



CO₂ Emissions, Energy Consumption, Income and Foreign Trade: A South African Perspective

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Abstract

The effect of trade liberalisation on environmental conditions has yielded significant debate in the energy economics literature. Although research on the relationship between energy consumption, emissions and economic growth is not new in South Africa, no study specifically addresses the role that SA's foreign trade plays in this context. A surprising fact given trade is one of the most important factors that can explain the Environmental Kuznets Curve. Our research employs recent SA trade and energy data and modern econometric techniques to investigate this. The main finding is the existence of a long run relationship between environmental quality, levels of per capita energy use and foreign trade in SA. As anticipated per capita energy use has a significant long run effect in raising the country's CO₂ emission levels, yet surprisingly higher levels of trade act to reduce these emissions. Granger causality tests confirm the existence of a positive bidirectional relationship between per capita energy use and CO₂ emissions. Whilst we also find positive bidirectional causality between trade and income per capita and between trade and per capita energy use, it appears that SA trade liberalisation has not contributed to a long run growth in pollution-intensive activities nor higher emission levels.

1 Introduction

If South Africa's greenhouse gas (GHG) emissions are compared on a global scale, it is immediately clear that the country is one of the world's most carbon-intensive economies. In fact, South Africa is the world's most carbon-intensive non-oil-producing developing country, measured in per capita CO₂equivalent emissions in 2010, and excluding island states (EIA, 2010). Furthermore, it is the largest emitter of GHGs in Africa, with 42% of the continents emissions coming from South Africa alone. South Africa is also a bigger emitter of CO₂ than all other Sub-Saharan African (SSA) countries combined (EIA, 2010)

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South Africa's total GHG emissions in 2000 were estimated to be 461 million tons CO₂equivalent of which, 83% of emissions were associated with energy supply and consumption, 7% from industrial processes, 8% from agriculture, and 2% from waste (DEA, 2010). The energy sector is therefore by far the largest sector responsible for emissions in South Africa at 380,988Gg CO₂e with the sector's combustion of fuel producing 81% of the sector's emissions and fugitive emissions from fuel contributing the remaining 19% (DEA, 2010). Factors which have contributed to South Africa's enormous energy related emissions include: a deliberate strategy by the pre-democratic government prior to 1994 of encouraging investment in energy-intensive industries, including aluminium and other non-ferrous metal beneficiation (the so called 'mineral-energy complex' identified by Fine & Rustonjee, 1996); and the carbon-intensity of a largely (90 per cent +) coal-based electricity generation base (EIA, 2010).

Of particular relevance to our work is a finding in a multi-country study on CO₂ embodied in international trade by Peters & Hertwich (2007) that around 40 per cent of South Africa's emissions are due to trade (in particular the export of carbon-intensive goods) rather than domestic consumption. According to this study, this is the highest proportion for any of the countries included in their analysis. Given that most of South Africa's energy needs are met by burning fossil fuels, a strong link between foreign trade and CO₂ emissions is to be expected. This fact makes South Africa vulnerable to trade-induced environmental degradation as a result of an increase in the burning of fossil fuels to meet the energy demands of an expanding export sector. This is particularly relevant given international trade is one of the most important factors that can explain the Environmental Kuznets Curve (EKC).

In this context, it is important to note that South Africa is both a member of the World Trade Organisation (WTO) since 1995 and a signatory to the 1992 UNFCCC and its Kyoto Protocol. Under Kyoto, the biggest emitters of GHGs are encouraged to implement mitigation measures that catalyse energy efficiency and motivate energy sustainability policies. South Africa is classified as a non-annex developing country and therefore has no mandatory emission reduction targets during the period 2008-2012. Nonetheless, the country is committed to the fight against climate change and has instituted several policies and strategies at the national level to reduce GHG emissions. The South African government is of the view that the country needs to reduce GHG emissions while working to ensure economic growth, increase employment, and reduce poverty and inequality (National Treasury, 2010).

The above discussion suggests South Africa is a compelling candidate for a separate study that investigates the role of trade openness on economic growth, energy consumption and pollutant emissions. Indeed, our study is the first attempt to incorporate foreign trade as a separate determinant of CO₂ emissions in a multivariate framework in the context of South Africa. Whilst there are some studies in the international literature that link economic growth, energy consumption and pollutant emissions in the same framework initiated by the work of Ang (2007) and Soytaş et al. (2007) these do not relate to South Africa. Studies that do focus on South Africa investigate either the link be-

tween economic growth and emissions (see, Nahman & Antrobus, 2005); or energy consumption and economic growth (see, Ziramba, 2009; Odhiambo, 2009; Wolde-Rufael, 2006, 2009). The only South African study that our research has revealed that employs modern advances in time series econometrics of cointegration and causality to test the relationship between energy consumption, pollutant emissions and economic growth in a coherent multivariate framework is that of Menyah & Wolde-Rufael (2010).

This paper's aim is to fill a gap in research in the South African context by employing the same econometric techniques of Halicioglu (2009) but in addition introducing foreign trade into the analysis as in the work by Baek et al. (2009). To our knowledge this is the first South African study that attempts to specifically understand the role of foreign trade on pollutant emissions through its effect on economic growth and energy consumption in a multivariate framework employing a single cointegration approach.

The remainder of the paper is structured as follows. In Section 2 we present a brief review of the empirical literature followed by a discussion in Section 3 of the data and methodology used. Section 4 presents the empirical evidence, while the concluding comments are outlined in Section 5.

2 A theoretical review

The economic literature on the subject of economic growth, energy consumption and environmental pollution is well established. Empirically, two dominant research streams have emerged over the last few decades. The first area of research which focuses on pollutant emissions and income is related to testing the validity of the environmental Kuznets curve (EKC) hypothesis. According to this hypothesis, which draws its inspiration from the work of Kuznets (1955) environmental degradation may follow a similar income-dependence as income-inequality and tends to become worse as a country grows out of poverty, stabilises at some middle income levels, and then gradually improves. The EKC hypothesises an inverted-U-shaped curve when pollution indicators are plotted against income per capita and was proposed and first tested by Grossman and Krueger (1991). In the first stage of industrialisation, an economy's pollution grows rapidly because high priority is given to increase material output, and people are more interested in jobs and income than clean air and water (Dasgupta et al., 2002). The rapid economic growth puts pressure on the environment through the greater use of natural resources and the emission of pollutants. In this stage of growth, people are too poor to pay for abatement, and there is general disregard for the environmental consequences of growth. In the later stages of industrialisation, as income rises, people value the environment more, regulatory institutions become more effective and pollution level declines. Theoretically, the EKC hypothesis thus identifies a well-defined relationship between the level of economic activity and resulting environmental pressures (either in the form of the concentration of pollution levels, flow of emissions or the depletion of resources, etc.).

According to Harbaugh et al. (2002), the inverted-U relation or EKC can however not be generalised for all types of pollutants in that there is little empirical support for an inverted-Ushaped relationship between income and several important pollutants. Environmental indicators, for which the EKC hypothesis is most plausible, are those pollutants with more short-term and local impacts (like SO₂, suspended particulate matter, NO_x and CO), rather than those with more global, indirect and long-term impacts (like CO₂ emissions, municipal waste, energy consumption and traffic volumes).

Dinda (2004) provides a detailed review of the EKC literature. The basic conclusion according to this review is that the EKC is a country and/or indicator specific phenomenon as the results vary both across countries and across different measures of environmental standards.

The second area of research focuses on the energy consumption and output growth relationship. This link has been examined extensively in the literature since the seminal work of Kraft and Kraft (1978) in an attempt to explore whether economic growth stimulates energy consumption or vice versa. Whilst Kraft and Kraft (1978) find that the causal relationship runs from economic growth to energy in the United States and the reverse does not hold true, studies for other countries reveal conflicting results. The direction of causality may therefore not be determined *a priori*. Ozturk (2010) provides a detailed review of the empirical literature on the subject.

A far more recent and emerging line of literature initiated by the work of Ang (2007) and Soytas et al. (2007) analyses both sets of relationships in the same multivariate framework in order to examine the dynamic links between economic growth, energy consumption and environmental pollutants together. In this respect see also the work by Zhang and Cheng (2009) & Soytas and Sari (2009). Our research follows the work of Halicioglu (2009) and Baek and Kim (2011) by extending this framework through the inclusion of the additional impact of foreign trade into the dynamic relationship yet in the context of South Africa.

Since the seminal work of Grossman and Krueger (1991) many economists have attempted to examine the effect of foreign trade or more specifically trade openness on the environment. The impact of foreign trade can be decomposed into scale, technique, and composition effects (Antweiler et al., 2001).

In order to examine the environmental consequences of South Africa's foreign trade and various measures of economic activity, we rely on a theoretical framework developed by Baek et al (2009).

We first define emissions (E) as a function of income (Y) and production technology (Z₁) as follows:

$$E = f(Y; Z_1) \tag{1}$$

In other words, if we assume that an economy follows the full trajectory of the environmental Kuznets curve (EKC), it could be hypothesised that emission levels increase with growing income up to a threshold level ($\partial E/\partial Y > 0$) beyond which emission levels decline with higher income levels ($\partial E/\partial Y < 0$). The combination of these two effects ($\partial E/\partial Y > 0$ and $\partial E/\partial Y < 0$) creates the

inverted U-shaped EKC relationship.

In light of the intense debate on the link between global warming and greenhouse gas pollutants, it may be useful to focus on the use of energy (ENG) as a productive technology (Z_1) amongst others inputs and its impact on a country's emission levels. To the extent that an increase in energy use induced by economic growth brings about a proportionate increase in emission levels, it could be hypothesised that energy use positively affects emission levels ($\partial E / \partial \text{ENG} > 0$) for a given source of energy inputs (ie, fossil fuels as opposed to renewables).

Next we define income (Y) as a function of foreign trade (T) and other exogenous variables (Z_2) as follows:

$$Y = f(T, Z_2) \tag{2}$$

Namely, if foreign trade leads to an increase in the scale of economic activity and, consequently, an increase in a country's income, it can be hypothesised that foreign trade has a positive relation with income ($\partial Y / \partial T > 0$). It is possible though that foreign trade does not positively affect income in a country in which case it is assumed that the country does not engage in globalisation via the World Trade Organisation (WTO) and other regional and/or bilateral trade treaties.

We then substitute Eq. (2) into Eq. (1), which yields the following relationship:

$$E = g(T, \text{ENG}, Z_2) \tag{3}$$

The relationship between emissions and foreign trade depends on the relationships derived from Eqs. (1) and (2). Since countries experience different levels of income and foreign trade depending on their level of economic development, the relationship between emissions, income and foreign trade depends on where an economy is currently placed in its development trajectory (Baek *et al.* 2009).

It is common for foreign trade to contribute to an increase income and energy use in the early stages of a country's economic development, in which case trade liberalisation may lead to more rapid growth of pollution-intensive industries and emission levels in these countries. Any restrictions on the use of energy in countries that have not reached income levels high enough to reach their EKC turning points through enforcement of environmental regulations may adversely affect economic growth and trade. On the other hand, for countries that move beyond the EKC turning points with energy consumption stimulated by growth and have a higher degree of openness, foreign trade may result in structural change towards less polluting industries and enforcement of environmental regulations with little or no adverse effect on economic growth, thereby improving environmental quality and reducing emission levels.

Ultimately, the effect of foreign trade on income, energy consumption and emission levels is an empirical question which depends on the stage of economic development, extent of foreign trade liberalisation and the stringency of the environmental regulations of the country under investigation.

The empirical literature relating to foreign trade's role on the environment is at best mixed. Studies which support the pro-environmental impact of trade openness include: Lucas et al. (1992); Birdsall and Wheeler (1993); Frankel and Rose (2005); and Grether et al. (2007). Other studies such as those by Suri and Chapman (1998); Cole et al. (2000); and Dean (2002) however conclude that foreign trade is harmful to the environment. Whilst such studies have undoubtedly expanded our understanding of the environmental consequences of economic growth and foreign trade, they pay little attention to the causal relationship between foreign trade, income growth, and environmental quality. More specifically, these studies treat foreign trade and income as exogenous determinants of environmental quality/damage. This assumes a unidirectional causal relationship, in that, a change in the level of trade openness and income causes a consequent change in environmental quality, but the reverse does not hold true. Such a presumption neglects the possible endogeneity of foreign trade and income in that environmental quality and income may jointly affect foreign trade. Frankel and Rose (2005) address the issue of endogeneity between foreign trade, income and environmental quality in their analysis through the use of instrumental variable (IV) estimates. Whilst most other studies which focus on the environmental consequences of foreign trade employ Granger causality tests with little regard to the possible cointegrating relationship amongst the variables. If, indeed, the selected variables are cointegrated in a model, work by Miller and Russek (1990) suggests that the causality tests undertaken in these studies provide misleading results. Furthermore, Granger causality tests focus specifically on short-run dynamics rather than any underlying long-run relationships.

Given that the environmental consequences of economic growth and foreign trade are essentially a long-run concept (Dinda and Coondoo, 2006), it is highly desirable to examine the true relationship amongst the variables using a cointegration approach. In particular, to establish the long-run relationship between foreign trade and pollutant emissions, the tests in our research are carried out using the co-integration procedure developed by Pesaran et al. (2001), while tests for causality are conducted using an augmented form of Granger causality analysis as employed in Halicioglu (2009).

3 Empirical methodology

3.1 Model

From the empirical literature in energy economics, it is plausible to form the long-run relationship between CO₂ emissions, energy consumption, economic growth (income) and foreign trade in a linear logarithmic quadratic form, with a view to testing the validity of the EKC hypothesis as follows:

$$c_t = \beta_0 + \beta_1 e_t + \beta_2 y_t + \beta_3 y_t^2 + \beta_4 f_t + \varepsilon_t \quad (4)$$

where c_t is CO₂ emissions per capita, e_t is commercial energy use per capita,

y_t is per capita real income, y_t^2 is square of per capita real income, f_t is openness ratio which is used as a proxy for foreign trade, and e_t is the regression error term.

Following theory, the expected signs are as follows: β_0 to be positive because a higher level of energy consumption should result in greater economic activity and stimulate CO₂ emissions. According to the EKC hypothesis, the sign of β_1 is expected to be positive whereas the sign of β_2 is expected to be negative. It is quite possible for β_3 to be statistically insignificant, in which case a monotonic increase in the relationship between per capita CO₂ emissions and per capita income is indicated. Finally, the sign of β_4 is expected to be either positive or negative depending on the level of income and stage of economic development of a country. For developed countries, it is expected to be negative since as these countries become more advanced; technological improvements allow them to produce less energy and pollution intensive goods and begin to import these from other countries with less protective environmental laws. For developing countries, as in the case of South Africa, this sign is expected to be positive as the country has less advanced production technologies and hence dirtier industries with a heavy share of pollutants/emissions.

3.2 Econometric procedure

The autoregressive distributed lag (ARDL) bounds testing approach to cointegration developed by Pesaran et al. (2001) is employed to test whether a long run dynamic inter-relationship exists between the four variables or not. The ARDL approach to cointegration is has several econometric advantages over traditional cointegration techniques. The approach also known as bounds testing, avoids endogeneity problems and the inability to test long run relationships of variables associated with the traditional Engel Granger method. Both short and long run parameters are calculated simultaneously and the ARDL approach can be used regardless of whether the data are intergrated of order: I(0) or I(1). Narayan (2005) argues that the ARDL approach is superior in small samples to other single and multivariate cointegration methods. As set out in Halicioğlu (2009) the ARDL representation of Eq.(4) is formulated as follows:

$$\begin{aligned} \Delta c_t = & b_0 + \sum_{i=1}^m b_{1i} \Delta c_{t-i} + \sum_{i=0}^m b_{2i} \Delta e_{t-i} + \sum_{i=0}^m b_{3i} \Delta y_{t-i} + \sum_{i=0}^m b_{4i} \Delta y_{t-i}^2 \\ & + \sum_{i=0}^m b_{5i} f_t + b_6 c_{t-1} + b_7 e_{t-1} + b_8 y_{t-1} + b_9 y_{t-1}^2 + b_{10} f_{t-1} + v_t \end{aligned} \quad (5)$$

The bounds test is based on the Wald's statistic, where the null hypothesis joint significance test implies no relationship (i.e. $H_0: b_6=b_7=b_8=b_9=b_{10}=0$), and the alternate implies cointegration (i.e. $H_1: b_6 \neq b_7 \neq b_8 \neq b_9 \neq b_{10} \neq 0$). This approach does not use a normal distribution, thus Pesaran et al. (2001) have computed critical values for given significance levels. However because of the small sample size used in this study, critical value ranges of the F-statistic as set out in Narayan (2005) are used as they are more appropriate. Using this test if the computed F-statistic exceeds the upper bound we can reject H_0 , if it

falls below the lower bound we fail to reject H_0 , and if lies between both bounds the test is inconclusive.

The ARDL bounds test for cointegration is complemented by Johansen and Juselius's (1990) multivariate cointegration methodology. This technique requires the estimation of a vector auto regressive (VAR) model. The VAR model is well documented and so the model is briefly described below:

$$X_t = \mu + \sum_{i=1}^k \Gamma_i X_{t-i} + v_t \quad (6)$$

Here X_t represents the vector of endogenous variables found in the EKC (c, e, y, y^2 and f). μ is a vector of constant terms, Γ_i is the coefficient matrix with k being the optimal lag length. Finally v_t is the residual matrix. This type of model has several benefits over univariate models, as researchers do not have to specify which variables are endogenous and exogenous. This property is appropriate when trying to model the environmental consequences of trade where there is bidirectional causality. A drawback with using such a model is found in the number of parameters used in an autoregressive model. For small samples such as those used in this study the VAR will use up degrees of freedom relatively quickly. For this reason the model is used to help describe the relationship between the variables, as opposed to the main test for cointegration. Therefore only the VAR, trace and max-eigen value, Granger Causality, and impulse response components of the Johansen and Juselius' (1990) cointegration method is included in the paper. The the Vector Error Correction Model is omitted in favour of the ARDL model as stipulated above given its suitability to small samples. The VAR model's appropriate lag length is determined utilising Information Criteria (IC) and the adjusted log likelihood ratio. The use of Akaike's Information Criteria (AIC), Schwarz's Bayesian Information Criteria (SBIC), Hannan-Quinn Information Criteria (HQIC), help determine the appropriate lag length. No criterion is superior to another but for the purposes of the model in our paper, AIC is used as the primary measure as it returns efficient results and works best with small samples.

After determining the lag length of the VAR the next step is to determine the amount of significant cointegrating relationships. Johansen proposes the two likelihood ratios to test for significant cointegrating relationships. The trace and max eigenvalue tests are formulated as follows:

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^g \ln(1 - \lambda_i) \quad (7)$$

$$\lambda_{max\ eig}(r, r + 1) = -T \ln(1 - \lambda_{r+1}) \quad (8)$$

Where r is the number of cointegrating vectors under the null hypothesis, and λ_i is the estimated value of the ith ordered eigenvalue from the Π matrix. Johansen and Juselius (1990) provide the critical values for these two tests, where the distribution is non-standard.

When a VAR model includes lags of variables it may be difficult to see which sets of variables have significant effects on each dependant variable and which

do not (Brooks, 2010). A variable x is said to Granger cause y when lags of x explain changes in the current value of y given sufficient information. The Granger causality test can be used to identify causality amongst the variables in the VAR model. Therefore, to complement the cointegration analysis, we carry out Granger causality testing by employing an augmented form of the Granger theorem as set out in (Halicioglu, 2009). A standard granger causality test run on a normal VAR model with differenced variables would omit any long run relationship between the variables under investigation. In order to account for the long run relationship, we include the error correction term as in Halicioglu (2009). This term is obtained by estimating the univariate long run EKC relationship set out in Eq(4).

The augmented form including the error correction term is as follows:

$$(1-L) \begin{bmatrix} c_t \\ e_t \\ y_t \\ y_t^2 \\ f_t \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \end{bmatrix} + \sum_{i=1}^p (1-L) \begin{bmatrix} d_{11i} & d_{12i} & d_{13i} & d_{14i} & d_{15i} & d_{16i} \\ d_{21i} & d_{22i} & d_{23i} & d_{24i} & d_{25i} & d_{26i} \\ d_{31i} & d_{32i} & d_{33i} & d_{34i} & d_{35i} & d_{36i} \\ d_{41i} & d_{42i} & d_{43i} & d_{44i} & d_{45i} & d_{46i} \\ d_{51i} & d_{52i} & d_{53i} & d_{54i} & d_{55i} & d_{56i} \end{bmatrix} \begin{bmatrix} c_{t-i} \\ e_{t-i} \\ y_{t-i} \\ y_{t-i}^2 \\ f_{t-i} \end{bmatrix} + \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \\ \lambda_5 \end{bmatrix} [EC_{t-1}] + \begin{bmatrix} \omega_{1t} \\ \omega_{2t} \\ \omega_{3t} \\ \omega_{4t} \\ \omega_{5t} \end{bmatrix} \quad (9)$$

Where (1-L) is the lag operator used to describe the amount of lags included in the VAR and $[EC_{t-1}]$ is the error correction term.

The Granger causality test applied to Eq. (9) checks for: (i) the statistical significance of the lagged differences of the variables for each vector; which is a measure of short-run causality; and (ii) the existence of a long-run relationship by examining the statistical significance of the error-correction term of the vector. Using the augmented form of the granger causality test as in Halicioglu (2009) one can identify both the short and long run relationships amongst the variables.

Bahmani-Oskooee and Chomsisengphet (2002) argue that the confirmation of cointegration, through for example an ADRL procedure, does not however necessarily imply that the estimated long-run coefficients are stable. Rather, the stability of these coefficients should be tested by means of tests developed by Chow (1960), Brown et al. (1975), and Hansen & Johansen (1993). In our study, we employ the stability tests of Brown et al. (1975), also known as cumulative sum and cumulative sum of squares tests based on the recursive regression residuals. These tests incorporate the dynamics of the short-run to the long-run through the residuals. A graphical plot showing that the cumulative sum and cumulative sum of squares statistics fall inside the critical bounds of 5% significance would provide confirmation that the coefficients of our ARDL regression are in fact stable.

3.3 Data

Based on the empirical model detailed above, annual time series data on carbon dioxide (CO₂) emissions, energy consumption, income and trade openness are collected for South Africa over the time period 1960-2009. The per capita CO₂ emissions (measured in metric ton) are used as a proxy for environmental quality and are collected from the World Development Indicators (WDI) provided by the World Bank. Commercial energy consumption is proxied by total primary energy supply per capita (measured in kilojoules) and is available from 1971 onwards from the International Energy Agency (IEA). Data for years prior to 1971 has been obtained from personal communication with Dr Chris Cooper from the South African National Energy Association who was instrumental in supplying SA energy data to the IEA in the 1960s and 1970s. Per capita real income figures were calculated using annual real gross national income and population figures available from the International Monetary Fund (IMF) and serve as a proxy for income. Finally, data on the degree of South Africa's trade openness is proxied by the ratio of the value of total trade to real GDP and is obtained from the IMF. All variables are converted to natural logarithms and used throughout.

4 Empirical results

We check the time series properties of the variables represented in our empirical model set out in Eq.(4) through employing the Dickey and Fuller (1981) and Phillips-Perron (1988) unit root-testing procedures. Table 1 summarises these results.

From this, we establish that the time series relating to the variables in Eq.(1) appear to contain a unit root in their levels but are stationary in their first differences, indicating that they are integrated at order one i.e., I(1). This is true, with the exception of income (y), income is however considered to be weakly stationary in 1st differences.

4.1 Cointegration tests

We proceed to estimate Eq. (5) as follows. In the first stage of the ARDL procedure, the order of lags on the first-differenced variables for Eq.(5) are obtained from the unrestricted VAR by relying on the indications of the AIC selection criteria. These results are shown in Table 2.

Using information criteria to determine the required lag It was found that using AIC, BIC and Adjusted R²'s that a single lag specification of the model is superior to either a zero or dual lag specification, the single lag was also chosen in order to minimise the loss of degrees of freedom given the small sample size.

Next we apply a bounds F-test based on the Wald's statistic to Eq. (5) in order to establish a long-run relationship between the variables. Note, in this study we implicitly assumes that Eq.(5) is free from a trend due to the differenced variables. In summary, the F-tests shown in table 3 indicate that there exist three cointegration relationships. In the first long-run relationship c

is the dependent variable. The second and third long-run relationships refer to a situation where e and f are the dependent variables respectively. Cointegration among the variables is taken as evidence that rules out the possibility of the estimated relationships being “spurious”.

With confirmation of the existence of a long-run relationship between the variables in our model established, the next stage in the ARDL cointegration procedure involves estimating the parameters of Eq.(5) with the maximum lag order set at 1 as previously established so as to minimise any potential loss in degrees of freedom. The long-run results of Eq.(5) in this paper are based on the AIC lag criteria and are reported in table 4.

The results suggest that the long-run elasticity of CO₂ emissions, with respect to energy consumption, is 1.17, indicating that for each 1% increase in per capita commercial energy consumption, per capita CO₂ emissions rise by 1.17%. The statistical insignificance of per capita real income and its square rule out the presence of a relationship between income growth and emissions in the case of South Africa as well as any EKC tendency where these emissions potentially stabilise.

The elasticity of CO₂ emissions with respect to the foreign trade openness ratio is -0.18 in the long-run, suggesting that whilst the contribution of foreign trade to CO₂ emissions is rather minimal during the estimation period, it rather unexpectedly serves to decrease the country’s emissions. This trade induced environment improving outcome one would expect to hold true in the case of a developed country such as Germany but not in the case of South Africa. The error-correction term is -0.828 with the expected sign, suggesting that when per capita CO₂ emissions deviates from its long-run trend 83% of that deviation will be corrected within a year. Thus the speed of adjustment in the case of any shock to the CO₂ emissions equation is sufficiently fast to support the notion that there is little control over the growth of CO₂ emissions (see Table 5 in this regard).

The robustness of ARDL bounds test of cointegration is checked by the Johansen and Juselius’s (1990) maximum likelihood cointegration approach. The VAR estimation is conducted at an optimal lag length for the variables of one, based on the AIC model selection criterion. The results from this test are displayed in table 6. Table 6 indicates the existence of three cointegration relationships amongst the variables, which confirm the results of the Pesaran et al. (2001) cointegration approach.

4.2 Granger causality test results

According to the bounds test results revealed in table 3, there exist three cointegrating relationships in the forms of $[c_t, e_t, y_t, y_t^2, f_t]$; $[e_t, c_t, y_t, y_t^2, f_t]$ and $[f_t, c_t, e_t, y_t, y_t^2]$. Granger causality tests were applied to Eq.(9) and three long-run relationships were estimated with an error correction term. Granger causality tests excluding the error-correction terms were applied to the other models given the absence of a long-run relationship for the other vectors. The statistical significance of the coefficients associated with the error correction

term provides evidence of an error correction mechanism that drives the variables back to their long-run relationship. Table 7 summarises the results of the long-run and short-run Granger causality. According to the coefficient on the lagged error-correction term, the Granger causality test confirms the results of the bound test indicating that in the long run energy consumption, income, squared income, and foreign trade granger cause CO₂ emissions.

In the long-run, energy consumption, income, squared income and foreign trade granger-cause CO₂ emissions and the direction of causality runs inter actively through the error-correction term from energy consumption, income, squared income and foreign trade to the CO₂ emissions. In the case of the short-run, causality tests results reported in table 7 indicate there are four bilateral granger causality relationships. There exists bi-directional granger causality between CO₂ emissions and per capita energy consumption, between per capita energy consumption and income, between per capita energy consumption and foreign trade, and between income per capita and foreign trade. The granger causality tests confirm the ADRL test showing a long run relationship between the variables and that there are multiple variables influencing CO₂ emission levels with bidirectional causality.

Whilst the Granger causality tests show causation between various variables the test cannot explain the direction or magnitude of the relationship, thus we run an impulse response test to determine this. By shocking the response variable, namely CO₂ emissions by various impulse variables: per capita energy use, foreign trade and per capita income and plotting the respective outcomes as in figure 1 below it is clear that we can confirm with 95% confidence that South Africa's per capita energy use has a significant and positive effect on its CO₂ emissions whilst the opposite is true for the effect of foreign trade and in the case of per capita income growth no discernible effect on CO₂ emissions is recorded. Specifically, the first graph in figure 1 shows that for a one standard deviation in per capita energy use (the impulse variable) this brings about up to a 0.5 standard deviation in CO₂ emissions (the response variable) from its mean value within two years from the initial shock. Whereas from the second graph in figure 1, it is clear that a one standard deviation in South Africa's foreign trade (the impulse variable) contributes to a -0.2 standard deviation in CO₂ emissions (the response variable) from its mean value within one year from the initial shock.

5 Results & Conclusions

The results of this study support the existence of a long run relationship between environmental quality, energy use and foreign trade in the case of South Africa. Specifically our study finds that South Africa's CO₂ emission levels increase in the presence of greater per capita energy use within the economy yet decrease as the country's levels of foreign trade levels as a portion of national income rise. A bounds F-test based on the Wald's statistic confirms the existence of three cointegrating relationships and that there are multiple variables influenc-

ing South Africa's CO₂ emission levels. The absence of a statistically significant long run relationship between growth in income per capita and CO₂ emissions in our model is most likely due to the endogeneity between foreign trade, income per capita and South Africa's emission levels. As such this result should not be interpreted to imply either the absence or presence of an EKC finding in the case of South Africa but rather that the precise relationship between the country's emissions and economic growth is difficult to identify in the presence of foreign trade. What is clear according to a very recent OECD study of South Africa is that as a result of the under-pricing of electricity and coal over the last two decades, the country's greenhouse gas emissions per unit of GDP are among the highest in the world and that South Africa has seen less decoupling of real GDP and CO₂ emissions in recent years than most other countries (OECD, 2013).

Whilst our study also finds positive bidirectional causality between foreign trade and income per capita and between foreign trade and per capita energy use, it appears however that trade liberalisation in South Africa has not contributed to a long run growth in pollution-intensive activities nor higher emission levels. Rather, our research suggests that a higher degree of trade openness possibly reduces CO₂ emissions in South Africa through an environment which stimulates technological innovations by increasing spending on energy R&D which results in energy efficiencies, fewer pollutants and hence environmental conservation. In the presence of the country's highly energy intensive economic activities and given South Africa's extreme dependence on coal as its major energy source, it is indeed surprising that the country's pollutant emissions outcome is not exaggerated in the presence of foreign trade. This econometric finding should however be interpreted with care, as it may not be sufficiently robust enough to categorically state.

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Table 1
Tests for integration¹

Variable	ADF test probabilities		Phillips-Peron test statistic	
	Levels (prob)	1 st differences (probabilities)	Levels (prob)	1 st differences (probabilities)
co ₂	0.198	0.000*	0.205	0.000*
e	0.484	0.000*	0.483	0.000*
y	0.982	0.368	0.049	0.142
y ²	0.997	0.992	1.000	0.002*
f	0.531	0.000*	0.177	0.000*

1. Sample levels 1960–2009 and differences 1962–2009.

Table 2
Selection order criteria²

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-279.2777	NA	0.479480	13.44686	14.63945	13.89361
1	41.46870	488.0924*	1.30e-06*	0.588318*	2.774737*	1.407363*
2	64.62221	30.20024	1.56e-06	0.668599	3.848845	1.859939
3	88.06430	25.48053	2.07e-06	0.736335	4.910407	2.299967

². Sample: 1960-2009. Significance at 5% is indicated with an asterisk.

Table 3
Results of the F-test for cointegration³

	Calculated F-statistic	
	1 lag	Critical Value Upper Bound
$F_c(c e,y,y^2,f)$	6.398	1%
$F_c(e c,y,y^2,f)$	6.399	1%
$F_c(y c,e,y^2,f)$	4.37	10%
$F_c(y^2 c,e,y,f)$	4.00	10%
$F_c(f c,e,y,y^2)$	5.17	5%

3. With four explanatory variables the critical value ranges of the F-statistic are 4.39–5.91, 3.17–4.45 and 2.63–3.77 at 1%, 5% and 10% level of significances, respectively Narayan (2005).

Table 4
ARDL (1,0,0,0,0) selected based on AIC4.

Dependent variable c_t	Coefficient	Standard error	t-Ratio [probability]
e_t	1.166	0.075	15.525*** [0.000]
y_t	0.008	0.014	0.602 [0.550]
y_t^2	-0.002	0.009	-2.278 [0.028]
f_t	-0.175	0.031	-5.739*** [0.000]
Constant	-11.380	0.830	-13.719*** [0.000]

4. Where *** denotes significant levels at 1%.

Table 5
ECM results

Dependent variable Δc_t	Model-selection criterion
Regressors	AIC ARDL (1,0,0,0,0)
Δe_t	0.965 (10.876)***
Δy_t	0.007 (0.592)
Δy_t^2	-0.002 (2.134)**
Δf_t	-0.145 (4.853)***
EC_{t-1}	-0.828 (10.932)***
R^2	0.795
F-statistic	33.380 ***
DW-statistic	2.078
RSS	0.016

5. *** and ** indicate 1% and 5% significance levels, respectively. The absolute values of t-ratios are in parentheses. RSS stands for residual sum of squares.

Table 6
Johansen and Juselius's maximum likelihood cointegration results⁵.

Hypothesised no. of cointegrating vectors	LL	Eigen value	Trace Statistic	95% critical value
None*	326.40	-	99.81	68.52
At most 1*	348.52	60.20	55.59	47.21
At most 2*	360.92	40.37	30.77	29.68
At most 3*	369.83	30.99	12.96	15.41
At most 4	375.35	20.55	1.92	3.76

*denote rejection of null hypothesis at 5

¹All variables are in natural logarithms. Sample levels 1960–2009.

Table 7
Granger causality results⁷

	Chi ² (probability)					
	Δc_t	Δe_t	Δy_t	Δy_t^2	Δf_t	EC_{t-1} (t-statistic)
Δc_t	--	764.77* (0.000)	2.19 (0.334)	2.87 (0.238)	1.35 (0.509)	-0.94* (4.367)
Δe_t	8.25* (0.016)	--	6.99* (0.030)	2.74 (0.254)	6.84* (0.033)	-0.47* (3.211)
Δy_t	42.74* (0.000)	1604.2* (0.000)	--	7.17* (0.028)	16.03* (0.000)	--
Δy_t^2	29.80* (0.000)	919.34* (0.000)	2.90 (0.234)	--	8.56* (0.014)	--
Δf_t	6.76 (0.034)	423.56* (0.000)	10.45* (0.005)	12.06* (0.002)	--	-0.12* (2.298)

⁷. Causality inference: $c \leftrightarrow e$, $e \leftrightarrow y$, $e \leftrightarrow f$, $y \leftrightarrow f$. * Indicates 5% significance level. The probability values are in brackets. The optimal lag length is 2 and is based on AIC.

Figure 1
Impulse response test

