy industry. Furthermore, the carbon mitigation in South Africa has attracted attention because of the embodied carbon principles and export of raw coal and thermal power.

The South African government promised to reduce $CO_2$ emissions by decreasing them by 34% in 2020 and 42% in 2025 and by trimming 90% of the emissions from the electric power sector (Devarajan et al., 2009; Winkler and Marquand, 2009), and the coal consumption will be reduced by 50% in 2050 with the increasing usage of the natural gas. In addition, the current tax on major industry is beneficial to the carbon abatement in South Africa with the risk of the increasing consumption of natural gas and renewable energy. Moreover, the carbon tax policy aiming to mitigate greenhouse gas (GHG) emissions and curb the climate change will only be released in 2016. Therefore, it may meaningful to detect some effectively carbon reduction policies by considering the carbon linkage among the industries in South Africa.

Theoretically, the appropriate measures to reduce $CO_2$ emissions are to improve energy efficiency, alleviate the dependence on fossil fuels, and implement clean energy technology. However, the study of indirect $CO_2$ emission linkage in industrial sectors, which has been ignored, caused by the input–output (IO) relationship

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through intermediate good, can examine the $CO_2$ emission inter-sector linkage and suggest targeted energy conservation policies.

This study analyzes $CO_2$ emission linkages using the environmental IO model and modified hypothetical extraction method (HEM). The study also discusses the policy implications on energy consumption and climate change negotiation in South Africa in accordance with the numerical results.

In this study, carbon linkages are divided into total emission linkage (TL), total backward emission linkage (BL), and total forward linkage (FL), which are used to estimate the linkage effects of industrial sectors. The effects of inner carbon linkage (IE), mixed emission linkage (ME), net backward emission linkage (NBE), and net forward emission linkage (NFE) are measured. Furthermore, NBE and NFE are decomposed to obtain the quantum of the net flow of $CO_2$ emissions in the industrial sectors.

## 2. Literature review

The linkage analysis of the industrial sector (Schultz, 1977) is based on HEM to analyze the effect of the changes in industrial structure on an economy. This analysis is performed by comparing the change in output by extracting any sector from a closed economy system. This analysis was promoted by Cella (1984), who proposed backward linkage, forward linkage, and total linkage among the sectors.

Backward linkage is the consumption relationship formed during the use of intermediate goods bought from the upstream industries by the downstream industries. Sectoral linkage is calculated by obtaining the sum of the elements by column in the Leontief inverse matrix by Rasmussen (1956), who proposed direct backward linkage and direct forward linkage widely recognized by several scholars (Alejandro Cardenete and Sancho, 2006; Cella, 1984; Cuello et al., 1992; Dietzenbacher, 1992, 2002; Duarte et al., 2002; Hewings, 1974; Laumas, 1975; Lenzen, 2003). Alternatively, the linkages among the industries may be estimated by obtaining the sum of the column elements in the direct consumption coefficient matrix (Chenery and Watanabe, 1958).

Forward linkage is the supply relationship formed when the upstream industry supplies the produced intermediate goods to the downstream industry. The sum of the row elements in the Leontief inverse matrix estimates the forward linkage by Rasmussen (1956) based on the backward linkage, which can make the estimate inaccurate. Therefore, the sum of the row elements in the Ghosh inverse matrix is used to investigate the forward linkage (Augustinovics, 1970; Miller and Blair, 2009).

The estimate of the backward linkage constitutes parts of the forward linkage, and some uncertainties are also included in the calculation of the forward linkage (Cai and Leung, 2004; Cai et al., 2005; Dietzenbacher, 2002; Leung and Pooley, 2001; Miller and Blair, 2009). This study uses the Leontief inverse matrix from the direct consumption coefficient to investigate the backward and forward linkages among the industrial sectors.

The linkage analysis of the industrial sector based on HEM has been widely applied to water use (Duarte et al., 2002), regional consumption motives (Turner et al., 2007), and agriculture sector (Cai and Leung, 2004).

Studies on carbon emissions in South Africa have focused on the issues of carbon price and tax, environmental policies, carbon intensity, carbon emission at the sectoral and regional levels, new energy, bio-energy development, and innovation in institution (Brent and Visser, 2005; Chandler et al., 2002; Devarajan et al., 2009; Friedrich et al., 2009; Hens et al., 2010; Menyah and Wolde-Rufael, 2010; Von Blottnitz and Curran, 2007).

On one hand, South Africa is typically aligned with other developing countries for having useful policies. For example, Chandler et al. (2002) investigated long-term carbon emission reduction policies in developing countries by studying the potential reduction of emissions in Brazil, China, India, Mexico, South Africa, and Turkey. On the other hand, the tax on emission also extended carbon mitigation in South Africa. Devarajan et al. (2009) analyzed how South Africa should develop and implement the carbon reduction targets of carbon emission reduction policies from a tax perspective, followed by the distortion assumption, for its economy. He also analyzed the effect of carbon tax on the economy (Devarajan et al., 2011). Moreover, the environmental Kuznets curve and Granger tests have been used to investigate energy consumption and $CO_2$ emissions per capita worldwide. Subsequently, Kohler (2013) concluded that the trade liberalization failed to increase the long-term emissions in South Africa.

Subsequent studies mainly focus on the implication of carbon tax in the South African economy (Alton et al., 2014), carbon price and energy policy (Hood and Guelff, 2013; Labuschagne et al., 2005), carbon intensity (Arndt et al., 2013), energy efficiency in electric sector (Inglesi-Lotz and Blignaut, 2014), emissions abatement in the machinery manufacturing sector (Pillay and Buys, 2013), and use of heat energy (Devarajan et al., 2011; Dhansay et al., 2014). However, this study analyzes the sectoral carbon linkage in South Africa by building the IO model by introducing carbon intensity, applying the modified HEM model to trace the carbon linkage and transfer among the industrial sectors, and identifying the key emission sectors in South Africa.

The remainder of this paper is organized as follows. Section 3 provides the model of the linkage analysis of industrial $CO_2$ emissions based on HEM, including the environmental IO model that considers imported intermediate goods. Section 4 presents the data resources and processing, which includes sector classification and aggregation. Section 5 offers the empirical results. Section 6 presents the conclusions and policy implications based on the numerical analysis.

## 3. Methodology

### 3.1. Total $CO_2$ emissions and its intensity

The intensity of the total $CO_2$ emissions is calculated by the total sectoral consumption of primary energy. With $n$ sectors in the economy and eight kinds of primary energy consumed, the sectoral $CO_2$ emission is as follows:

$$C_i = \sum_{j=1}^{8} E_{ij}\delta_j, \quad i = 1, 2, \cdots, n \tag{1}$$

where $C_i$ is the total $CO_2$ emissions of sector $i$ and $E_{ij}$ is the consumption of energy $j$ in sector $i$. In this study, energy includes coal, coke, crude oil, gasoline, kerosene, diesel and fuel oil, and natural gas ($j = 1,2, \ldots 8$). Electricity is excluded to avoid double counting. The $CO_2$ emissions from the electricity consumption have been measured in the primary energy for the use of fossil fuels in generating electricity. $\delta_j$ is the carbon emission factor of energy $j$.

The $CO_2$ emission intensity is calculated as the ratio of the total $CO_2$ emissions to the total output:

$$\bar{c}_i = \frac{C_i}{X_i} \tag{2}$$

where $\bar{c}_i$ is the carbon intensity of the industrial sector $i$, $\overline{C} = (\overline{c_i})$ denotes is the direct $CO_2$ emission intensity vector, and $X_i$ is the total output of sector $i$.