The Nexus between Coal Consumption, CO_2 Emissions and Economic Growth in South Africa

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This paper examines the impact of the coal industry in South Africa's economy. A supply-side approach allowed estimation of the impact of energy consumption on economic growth with a Cobb-Douglas type production function involving economic output, labour, technology, flow of services and capital stock. Demand-side analysis examined the interaction among output, coal prices, coal consumption and carbon emissions. Overall, the study finds uni-directional causality from output to both labour and capital formation in the short and long-run. Coal consumption tends to heighten carbon emissions. An examination of the Environmental Kuznets Curve (EKC) shows a link between per capita GDP and pollutant emissions, giving strong support to the EKC hypothesis. We argue that reducing carbon emissions without compromising economic growth will be difficult hence the need to harness alternative sources of energy.

Keywords: *Carbon emissions; economic growth; cointegration; EKC hypothesis.*

INTRODUCTION

Coal is arguably one of the most important natural resources in the South African economy. At constant 2010 prices, coal contributed R51 billion to South Africa's economy in 2013, compared with gold's R31 billion in that year, establishing the former as a more economically important commodity (StatsSA, 2016). South Africa substantially depends on coal for its electricity production and for use in industry. However, as Menyah and Wolde-Rufael (2010) note, South Africa is also endowed with diverse and sustainable energy sources including abundant sunshine and lots of wind flow.

As coal is a non-renewable fossil fuel, complete dependence on it may not be sustainable in the long-run. This is despite the coal reserves-to-production (R/P) ratio analysis showing South Africa has at least 100 years of coal at current consumption levels (Baruya et al., 2011). More than half of the coal produced in South Africa is used for electricity production: electricity generation (62%), petrochemical pro-

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duction (23%), general industrial use (8%), metallurgical use (4%) and commodity trading by merchants (3%). South Africa has the world's biggest commercial coal synfuel[1] plant, operated by Sasol, which converts coal to petroleum products (Eberhard, 2011). The state-owned power utility Eskom, which operates 23 power stations with a total nominal capacity of at least 42,090 Megawatts of electricity, is the biggest consumer of coal in the country (SACRM, 2011). Eskom (2016) puts the total nominal capacity from coal-fired power stations at 37,721 Megawatts. The increasing reliance on coal for power generation has brought about noticeable effects on the environment, especially in the light of concerns about climate change. In CIAB (2015), the South African government committed to reducing carbon dioxide (CO_2) emissions by 34% from the Business as Usual (BAU) context by 2020, and then by 42% from the BAU by 2025. This is conditional on the adoption of a global climate agreement and South Africa receiving international financing and technological assistance. On the other hand, the demand and supply factors driving the coal industry in South Africa are less understood. More importantly, the connections between the coal industry and economic growth, and the environmental impact of coal and alternative sources of energy have not been adequately interrogated in the literature.

This paper analyses the coal industry in South Africa and the implications of inefficient use of energy. We examine the long-run relationship between coal consumption and income in a multivariate time series framework. A distinction is made between supply-side factors and demand-side factors that drive coal production and consumption. Following Bloch et al. (2012), we account for supply-side variables incorporating economic output, capital, labour and coal consumption.[2] The link between income, coal consumption and coal prices on one hand and the long-term linkages between carbon emissions, output and coal consumption on the other, are examined. Previous approaches have predominantly looked at only the interaction among energy consumption, gross domestic product (GDP) and energy prices (see Rafiq and Salim, 2009; Salim et al., 2008).

At the heart of this article are three themes and contributions: a) the long run relationship between coal consumption, economic growth and carbon dioxide emissions and their direction of causality; b) The contribution of shocks to the demand and supply factors driving coal production and consumption; c) the environmental considerations that should be looked at when using coal as a major energy source in the economy.

The results show that economic output has uni-directional causality on coal consumption, labour and capital formation. The results lend support to the conservation hypothesis of Alshehry and Belloumi (2015) where economic growth influences energy use. Further, causality is observed from coal consumption to carbon emissions, and from coal prices to coal consumption. Lastly, South African data confirms the Environmental Kuznets Curve (EKC) hypothesis where economic growth tends to engender a shift from environmentally polluting sources such as coal to cleaner and more sustainable fuels.

The rest of the paper is structured as follows. The second section highlights the unique nature of the coal industry globally with specific emphasis on South Africa. We then examine linkages between energy consumption and economic growth in the literature with particular interest in coal. The next section presents the empirical methodology. This is followed by the sections that describe the data and the major findings. The final section looks at EKC hypothesis and whether it is supported by South African data.

THE COAL INDUSTRY, CO_2 EMISSIONS AND THE ENVIRONMENT

SACRM (2011) makes the distinction between coal resources and reserves. The former entail the geological occurrence of a mineral expressed in volume, quality and geological formation indicating possibility of economic extraction. Reserves on the other hand comprise the portion of resources confidently proven and are economically mineable. Estimates of South African coal resources and reserves are given in Baruya *et al.* (2011) and amount to 121.2 billion tons and 55.3 billion tons respectively. It is also confirmed in Baruya *et al.* (2011) that coal seams around South Africa are generally shallow, making the costs of extraction relatively manageable. As such, South Africa is reasonably competitive in the global markets, with fair access to the Atlantic and Pacific coal markets (Eberhard, 2011). SACRM (2011) gives projections for South African annual thermal and metallurgical coal exports of 93 million tons (by 2017) and 7.8 million tons (by 2020) respectively.

Heinberg and Fridley (2010) and Vogler (2007) give a broad international context on coal reserves and the extent of mining operations around the world. The largest coal reserves in the world amounting to about 237 billion tons are in the USA and were estimated to last an additional 240 years in 2010. About 1 billion tons of coal is produced in the USA per year, virtually all of which is consumed domestically in the power-producing sector. Russia has the second largest recoverable coal reserves estimated in Heinberg and Fridley (2010) to be about 157 billion tons. With the third largest proven coal reserves after the USA and Russia, China estimates its coal reserves (115 billion tons) could be available for another 62 years. Heinberg and Fridley (2010) acknowledge China is globally the biggest consumer and producer of coal accounting for 40% of global coal production. Recoverable coal reserves in Australia and India are estimated at respectively 77 billion tons and 61 billion tons. Estimates of recoverable coal reserves in South Africa have been put at 55 billion tons (Baruya et al., 2011; Heinberg and Fridley, 2010). We present in Table 1 the world proven recoverable coal reserves for the top ten producing countries.

Table 1: World proven recoverable coal reserves

Rank	Country	Recoverable coal reserves
1	USA	237
2	Russia	157
3	China	115
4	Australia	77
5	India	61
6	South Africa	55
7	Germany	41
8	Kazakhstan	34
9	Ukraine	34
10	Serbia	14
11	Other countries	61
	Global	886

Source: The information in the table has been adopted from Heinberg and Fridley (2010) and Baruya et al. (2011).

Some countries have been depleting their coal reserves faster than others. In Heinberg and Fridley (2010), coal reserves in China and Germany were depleted by one third between 2003 and 2008. Countries that have surpassed peak coal production levels include Japan, United Kingdom and Germany (Lin and Liu, 2010). Vogler (2007) has analysed coal production in Canada, which presents a different experience, estimating annual output at approximately 76 million tons. Canada uses domestically the bulk of the coal it produces. Around 2007, imports of coal by Canada were 22.1 million tons, largely meant for industrial use and power generation. The global biggest coal exporters are Australia, South Africa and Indonesia, each producing between 250 and 400 million tons of coal per year.

Eskom (2016) and SACRM (2011) are in agreement that South African coal is generally regarded as low-grade by international standards. While high-grade bituminous coal has low ash content (< 7%), South African coal typically has ash content between 20 and 30%. Further, SACRM (2011) explains that about half of the saleable coal from South Africa is produced by washing, which builds into the costs of delivering onto the markets. Presently though, there are significant advantages of using coal in South Africa. Crocker (2010) confirms South African coal is relatively cheap and easy to extract and the country has large deposits of the commodity. It is noted the country has very little potential for hydro-electric power generation as substantial water supplies into the country are drawn from Lesotho via pipeline for every-day use. There is presently not much crude oil extraction that is economically possible in the country owing to limited reserves. Coal has therefore enjoyed a significant advantage over the other possible sources of energy.

SACRM (2011) acknowledges coal mining has adverse environmental impacts, including ground surface disturbance, overburden waste stockpiles, formation of acid mine drainage, increased soil erosion, discharge of contaminated waters and destruction of fauna and flora habitats. Apart from CO_2, coal fire power generation has other emissions including dust and particulate matter, sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). SACRM (2011) notes these emissions can cause respiratory problems, smog, visibility problems and acid deposition from the resulting acid rain.

There are significant concerns about the sustainability of pollution levels in South Africa as new power stations are still being commissioned. Critiques have therefore wondered whether the country should not be moving towards greener energy sources. South Africa is in the top twenty globally in carbon emissions production (Eberhard, 2011). Some 80% of CO_2 emissions in South Africa emanate from the electricity, metals and transport sectors. Carbon emissions in the country in 2004 were 387 million tons calculating to about half of aggregate CO_2 emissions by the entire African continent that year. Eskom, the leading coal consumer in South Africa annually emits 225 million tons of carbon dioxide. Emissions by Sasol amount to approximately 72.7 million tons per annum. DNTSA (2010) acknowledges that on average, South African CO_2 emissions calculate to 2.03 kg of CO_2 per dollar of GDP. If South Africa continues to be heavily dependent on coal, economic expansion could mean higher coal consumption that could come with higher pollutant emissions. High dependence on coal could mean the difficult dilemma of either sacrificing on pollutant commitments or prejudicing economic growth.

The overall rate of increase in average temperatures by 0.2 degrees Celsius per decade has been attributed to the increase in atmospheric greenhouse gas (GHG) concentrations (Greenstone et. al, 2013). Geels (2014) alludes to a global target to limit long-term rise in average global temperatures to 2 degrees Celsius. As such, low-carbon transition goes beyond adoption of “green” alternatives, but preventing and limiting existing fossil fuel reserves from “burning”. DNTSA (2010) observed that in terms of individual country carbon dioxide emissions, South Africa globally ranks in the top 20.

Diverse measures are used around the world to limit GHG emissions. Greenstone et al. (2013) describe the USA framework which monetizes environmental damages caused by incremental CO_2 emissions. Commonly known as the social cost of carbon dioxide (SCC), a central value of the SCC is US$21 per ton of CO_2 emissions. This cost is equated to the economic value of disruption to human health, ecosystems, agriculture and the environment emanating from impacts of climate change. The framework is for use in giving value to CO_2 emissions impacts accounted for by national laws, rules and regulations within the USA economy.

Inappropriate regulations for controlling carbon emissions may also have unintended consequences. An example of such government regulations effects is described in Black et.al (2005). The USA’s coal industry boom in the 1970’s was followed by a bust in the 1980’s. The boom was caused by regulatory change which led to an increase in coal prices of 28% during 1969 through 1970. However, the regulations adversely impacted some coal mining entities resulting in a number of coal power plants closing down.

Two economic policy measures for controlling GHG are carbon taxation and emissions trading schemes. Carbon taxation is direct and the price is paid by the entity responsible for the emissions. Trading schemes give targets and provide for trade in CO_2 allowances. A fully-functional carbon futures market has been introduced in the European Union (EU) area, called the EU Emissions Trading System (EU ETS). The biggest such scheme globally, the EU ETS covers some 11,000 power stations and industrial plants in 30 countries (Ellerman and Joskow, 2008). A cap is imposed on emissions allowed within the scheme, and allowances adding up to the cap are given to participating firms or entities. Companies trade their allowances in the futures markets, providing incentives for them to reduce emissions.

The use of carbon taxes as a mechanism to reduce emissions was recommended in South Africa in DEAT (2007). Some administrative advantages of carbon tax over emissions trading schemes include i) management of the tax collection by an existing authority; ii) fewer intermediaries are involved in tax implementation; iii) structured management minimising possible abuse of the system; iv) lower administrative burden (use of existing accounting platforms); v) lobbying efforts would be minimal. The South African government has introduced the tax in the form of an electricity levy (2 cents/KWh in 2009) and a carbon tax on the use of fossil fuel inputs. More specifically, a carbon tax element has been incorporated into the prices of petrol and diesel.

Climate change is a threat to social, ecological and economic sustainability. In creating social justice Stilwell (2011) explores the question of how reasonable equality of opportunity can be established for diverse socio-economic classes. ETS's empower government to limit on the permits issued to reach a target, while carbon tax is more indirect in achieving planned emissions targets. Trial and error adjustments to carbon tax would be needed. A key distinction to the alternative systems in Stilwell (2011) is ETS's give rights to pollute while carbon taxes ensure a right to consume. Further, ETS's create secondary trading markets involving futures and derivatives increasing economic interests and commissions paid by market users. As such, speculation and the relentless drive for capital accumulation may lead to the dreaded cyclical market instability. Yet a carbon tax restricts access based on the ability to pay. Potential alternatives may include compensation payments and raising tax-free thresholds for income tax to better protect the poor. A framework proposed in Beder (2013) harmonises sustainability, polluter pays principle, precautionary principle, equity, human rights and public participation. Current suggested carbon emissions control strategies are found inadequate in balancing out these six considerations.

ENERGY CONSUMPTION, ECONOMIC GROWTH AND THEIR LINKAGES

Mainstream and classical macroeconomic theories have traditionally viewed capital, labour and land as primary factors of production and economic growth (Stern, 2004). The close relationship between growth, capital and labour led to the recognition of the Cobb-Douglass production function in Cobb and Douglas (1928). In neo-classical economics on the other hand, energy, fuels and materials are viewed as intermediate factors in production and economic development. As Awan (2013) notes, energy economists acknowledge the critical role of energy in impacting the production process. Erbaykal (2008) proposed energy should be accounted for as a production factor, while Pokrovski (2003) posited production and output are dependent on energy service, capital stock and labour. These views are in agreement with many scholars who acknowledge the central role of capital, labour and energy in the production process (Ghali and El-Sakka, 2004; Menyah and Wolde-Rufael, 2010; Sadorsky, 2012; Yuan et.al., 2008).

In Cheema and Javid (2015), an increase in energy use theoretically leads to higher economic activity. When fossil fuels are used in this process, CO_2 will be emitted and the environment is polluted. Awan (2013) agreed energy extraction, processing and use resulted in environmental disruption and pollution. However, shifts to higher quality energy sources may reduce overall emissions, for example, the use of greener sources of energy (CIAB, 2015). This conserves non-renewable energy while reducing environmental impacts of fuelling an economy. In the same vein, technological innovation can help reduce emissions just as opting for greener sources of energy leads to a cleaner environment. CIAB (2015) explains that substantial CO_2 emissions mitigation could be achieved in the short-term using high-efficiency, low-emission coal-fuelled power generation technologies known as HELE. With these new technologies, GHG emissions could be reduced by around 20%, burning the same coal. On the other hand, CIAB (2015) has noted that state-of-the-art emissions control systems fitted to coal-fuelled power plants have reduced emissions of nitrogen oxide, sulphur oxide and particulate matter by 70% over time.

Similar to a number of recent studies, this paper employs the demand-side and supply side analysis of economic variables (see Bloch et al., 2012; Oh and Lee, 2004b; Salim et al., 2008; Wu et al., 2006, among others). For supply-side estimation, variables of interest are income, coal consumption, labour and capital. Two versions of demand-side analysis have been used in literature and the approach is adopted here. Firstly, the possible long-run relationship between output, coal price and carbon emissions is investigated. Secondly, relationships among output, carbon emissions and coal consumption are examined.

A number of studies on economic growth and pollution levels have employed the Environmental Kuznets Curve (EKC) hypothesis (Ang, 2007; Antweiler et al., 2001; Coxhead, 2003; Cropper and Griffiths, 1994, among others). The EKC hypothesis posits an inverted U-shape relationship between pollution and per capita income levels in an economy (Dinda, 2004). Essentially, the hypothesis asserts that environmental quality first deteriorates with industrialization and ultimately, pollutant pressures stabilise, and then reduce relative to the growth in income as the economy becomes more sophisticated. The empirical validity of the EKC hypothesis is rather mixed.

Alshehry and Belloumi (2015) allude to four hypotheses used in the analysis of direction of causality between energy consumption and economic growth. Firstly, the conservation hypothesis suggests one-directional causality where economic growth influences energy use. Under the growth hypothesis, energy use impacts economic growth. Bidirectional causality to and from energy consumption and economic growth characterises the feedback hypothesis. Neutrality hypothesis suggests no link between energy and economic growth.

A number of papers have looked at whether energy consumption is the cause or effect of economic growth (Bloch et al., 2012; Fei et al., 2011; Kivyiro and Arminen, 2014; Zhang and Cheng, 2009). There is no consensus in literature with some findings matching the growth hypothesis and others the conservation, feedback or neutrality hypothesis. Studies supporting the growth hypothesis in finding unidirectional causality from output to energy consumption include Narayan and Smyth (2005), Al-Iriani (2006) and Mozumder and Marathe (2007). Uni-directional causality from energy consumption to output is confirmed in Wolde-Rufael (2004), Chen et al., (2007) and Morimoto and Hope (2004) among other studies. Under this literature additional energy could be used in industry assisting to raise capacity utilisation. Bi-directional causality between output and energy consumption is confirmed in many studies (see Oh and Lee, 2004a, 2004b; Salim et al., 2008; Wolde-Rufael, 2006; Yoo, 2005).

Halicioglu (2009) examined the link amongst income, foreign trade, carbon emissions and energy consumption for Turkey from 1960 to 2005. Evidence that carbon emissions were determined by energy consumption, income and foreign trade was found for the short and long-run. At the same time, carbon emissions, energy consumption and foreign trade had a long-run impact on income. In a study of six Asian countries, Salim et al. (2008) found bi-directional causality between energy consumption and income for Malaysia. China and Thailand had unidirectional relationship flowing from output to energy while India and Pakistan had unidirectional relationship from energy consumption to output. Energy neutrality was observed for Bangladesh. China and Thailand were identified as countries requiring both energy conservation and reduction in pollution to the environment.

In a study of the Korean economy by Oh and Lee (2004a), demand and production side approaches were employed estimating the relationship between energy consumption, GDP growth, real energy prices, capital and labour. Demand-side estimation used energy, GDP and real energy price while production side analysis included GDP, energy, capital, and labour. Causality flowing from energy to GDP could not be confirmed in the short run while unidirectional causal relationship running from GDP to energy in the long run was found. This entailed a conservation policy that could be pursued without compromising economic growth in the long run.

Ang (2007) examined relationships amongst pollutant emissions, energy consumption and output with data on France from 1960 through 2000. Long-run causal relationships were found with flows from economic growth to energy use, then to growth in pollution. Short-run unidirectional flow-through of output growth due to growth in energy use was also confirmed. These findings meant economic growth caused growth in energy use and economic expansion was found impacting CO_2 emissions.

This study has paid special attention to extant literature from countries within the BRICS[3] grouping and other developing countries which are easier to compare with South Africa. Bloch et al. (2012) examined the interaction between coal consumption, income and CO_2 emissions using the supply-side and demand side approaches. Annual data for China for the period from 1977 to 2008 and 1965 to 2008 was used for the supply-side and demand-side analysis, respectively. Evidence was found of uni-directional causality running from coal consumption to GDP in both the short and long run after employing demand side equations. Further, a significant bi-directional link was found between carbon emissions and coal consumption.

Pao and Tsai (2011) examined the relationship between pollutant emissions, energy consumption and output in Brazil from 1980 to 2007. Energy consumption was found a more significant determinant of emissions than output. There was evidence that emissions and energy consumption rise with income, before stabilizing and declining forming an inverted U-shape. Strong bi-directional causality in the Brazilian economy runs across income, energy consumption and emissions. Pao et al., (2011) looked at Russian data from 1990 to 2007 finding the economy not in support of the EKC hypothesis. High emissions were found to cause more energy use repeating the cycle of higher pollution levels. Bi-directional causality is confirmed between output, energy use and emissions.

Data from India for the period 1969 to 2006 is analysed in Wolde-Rufael (2010). Short and long-run relationships are found between economic growth, nuclear energy consumption, labour and capital. It is concluded that economic development in India is dependent on nuclear energy consumption. Ang (2008) investigated the relationship between output, pollutant emissions and energy consumption in Malaysia from 1971 through 1999. Evidence of positive long-run relationships between pollution and output, and energy use and output was found. Causality flowing from economic growth to energy consumption was also confirmed in the short and long-run. Further, bi-directional causality involving economic output and energy use is found by the study.

The economic-growth-energy-use nexus focussing on the South African case has not been extensively looked at in the literature. Wolde-Rufael (2006) looked at electricity and GDP per capita data from 17 African countries. Long run relationships are confirmed for 9 countries. Evidence of Granger causality is found in 12 countries, moving from GDP per capita to electricity use in 6 countries while the reverse causality occurred in 3 countries. Bidirectional causality was confirmed for the other three countries. Although a long-run relationship was established between electricity consumption and GDP per capita for South Africa, the study could not detect evidence of causality between the two variables.

Under the South African government universal electrification programme, Ziramba (2008) and Dinkelman (2011) note that some 2.8 million households were connected to the electricity grid from 1994 through 2001. The target was residential homes, which are typically low-capacity electricity users, rather than industrial connections. This could partly explain the absence of causality between electricity generation and economic growth in Wolde-Rufael (2006). It is however interesting to note that an increase in women's employment was experienced in Dinkelman (2011) attributable to government electrification of rural households in South Africa. Additional inference on these findings was that electrification reduced the need for women to spend long hours looking for firewood for household cooking. More time became available for them to be involved in financially beneficial employment.

Kivyiro and Arminen (2014) looked at long-term linkages between carbon dioxide, energy consumption, economic development and foreign direct investment (FDI). The six Sub-Saharan African countries examined for the period 1971 to 2009 were the Republic of Congo, Democratic Republic of Congo, Kenya, South Africa, Zambia and Zimbabwe. The autoregressive distributed lags (ARDL) approach was used finding a number of long-run relationships. In the same study, DRC, Kenya and Zimbabwe were found supporting the Environmental Kuznets Curve (EKC) hypothesis. FDI was also found impacting CO_2 emissions in some countries. The more common causality was from all the other variables to CO_2 emissions and from GDP to FDI. Causality from CO_2 emissions to the other variables was more common in countries supporting the EKC hypothesis.

Further, in the case of FDI, evidence of the halo effect was found for South Africa suggesting multinationals investing in the economy brought relatively cleaner and advanced manufacturing technology. Such a development assists industrial operators to be less harmful to the environment. The difference between the Kivyiro and Arminen (2014) study and the current one is that capital formation is now employed instead of FDI. Further, the current study uses the supply-side and demand-side approaches involving testing a total of three cointegrating relationships, besides investigating the validity of the EKC hypothesis in South Africa.

We extend literature from Menyah and Wolde-Rufael (2010) who looked at energy consumption, pollutant emissions and economic growth in South Africa using annual data from 1965 to 2006. That study found long-run positive relationships between pollutant emissions and economic growth. Bi-directional causality was found flowing from pollutant emissions to economic growth, energy consumption to economic growth and from energy consumption to emissions. Findings from this study suggested causality from emissions to economic growth to the extent the country was faced with sacrificing economic growth to reduce emissions.

In this paper, we now use quarterly data up to the third quarter of 2015 capturing not only the entirety of the post-democratic period but also both the pre and post global financial crisis periods. We also orientate the analysis of extant literature to give focus to findings from the BRICS grouping and other developing countries at comparable levels of development. We break away from existing literature on South Africa by using supply-side and demand-side analysis of economic variables in the current paper.

METHODOLOGY AND DATA

The econometric approach for the study involves multivariate analysis of the economy's supply side and demand side. Supply side analysis assumes a production incorporating coal consumption, aggregate output (represented by constant-dollar GDP), capital and labour. Demand side analysis on the other hand includes coal consumption, GDP growth and coal prices. A comparable trivariate demand-side approach was used in Salim et al. (2008) involving energy, income and prices.

Relationships developed from the Cobb-Douglas type production function are represented as:

$$Y_t = A_t K_t^{\alpha} L_t^{\beta} C_t^{\gamma} \varepsilon_t \tag{1}$$

Y_t is aggregate output, K_t is the flow of services, L_t represents labour, A_t is the level of technology which also measures total factor productivity and C_t is coal consumption. Parameters α, β, and γ respectively represent elasticity of output (in relation to capital), labour and coal consumption. Equation (1) gives the basis for grouping economic variables for the supply-side analysis.

The demand-side models look at the impact of energy use on economic production. Variables in the demand side relation are coal consumption, income, coal prices and carbon emissions. Representations for the first demand-side model are:

$$C_t = F(Y, P) \tag{2}$$

$$C_t = Y_t^{\delta} P_t^{\xi} \varepsilon_t \tag{3}$$

C_t is coal consumption, Y_t is income and the coal price is P_t. Parameters δ and ξ embody elasticity of coal consumption with respect to output and coal prices. Equations explaining CO_2 emissions are:

$$CO_2 = F(Y, C) \tag{4}$$

$$CO_{2t} = Y_t^{\eta} C_t^{\sigma} \varepsilon_t \tag{5}$$

C_t is coal consumption and parameters η and σ are elasticity of carbon emissions with respect to output and coal consumption.

Firstly, there is need to test for unit root in the variables under study. If given the variables are all not stationary and are I(1), we test for cointegration going by Johansen (1991). Where at least one or two cointegrating relationships exist, we proceed with analysis using the vector error correction model (VECM). VECM has the following relations:

$$\Delta y_t = \alpha_1 \sum_{i=1}^{l} \beta_{1i} \Delta x_{t-1} + \sum_{i=1}^{m} \gamma_{1i} \Delta y_{t-i} + \sum_{i=1}^{n} \delta_{1i} \Delta z_{t-1} + \sum_{i=1}^{\gamma} \xi_{1i} ECT_{i,t-1} + u_{1t} \tag{6}$$

$$\Delta x_t = \alpha_2 \sum_{i=1}^{l} \beta_{2i} \Delta x_{t-1} + \sum_{i=1}^{m} \gamma_{2i} \Delta y_{t-i} + \sum_{i=1}^{n} \delta_{2i} \Delta z_{t-1} + \sum_{i=1}^{\gamma} \xi_{2i} ECT_{i,t-1} + u_{2t} \tag{7}$$

$$\Delta z_t = \alpha_3 \sum_{i=1}^{l} \beta_{3i} \Delta x_{t-1} + \sum_{i=1}^{m} \gamma_{3i} \Delta y_{t-i} + \sum_{i=1}^{n} \delta_{3i} \Delta z_{t-1} + \sum_{i=1}^{\gamma} \xi_{3i} ECT_{i,t-1} + u_{3t} \tag{8}$$

Where y_t, x_t, z_t are the model variables, applicable for both the supply-side and demand side. Error correction terms are captured in ECT's while uit's are white noise terms. Variance decomposition and impulse response analysis are carried out similar to et al., (1996) and Pesaran and Shin (1998). The use of the vector autoregressive (VAR) system allows for carrying out Johansen's cointegration test, variance decomposition and impulse response.

Similar to Bloch et al. (2012) supply side data includes output, labour, capital and coal consumption. The demand side has income, coal price, carbon emissions and coal consumption. For output and income, we follow Bloch et al. (2012) and use constant dollar GDP levels such that the value of aggregate output will equal the value of aggregate income. In the case of capital, we use constant dollar gross fixed capital formation. Quarterly data has been used for this study increasing frequency of observations, unlike previous studies on South Africa. GDP figures were collected from the South African Reserve Bank (SARB) and the World Bank World Tables. General employment levels were collected in thousand units and the data was sourced from the International Labour Organisation (ILO) LABORSTA Labour Statistics Database as well as Statistics South Africa (StatsSA). Coal consumption data is available from the statistical review of world energy published by British Petroleum (BP). International coal prices were sourced from BP publications and were converted to Rands using the ruling exchange rates.

Additional data for coal prices, output and coal consumption was collected from the South African Department of Mineral Resources. CO_2 emissions were derived from the population numbers multiplied by the per capita emissions. The data is available from World Development Indicators (WDI) of the World Bank. A lot of data was also available from the US energy administration department.[4] Logarithms for each series were used for the actual analysis.

Results of unit root tests are presented in Table 2 with estimation based on the augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests. It is worth noticing that the null hypothesis for the KPSS test says the series is stationary. Both the ADF and the PP tests give fairly similar results and have a uniform null hypothesis. For the KPSS test only the log of income in first difference gives a different result to the other two. In this case there is evidence of stationarity at 10% level, which however breaches the benchmark of 5% used in this study. Stationarity analysis therefore concludes that unit root is rejected in the first differences but confirmed in the levels for all series. These results clear the way for testing potential cointegrating relationships in both the supply side and demand side relations.

Table 2: Unit root tests

	ADF		**PP**		**KPSS**	
	Level	**1^{st} difference**	**Level**	**1^{st} difference**	**Level**	**1^{st} difference**
LnY	-1.0902	-4.8145***	-1.2310	-4.7585***	0.1460***	0.1167*
	(0.7166)	(0.0001)	(0.6579)	(0.0002)	(0.0000)	(0.0804)
LnLAB	-0.6770	-6.8542***	-0.7770	-6.9744***	0.1803***	0.0922
	(0.8462)	(0.0000)	(0.8203)	(0.0000)	(0.0000)	(0.7243)
LnK	-1.0965	-4.9863***	-1.1620	-4.9863***	0.1156***	0.0990
	(0.7141)	(0.0001)	(0.6876)	(0.0001)	(0.0000)	(0.2134)
LnC	-1.9773	-4.2246***	-2.5444	-3.1135**	0.8685***	0.1343
	(0.2962)	(0.0011)	(0.1088)	(0.0293)	(0.0000)	(0.1020)
LnP	-1.1535	-6.9950***	-1.2623	-4.2341***	0.1717***	0.0248
	(0.6909)	(0.0000)	(0.6438)	(0.0010)	(0.0000)	(0.4032)
$LnCO_2$	-0.5045	-9.2252***	-0.5045	-9.2252***	1.1113***	0.0694
	(0.8843)	(0.0000)	(0.8843)	(0.0000)	(0.0000)	(0.1249)
LnGt	-0.7226	-4.9948***	-0.8183	-4.9948***	1.1274***	0.1481
	(0.8347)	(0.0001)	(0.8087)	(0.0001)	(0.0000)	(0.4587)
LnG^2	-0.7226	-4.9948***	-0.8183	-4.9948***	0.1380***	0.1481
	(0.8347)	(0.0001)	(0.8087)	(0.0001)	(0.0000)	(0.4587)

Augmented Dickey-Fuller (ADF), Phillips-Peron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests are carried out to determine the stationarity of the variables in this study. Prices are first converted to logarithms. The first row gives the tests for the price series while the second row presents first-differenced unit root tests. Parentheses present the p-values. Significance at 1%, 5% or 10% is shown with ***, ** or * respectively.

RESULTS

We first present the results for the cointegration test. The search for the optimal lag length is carried out starting with 4 and going downwards. AIC criteria confirm the most ideal levels. Further, a series of nested likelihood ratio tests are employed on level VARs determining the optimal lag length for the cointegration tests. The VAR framework is used to conduct the Johansen cointegration test following Johansen (1988). Table 3 gives the results for the test of cointegration employing maximum likelihood approach in Johansen (1988) and Johansen and Juselius (1990). This way, multiple cointegrating relationships can be detected in line with the methodology developed in Johansen (1991, 1995). Results are interpreted with the MacKinnon-Haug-Michelis (1999) p-values.

Table 3: Joint estimation of models in Equations (1) to (2) and (4)

		Statistic			
Null hypothesis	Eigenvalue	Max. eigenvalue		Trace statistic	
Supply side analysis (Equation 1)					
r=0	0.3612	36.752***	(0.0036)	63.577***	(0.0057)
r≤1	0.1681	15.089	(0.3677)	26.825	(0.2977)
r≤2	0.0903	7.7604	(0.5765)	11.736	(0.4728)
r≤3	0.0473	3.9753	(0.4158)	3.9753	(0.4158)
Demand side analysis (Equation 2)					
r=0	0.3299	33.630***	(0.0009)	54.099***	(0.0002)
r≤1	0.1426	12.924	(0.1385)	20.469**	(0.0468)
r≤2	0.0859	7.5455	(0.1005)	7.5455	(0.1005)
Demand side analysis (Equation 4)					
r=0	0.2513	24.312**	(0.0258)	45.657***	(0.0027)
r≤1	0.1384	12.512	(0.1582)	21.345***	(0.0354)
r≤2	0.0998	8.8329*	(0.0578)	8.8329*	(0.0578)

Cointegration results with restricted intercepts and no trends in the VAR system are presented. Variables used in this analysis are in equations (1), (2) and (4). The term r is the number of cointegration relationships. AIC criteria are used for optimal lag length. Significance at 1%, 5% and 10% is depicted by ***, ** or * respectively.

For the supply-side equation there is agreement between the trace test and the maximum eigenvalue test that there is at least one cointegrating relationship. Variables involved in this test are output, labour, capital and coal consumption. Evidence suggests at least one cointegrating relationship exists with a 1% significance level for these supply-side variables. In the case of demand-side relation in Equation (2), both the trace and maximum eigenvalue test agree there is at least one cointegrating relationship. However the trace test suggests there could be an additional cointegrating relationship not detected by the maximum eigenvalue test. Theory suggests that in this case the cointegrating relationship should be critically assessed to decide on the linkages (Johansen and Juselius, 1990). In a similar manner, the cointegration test for variables in Equation (4) suggests at least 2 cointegrating relationships for the trace test and 1 long-term relationship for the maximum eigenvalue test.

The next step is to proceed according to the VECM estimation finding out the long-run and short-run interaction among the variables. In the VECM, the ECT term embodies long-run equilibrium. Short-run dynamics are captured by coefficients of lagged difference terms. Granger causality has been carried out by way of parsimonious vector error correction model (VECM). Restricted VARs are used to allow the cointegrating relationships in the level series to converge. The coefficient of the error correction term gives the speed of adjustment towards long-term equilibrium. Results for supply-side analysis are given in Table 4. VECM analysis for Equation (1) suggests economic output has uni-directional causality on labour. This relationship exists apparently in both the short-run and the long-run. This suggests the country requires growing its GDP first if it is to create meaningful and sustainable jobs. Supply side VECM results tend to differ with those for China in Bloch et al. (2012) where there is unidirectional causality from coal consumption to output both in the short and long run. The conservation hypothesis in Alshehry and Belloumi (2015) seems to better describe the South African data. It should be noted that China has a globally significant industrial base compared to South Africa and uses the bulk of its coal for manufacturing which directly adds to GDP growth.

The bulk of locally consumed coal in South Africa goes to electricity production. In Wolde-Rufael (2006) causality between electricity generation and economic growth in South Africa could not be found. This could imply that perhaps South Africa requires using more coal for industrial production in order to impact economic growth. After 1994, there has been increased demand for electricity in the country against a background of rural and township electrification programs by the new government. Such electrification may not necessarily have contributed substantially to economic output though using a good deal of the additional coal consumed.

Table 4: Parsimonious VECM and Granger causality results for Equation (1)

Null hypothesis		***ΔlogY***	***ΔlogL***	***ΔlogK***	***ΔlogC***	***ECT***	***Joint Wald Tests***
		(p-values)	(p-values)	(p-values)	(p-values)	(t-statistics)	(χ^2-statistics)
	ΔlogY	-	3.2589	4.6894*	1.2852	-0.0107***	10.449
			(0.1960)	(0.0959)	(0.5259)	(-4.7006)	(0.1070)
Wald tests	*ΔlogL*	9.6496***	-	3.3571	4.1093	0.0080**	15.936**
		(0.0080)		(0.1866)	(0.1281)	(2.5386)	(0.0141)
	ΔlogK	8.5177**	1.9984	-	2.9673	0.0043	20.933***
		(0.0141)	(0.3682)		(0.2268)	(0.5122)	(0.0019)
	ΔlogC	0.4754	2.0835	1.1639	-	-0.0023	3.9298
		(0.7884)	(0.3528)	(0.5588)		(-1.1997)	(0.6862)

Parsimonious VECM and Granger causality results estimating Equation (1) are presented. VECM uses lag structure optimized by applying AIC criterion. *ΔlogY, ΔlogL, ΔlogK* and *ΔlogC* are changes in output, labour, capital and coal consumption respectively. *ECT*'s are the error correction terms. ***, ** or * are significance levels respectively at 1%, 5% and 10%.

At the same time, more efficient use of the country's coal resources will require faster economic and technological development. GDP growth has however been slowing in recent years.

There is also evidence at 5% level of significance that output has causality on capital formation in the short term.[5] This is expected in that as the economy grows local investors have more confidence and are likely to expand operations. In Table 3, it would appear coal consumption is not in any long or short term relationship with the other 3 variables. Similar to Wolde-Rufael (2006) and Ang (2007), we perform the strong exogeneity test of joint significance between dynamic lagged variables. In the case of labour and capital formation, there is joint significance that all the other variables are important in impacting the former and the latter. This therefore means that to create sustainable jobs in South Africa, the economy should be growing and coal consumption must be increasing while investment in physical or capital stock is rising. One way to achieve this is to ensure conducive conditions for attracting investment are in place and there is sufficient electricity and other forms of energy to run the economy at full capacity. Load shedding has been experienced a couple of times in recent years. No joint significance of explanatory variables is observed in causing output and coal consumption.

Figure 1 presents results of the impulse response function analysis for Equation (1).

An impulse response tracks the effect of a shock to current and future innovations of the endogenous variable. In the analysis of impulse response, we generally ignore own impact to innovations. Notable jumps in the graphs include the substantial impact of output on capital formation and on labour, similar to the above findings. One standard deviation innovation in output results in a 2% increase in capital formation in about a year, staying at those levels at least for the next 5 years. Further, one standard deviation in output can be attributable to slightly over 2% increase in capital formation in about 1 year. Of all the variables in Equation (1), coal consumption appears to have the largest potential to impact economic output.

Variance decomposition over 20 quarters (5 years) for the VECM system in Equation (1) is presented in Table 5. Variance decomposition separates the variation in an endogenous variable into the component shocks emanating from the full set of variables in the VECM system. Results in Table 5 suggest the forecast error for output over 5 years (20 quarters) is largely explained by its own innovations (46.2%) and coal consumption (45.2%) showing that coal plays a pivotal role in the economic well-being of the country.

The situation for labour indicates 56.6% forecast error for the variable after 5 years is explained by output. Some 8.39% 1-quarter forecast error variance for capital formation is attributable to shocks from output increasing to 48.1% in 5 years. Coal consumption forecast error appears to be largely explained by its own innovations for the entire forecast period. This suggests there could be scope for increasing economic growth using alternative sources of energy.

Table 5: Forecast error variance decomposition for Equation 1

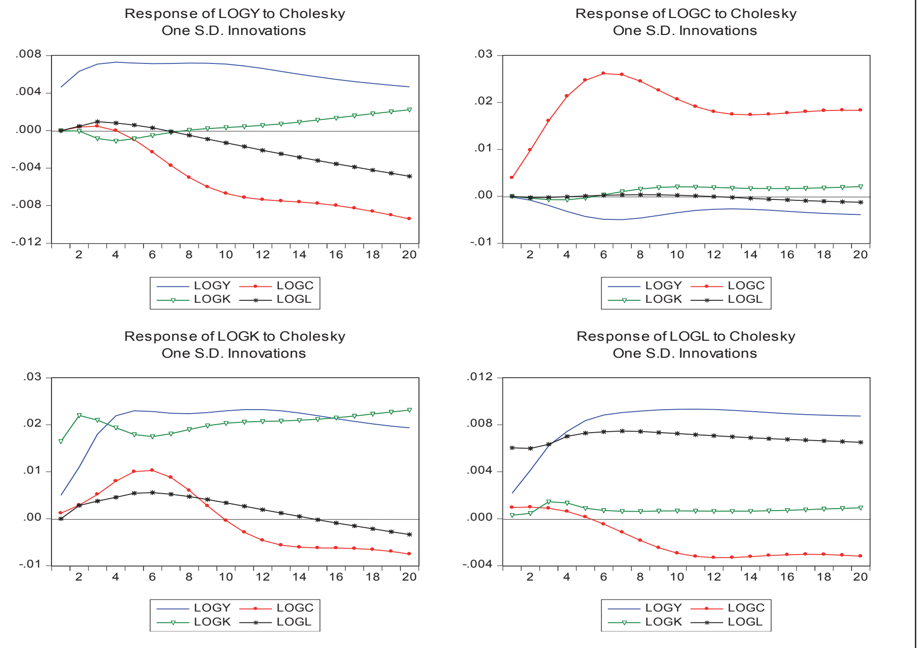
		Quarters				
		1	5	10	15	20
Decomposition for logY	logY	100	97.3	77.9	60.0	46.2
	logL	0.00	0.95	0.82	3.27	7.30
	logK	0.00	1.19	0.51	0.56	1.32
	logC	0.00	0.59	20.8	36.2	45.2
Decomposition for logL	logY	11.2	45.4	53.8	55.7	56.6
	logL	86.5	52.6	43.5	39.7	38.0
	logK	0.20	1.23	0.64	0.51	0.51
	logC	2.13	0.75	2.04	4.09	4.92
Decomposition for logK	logY	8.39	40.6	48.5	50.1	48.1
	logL	0.00	1.99	2.17	1.46	1.22
	logK	91.2	51.9	44.2	44.2	46.3
	logC	0.45	5.52	5.12	4.25	4.38
Decomposition for logC	logY	0.27	2.28	2.96	2.82	3.02
	logL	0.00	0.01	0.01	0.02	0.09
	logK	0.00	0.09	0.28	0.47	0.58
	logC	99.7	97.6	96.7	96.7	96.3

Variance decomposition for Equation (1) is presented. LOGY, LOGC, LOGK and LOGL are the logs of output, coal consumption, capital formation and labour.

Table 6 presents the results of demand-side VECM given in Equation (2). There is evidence of causality from coal price to coal consumption. This suggests some sensitivity to coal price by users of the commodity in the short run. This could be the case given the difficulties that have been faced by Eskom when negotiating with the local regulator to increase electricity prices. An increase in electricity prices must be approved first and an important consideration is the need to avoid disproportionate price increases that could impact low-income earners. While there could be sensitivity to coal prices by major users like Eskom, down the value chain, Ziramba (2008) found that residential electricity demand in South Africa was price and income inelastic. This means electricity price increases alone will not discourage residential electricity consumption. On the other hand, an increase in income does not cause a substantial increase in residential electricity demand.

The results also indicate evidence of joint significance for output and price in the determination of coal consumption. It is important to however note that output on its own has no causality on emissions in the short run. There seems to be some disconnection between coal consumption and economic growth as the bulk of the coal produced in the country is used for generating electricity. A good deal of the additional electricity requirement after 1994 was for electrification of some rural areas and townships which may not necessarily have added to growth. There has indeed been need to generate more electricity as the population is expanding.

Figure 1: Generalized impulse response for Equation (1)



Notes: Impulse response function for Equation (1) is presented. LOGY, LOGC, LOGK and LOGL are the logs of output, coal consumption, capital formation and labour.

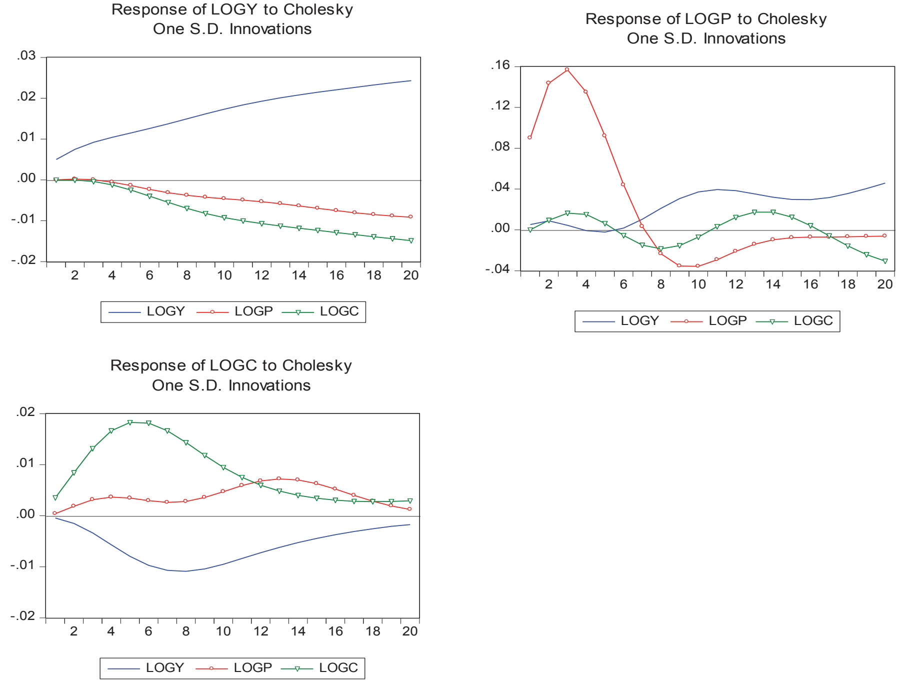
Table 6: Parsimonious VECM and Granger causality results for Equation (2)

Null hypothesis		ΔlogY	ΔlogC	ΔlogP	$ECT_{1,t-1}$	$ECT_{1,t-2}$	Joint Wald Tests
		(p-values)	(p-values)	(p-values)	(t-stats.)	(t-stats.)	(χ^2-statistics)
	ΔlogY	-	0.9568	0.5979	0.0098	-0.0019	1.7585
			(0.6198)	(0.7416)	(1.6280)	(-0.8272)	(0.7801)
Wald tests	*ΔlogC*	3.9830 (0.1365)	-	8.6362*** (0.0133)	0.0001 (0.0285)	0.0016 (0.9835)	15.139*** (0.0044)
	ΔlogP	0.5359	3.8660	-	0.4572***	-0.1706***	5.3332
		(0.7650)	(0.1447)		(4.2166)	(-4.1795)	(0.2548)

Parsimonious VECM and Granger causality results estimating Equation 2 are presented with lag structure optimized using AIC criterion. *ΔlogY, ΔlogC* and *ΔlogP* are changes in output, coal consumption and coal price respectively. ***, ** or * are significance levels respectively at 1%, 5% and 10%

Impulse response functions for Equation (2) are presented in Figure 2. One standard error shock in coal consumption causes output to respond by -1 % at the end of 10 quarters (2.5 years).

Figure 2: Generalized impulse response for Equation (2)



Notes: Impulse response functions for Equation (2) are presented. LOGY, LOGP and LOGC are the logs of output, coal price and coal consumption.

Variance decomposition for Equation (2) is presented in Table 7. Output largely accounts for its own forecast error innovations over the 20-quarter horizon contributing 71.8% to own shocks at the end of this period. After 5 quarters, 99.1 % of variation in forecast error for price is explained by own innovations. This drops to 81.0 % at the end of 20 quarters (5 years). Some 26.3% of forecast error variance for coal consumption is explained by output after 5 years. As the economy grows, the need arises to use more coal and the increase in demand for the commodity will likely result in higher emissions.

Table 7: Forecast error variance decomposition for Equation (2)

		Quarters				
		1	5	10	15	20
Decomposition for logY	logY	100	97.6	82.5	75.7	71.8
	logC	0.00	1.86	13.7	19.0	21.3
	logP	0.00	0.54	3.81	5.25	6.90
Decomposition for logC	logY	1.44	10.8	24.1	26.3	26.3
	logC	97.3	85.4	72.2	63.8	62.5
	logP	1.23	3.83	3.69	9.94	11.2
Decomposition for logP	logY	0.34	0.16	3.36	9.36	15.0
	logC	0.00	0.77	1.69	2.48	3.96
	logP	99.7	99.1	94.9	88.2	81.0

Variance decomposition for Equation (2) is presented. LOGY, $LOGCO_2$ and LOGP are the logs of output, carbon emissions and coal price.

Results for Equation (4) are presented in the Table 8. Evidence of causality is found flowing from coal consumption to carbon dioxide emissions in the short run.

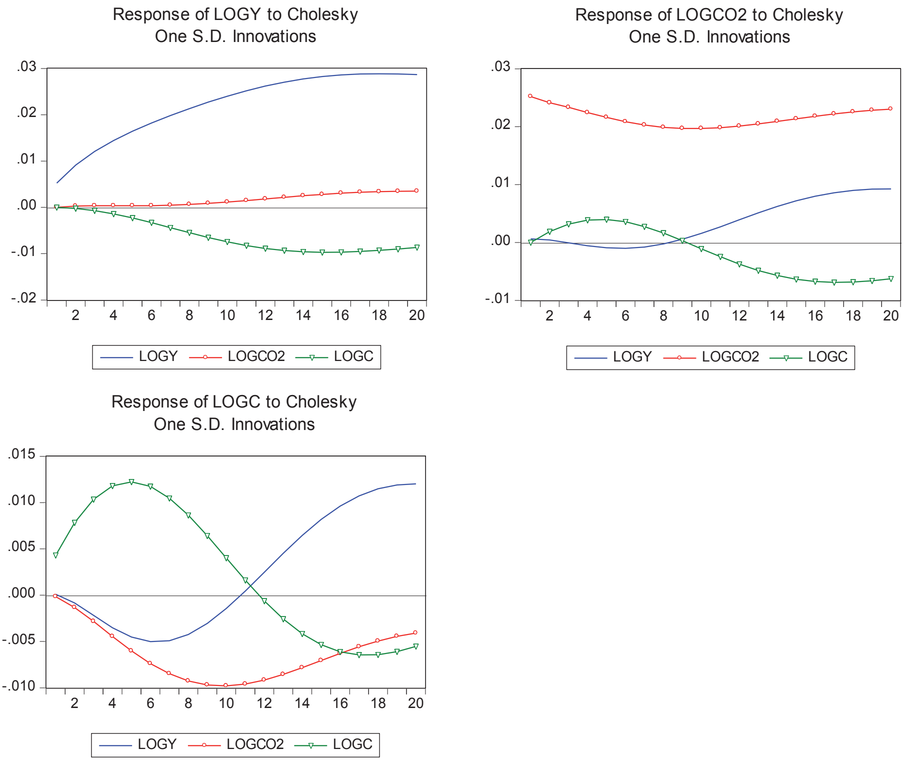
Table 8: Parsimonious VECM and Granger causality results for Equation (4)

Null hypothesis		***ΔlogY***	***ΔlogC***	ΔlogCO2	$ECT_{1,t-1}$	Joint Wald Tests
		(p-values)	(p-values)	(p-values)	(t-statistics)	(χ^2-statistics)
	ΔlogY	-	0.4176	0.5682	0.0095*	0.8184
			(0.5181)	(0.451)	(1.8180)	(0.6642)
Wald tests	*ΔlogC*	10.5354***	-	1.1543	0.0283***	12.831***
		(0.0012)		(0.2827)	(6.5900)	(0.0016)
	$\Delta logCO_2$	0.0230	4.0844**	-	0.0176	4.0895
		(0.8795)	(0.0433)		(0.6984)	(0.1294)

Parsimonious VECM and Granger causality results for Equation 4 are presented. VECM uses optimal lag structure. ΔlogY, ΔlogC and ΔlogCO2 are changes in output, coal consumption and carbon emissions respectively. ***, ** or * are significance levels respectively at 1%, 5% and 10%.

Further, there is substantial causality flowing from economic growth to coal consumption with both short-run and long-run relationships significant at 1% level. This therefore means that in the case of South Africa, higher coal consumption will become necessary if increased economic growth is to be sustained. This calls for investigating further structural efficiencies in the way the economy works as well as to begin to adopt other forms of energy to drive the economy. This is because coal consumption increases pollution as noted above. China has done very well with hydroelectric power and solar energy such that much of the coal is channelled towards industrial production.

Figure 3: Generalized impulse response for Equation (4)



Notes: Impulse response functions for Equation (4) are presented. LOGY, LOGCO$_2$ and LOGC are the logs of output, carbon dioxide emissions and coal consumption.

The response of coal consumption to one standard error shock in output is about -0.5% in 1 and a half years changing sign and increasing to 1.2% in about 5 years. A shock of one standard error to coal consumption causes carbon dioxide to first rise by about 0.45% in one year changing direction to about -0.7% in just over 4 years.

Variance decomposition for Equation (4) is presented in Table 9. Results in this table suggest both output and carbon emissions are largely responsible for their own innovations within a 5-year forecast period. Output explains 8.12% of variations in coal consumption after 2.5 years rising to 29.9% after 5 years. Carbon emissions have an even more significant impact on forecast error of coal consumption accounting for 32.7% of variations at the end of 5 years.

Table 9: Forecast error variance decomposition for Equation (4)

		Quarters				
		1	5	10	15	20
	logY	100	98.9	94.7	91.5	90.8
Decomposition for logY	logC	0.00	1.05	5.22	8.09	8.54
	logCO_2	0.00	0.06	0.10	0.38	0.70
	logY	0.05	6.60	8.12	12.7	29.9
Decomposition for logC	logC	99.8	82.0	59.4	45.7	37.4
	logCO_2	0.13	11.4	32.5	41.6	32.7
	logY	0.06	0.06	0.13	2.02	5.17
Decomposition for logCO_2	logC	0.00	1.59	1.42	2.57	3.95
	logCO_2	99.9	98.3	98.5	95.4	90.9

Variance decomposition for Equation (4) is presented. LOGY, LOGC and LOGCO_2 are the logs of output, coal consumption and carbon emissions.

Environmental Kuznets Curve (EKC) Analysis

We have already seen that coal consumption has unidirectional causality on carbon emissions in the VECM analysis and Granger causality estimation for demand Equation (4). It is of theoretical interest to investigate further the long-run steady state relationship between carbon emissions, coal consumption and output. To check for this relationship we have used a model from literature involving these variables. We follow Ang (2007) testing the relation:

$$C_t = \beta_0 + \beta_1 E_t + \beta_2 G_t + \beta_3 G_t^2 + \varepsilon_t \tag{9}$$

Where Ct are CO_2 emissions, E_t is commercial energy use, G_t is per capita real GDP and Gt_2 is the square of per capita real GDP. The sign for β_3 is typically expected to be negative. This model comes from the Environmental Kuznets Curve (EKC) hypothesis. An inverted U-curve relationship between economic development and the environment is envisaged under the hypothesis (Ang, 2007; Antweiler et al., 2001; Coxhead, 2003; Cropper and Griffiths, 1994; Grossman and Krueger, 1995; Selden and Song, 1994). Three factors defining this relationship are scale, composition and technique effects. As the economy expands, pollution rises as per the scale effect. Composition will see changes in the economy's production structure, from agricultural to industrial, to the service-based stage of development. Resources are then re-allocated and techniques of production improve thereby reducing pollution. The cointegrating equation and speed of adjustment coefficient of the EKC hypothesis are presented in Table 10.

Table 10: Cointegrating vector for Equation 9

Cointegrating Equation				ECT
$CO_{2,t} = -294.56$	$+ 0.02\ E_t$	$+ 52.16^{**}\ G_t$	$- 2.47^{**}\ G^2_t$	$- 0.4540$
	[0.1447]	[2.4597]	[-2.5237]	[-4.4614]
$\chi^2_{SERIAL}(1) = 13.40(0.6437)$				
$\chi^2_{SERIAL}(2) = 14.36(0.5719)$				

The table presents the cointegrating equation involving the variables in the EKC hypothesis test with CO2 as the normalized variable. ECT gives the speed of adjustment coefficient for the cointegrating vector. χ2SERIAL (1) and χ2SERIAL (2) are respectively Lagrange multiplier test statistics for no first and second serial correlation. Square brackets present t-statistics while round brackets show p-values. Significance at 1%, 5% and 10% is represented by ***, ** and *.

There is no evidence of serial autocorrelation in the residuals up to second order as indicated by the Lagrange Multiplier (LM) test statistics. Coefficients for G_t and G^2_t are significant at 5%. The results also show the signs for the coefficients for G_t and G^2_t are as expected. This to some extent shows some support for the EKC hypothesis with the level of pollution first increasing with income then stabilizing before declining. Similar to Ang (2007) the coefficient of the speed of adjustment is negative with adjustment of about 45% within a quarter of a year. It takes about 6.6 months to accomplish long-run equilibrium.

The analysis also considered the possibility of causality using the cointegration-based Granger causality tests. Results of this analysis are presented in Table 11. Evidence of uni-directional causality from energy consumption to both Gt and G^2_t is found at 5% significance level. Reverse causality in both cases is not observed. The results mean that the country is dependent on coal consumption in order to increase GDP per capita. This further confirms the heavy reliance of the economy on coal use calling for diversification of energy sources. Analysis involving Equation (4) already showed that a rise in coal consumption would cause carbon emissions in South Africa to increase. Excessive emissions of CO_2 are detrimental to both the environment and human health.

It would therefore be difficult to reduce carbon emissions without impacting GDP growth and per capita income if alternative sources of energy are not used. It is also acknowledged the findings on EKC analysis for South Africa above are not easy to link to specific environmental damage due to carbon emissions by individual firms or entities. This report has therefore described earlier the major users of coal in South Africa to whom carbon emissions, and therefore environmental damage, can be attributed.

Table 11: EKC and Granger causality results for Equation (9)

Null hypothesis		ΔCO_2 (p-values)	ΔE_t (p-values)	ΔG_t (p-values)	ΔG^2_t (p-values)
	ΔCO_2	-	2.7293 (0.2555)	0.7670 (0.6815)	0.8061 (0.6683)
Wald tests	ΔE_t	0.8431 (0.6560)	-	3.1516 (0.2069)	3.2264 (0.1992)
	ΔG_t	0.7394 (0.6909)	6.4826** (0.0391)	-	2.7041 (0.2587)
	ΔG^2_t	0.7283 (0.6948)	6.5577** (0.0377)	2.6742 (0.2626)	-

EKC analysis and Granger causality tests for Equation 9 are presented in the table using the parsimonious VECM approach. VECM is used with the optimal lag order determined by AIC criterion. ***, ** or * are significance levels respectively at 1%, 5% and 10%.

CONCLUSIONS AND IMPLICATIONS

The paper firstly looked at the long-term interaction between output, coal consumption, capital formation and labour using supply-side analysis. Demand-side analysis had two stages of investigation, first the link between output, coal price and coal consumption, secondly, output, coal consumption and carbon emissions. Lastly, the study tested the extent to which South African data supports the EKC hypothesis.

The study finds unidirectional causality from output to both labour and capital formation in the short-run and long-run. This suggests creating long-term jobs in South Africa and maintaining an environment ideal for capital formation requires the economy to be growing first.

Evidence is also found of unidirectional causality from coal price to coal consumption. Price increases of electricity by Eskom have to be motivated for approval by the local energy regulator suggesting Eskom would be sensitive to coal price increases. Results also suggest there is potential to increase economic growth by harnessing alternative sources of energy. This could leave the environment cleaner in line with commitments on reduction of pollution made at the 2009 Copenhagen climate change gathering. Governments will need to promote renewable energy which is sustainable in increasing economic growth while comparatively being less harmful to the environment. This supports the long-term goal of keeping the global average temperature rise below 2°C above pre-industrial levels, as agreed by 195 countries under The Paris Agreement of 2015. Investment in an expanded renewable energy sector will be beneficial to the public and private sectors at all levels while helping to create sustainable jobs.

As expected, coal consumption causes carbon emissions in the short-run. Furthermore, it is observed from the second demand-side relation that there is uni-directional causality from economic output to coal consumption in both the short and long-run. The bulk of the coal consumed in the country is used for generating electricity. Additional electricity has been generated after 1994 to provide power to rural and township homes that were previously not on the grid. Economic expansion can cause incomes in the lower bracket to rise thereby increasing demand for electricity, and consequently coal consumption. In fact, the country started struggling to meet national electricity requirements in recent years resulting in planned rationing (load shedding). The recommendation here is for alternative sources of energy to be effectively employed, particularly in the area of greener energy sources.

These conclusions and recommendations are consistent with Frankel (2008) in advocating for use of alternative sources of energy, especially solar energy, arguing that costs of fossil fuel production are increasing significantly. This is the case where, for example, new oil wells are established, or when there is need to dig deeper to extract coal. The key message in the book review in Obeng-Odoom (2015) is for the diversification of sources of energy, increasing investment in biofuels and solar energy. This literature tends to support the generality of the findings and suggestions in this paper.

A test involving the EKC hypothesis using a cointegrating vector shows South African data supports the hypothesis. There is evidence of uni-directional causality from coal consumption to per capita GDP confirming the country's heavy reliance on coal. Unless diversification of energy sources takes place, it would be difficult to reduce carbon emissions without impacting output.

Energy efficiency coupled with increased substitution of fossil fuels with renewable energy sources should be the pillars of the strategy to reduce emissions in South Africa. In this regard, Obeng-Odoom (2016) finds urban green growth essential in attaining sustainability, connecting eco-technology, cleaner as well as greener technologies with reduction of emissions, while saving energy. Specific recommendations include instituting energy reward systems, promoting green homes, using energy-saving house appliances and improving public awareness on energy efficiency.

Environmental agencies should monitor all economic participants ensuring government adheres to its own environmental commitments in line with set timelines. Agencies are also instrumental in supervising industrialists ensuring laws and regulations are not violated. Increased industrial innovation and energy efficiency will reduce the energy required per unit GDP while leaving a cleaner environment. The contribution in Frankel (2008) suggests that energy markets, communities and states will facilitate balanced allocation among energy deficit and surplus areas, increasing efficiencies within the global energy markets. While the ETS movement is dependent on the markets to achieve allocative efficiency, the downside is the potential deepening of inequalities occasioned by corporate power, capital accumulation and speculation. This could mortgage environmental sustainability to the very entities responsible for creating the problem (Stilwell, 2011). It is imperative to consider more intensified interventions "beyond the market", if environmental sustainability is to be maintained. Legal frameworks and policies on environmental protection should be strengthened at the national level ensuring effective waste management and carbon emissions control.

NOTES

1. Synthetic fuel or synfuel is a liquid or gaseous fuel extracted from syngas (mixture of carbon monoxide and hydrogen). Syngas derives from gasification of solids like coal or biomass or by reforming of natural gas (Crocker, 2010).
2. Output equals income and equals constant-dollar GDP. Capital equals constant dollar gross capital formation as supplied by the South African Reserve Bank (SARB). Gross fixed capital formation (constant 2010 prices) has been used.
3. BRICS is the acronym used for the grouping incorporating Brazil, Russia, India, China and South Africa.
4. Energy-related data is also available from the Energy Information Administration (EIA).
5. Capital formation describes by how much the total physical capital stock increased during an accounting period.

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