African Review of Economics and Finance | ISSN 2042-1478 |

Estimating the trade-environmental quality relationship in SADC with a dynamic heterogeneous panel model

MAXWELL CHUKWUDI UDEAGHA[1*] AND
MARTHINUS CHRISTOFFEL BREITENBACH[1]

[1] School of Economics, University of Pretoria, Hatfield Campus, South Africa
[*] Corresponding author's email: maxwelluc@yahoo.com

Abstract

The paper revisits the dynamic relationship between trade openness and carbon dioxide (CO_2) emissions for member countries of the Southern African Development Community (SADC) over the period 1960-2014. Our approach for SADC is uniquely different from others. For the SADC region, we find that: (i) increased trade openness improves environmental quality; (ii) the scale effect contributes to increase CO_2 emissions while the technique effect reduces it, confirming an environmental Kuznets curve (EKC) hypothesis; (iii) the pollution haven hypothesis (PHH) holds; (iv) the technological innovation, composition effect, financial development, agricultural GDP, service sector GDP and Kyoto Protocol Commitment variable contribute to improve environmental quality; (v) energy consumption, the comparative advantage effect, industrial GDP and institutional quality deteriorate environmental quality. Our results are generally robust to different estimation techniques. Finally, this research suggests that trade policy should be aligned with other policies aimed at minimising CO_2 emissions and promotion of new technologies to improve the region's environmental quality.

Keywords: Trade openness; international trade; CO_2 emissions; EKC; SADC.

Article history:
Received: 23rd April, 2020
Accepted: 20th November, 2020
Handling editor: Muazu Ibrahim (PhD)

1. Introduction

Africa is the world's second largest continent with a population that is estimated to be the second largest in the world. The continent has five regions: North Africa, Southern Africa, Central Africa, East Africa and West Africa. Africa is blessed with several mineral resources such as gold, metal ores, phosphate ore, coal and oil distributed throughout the five regions (Nriagu, 1992). The mining of these resources has contributed in no small measure to the environmental pollution in Africa. Besides this, the major sources of air pollution in Africa include use of solid cooking fuel for cooking (Armah *et al*., 2015); re-suspended dust from unpaved roads (Rooney *et al*. 2012); waste incineration and bush burning (Sam *et al*., 2015); use of insecticides to control malaria (Gaspar *et al*., 2015); and the Sahara desert in West Africa. The Sahara-Sahel desert is the largest source of atmospheric particulate matter in the world with about 300–800 million metric tonnes of Saharan dust eroded from the surface each year, mobilized into the atmosphere (Ridley *et al*., 2012; Garrison *et al*., 2014).

Concerns over global warming and climate change have increased in recent times due to the negative effects on human. This has led to an extensive research agenda on the causes and impacts of environmental degradation (Khan *et al*., 2020). It is not surprising that Beeson (2010) describes the environment as defining public policy issue of the epoch. Many governments across the world have jumped at the policy of protecting the environment. The African region as a whole, for instance, contributed just about 2.5% to the global anthropogenic CO_2 emissions for the period 1980–2005 (Canadell *et al*., 2009). More recently, the continent accounts for 3% of global fossil fuel carbon and 5.3% of global greenhouse gases (GHGs) from all non-land use sectors (*The Economist*, 2018). These statistics encourage SADC in its aim of reducing emissions in line with the United Nations Framework Convention on Climate Change. However, since 1990, Southern Africa has experienced the highest rate of deforestation in Africa, contributing 31% to Africa's deforested area. Biomass carbon losses from deforestation in SADC Member States amount to 54% of those from the entire continent. Carbon emissions from combined deforestation and degradation are over five times larger than those from all other sources.

Since slowing deforestation and reducing CO_2 emissions are the highest priority for climate change mitigation in the region, this therefore makes the region a good candidate for this case study. Furthermore, the SADC region is an interesting case because it has advocated for sustainable management and conservation of the regional forests as particularly urgent measures as well as enacted policies aimed at climate change adaptation, and also participating in efforts to turn back the effects of rising global temperatures and reducing their potential harm to the region.

Over the past three decades, the impact on the environment of trade openness among developing and transition economies, has become one of the most researched areas in trade literature (Taylor, 2004; Copeland and Taylor, 2005, 2004; Managi *et al*., 2009; Inglesi-Lotz, 2018; Mapapu and Phiri, 2018; Udeagha and Ngepah, 2019a). The rise in GHGs resulting from intensive production to satisfy export markets, excessive exploitation of natural resources and loss of biodiversity are now affecting all countries across the world (World Bank, 2007; Ehrilch *et al.*, 1993). More importantly, balancing investments in natural resources and foreign agricultural land aimed at energy (via biofuel) and food security while fulfilling trade objectives are continuously emerging as a key phenomenon. The environmental effects associated with these investments have always been a subject of intensive debate. For instance, as noted by GTZ (2009), such investments substantially worsen climate change via deforestation, interruption of local ecological systems, decreases in biodiversity, loss in soil quality, water availability and quality. Cotula (2011) and Kugelman and Levelstein (2012) are among those who have raised concerns regarding the environmental sustainability of these investments. In the early 2000s, CO_2 emissions represented more than 62% of the entire GHGs and it continues to rise. In 2009, world CO_2 emissions increased to 31.3 billion tonnes, an increase of 40% since 1990, according to Grunewald and Martinez-Zarzoso (2015).

Many researchers have investigated the environmental effects of trade openness in the recent time. Even though the empirical findings about the relationship between trade openness and the environment remains ambiguous, the theoretical literature has identified a number of channels through which trade openness can impact the environment. Motivated by the seminal work of Grossman and Krueger (1991, 1995), Antweiler *et al.* (2001) provide a theoretical framework in which the environmental effects related to trade openness are decomposed into scale, technique and composition effects. Finding empirical evidence of these different environmental effects has given rise to expansive literature, yielding mixed and conflicting results (Wan *et al.*, 2018; Kwakwa *et al*., 2018; Raza and Shah, 2018; Oh and Bhuyan, 2018).

Earlier works examining the trade-environment nexus were criticised with the way it defined and measured trade openness. These studies made use of the ratio of trade (sum of imports and exports) to GDP to measure trade openness. This measure of trade openness, traditionally called 'trade intensity (TI)', was criticised because it only considers the comparative position of trade performance of a country in relation to its domestic economy. The TI-based measure overlooks the country's openness relative to global trade, and is unable to capture the true impact of trade on the environment. The reason for this is that it penalises bigger economies due to their larger GDP, by classifying and portraying them as the closed economies (Squalli and Wilson, 2011). The mixed results and lack of empirical consensus about the trade-environment nexus are also blamed on differences in methodological frameworks as well as misspecification problems.

Against this background, this paper contributes to the empirical literature on the trade-environment nexus in four ways: (i) It constructs and uses an innovative proxy of trade openness suggested by Squalli and Wilson (2011), which accounts not only for a country's trade share in GDP, but also the size of trade relative to world trade. Using the Squalli and Wilson measure of trade openness therefore distinguishes our paper from others, which primarily depend on the TI-based proxy. (ii) Previous studies, especially on SADC, only looked at the direct environmental effects of openness to international goods markets, while ignoring the indirect consequences such as composition of economic activities and comparative advantage as explained in Cole and Elliott (2003) and Cole (2006). Our paper fills this gap by considering both direct and indirect impacts on the environment in the trade-environment nexus in SADC. The paper achieves this by decomposing environmental effects of openness to international goods market into scale, technique, composition and comparative advantage effects. (iii) It investigates the relative effects of sector-wise disaggregated GDP on carbon emissions in the presence of trade openness. (iv) It uses the testing strategies suggested by Pesaran (2007), Pedroni (1997) and Westerlund (2007) to account for cross-sectional dependence and multiple heterogeneous structural breaks proposed by Clemente-Montanes-Reyes (1998) to test for robustness in the model. To the best of our knowledge, for the SADC region, previous studies have not considered the existence of cross-sectional dependence and the presence of structural breaks in the relationship between trade and CO_2 emissions.

Our empirical evidence shows that the scale effect contributes to increase CO_2 emissions while the technique effect reduces it. This evidence suggests an inverted U-shaped curve in the relationship between openness and environmental quality, confirming that the EKC hypothesis holds for SADC. Technological innovation, the composition effect, financial development, agriculture GDP, service sector GDP and Kyoto Protocol Commitment contribute to improve environmental quality; however, energy consumption, the comparative advantage effect, foreign direct investment, industrial GDP and institutional quality increase CO_2 emissions. Furthermore, the long-run relationship between trade openness and CO_2 emissions is investigated and the evidence shows that trade openness substantially improves environmental quality in the SADC member countries.

The rest of the paper is structured as follows: Section 2 reviews the relevant literature on the trade-environment nexus. Section 3 discusses the methodological framework. The results are discussed in Section 4, and Section 5 concludes with policy implications.

2. Literature review

2.1. Theoretical literature

The literary work regarding the relationship between trade openness and the environment was first introduced with the environmental Kuznets Curve (EKC) hypothesis and gained popularity in the early 1990s. Grossman and Krueger (1991, 1993, 1995) and Copeland and Taylor (1994) are among the earlier researchers to study the trade-environment nexus. Grossman and Krueger (1991) offered the basic theoretical foundation for examining the EKC hypothesis at a time when the environmental implications of North American Free Trade Agreement (NAFTA) were investigated. However, the literature on the growth-environment nexus emerged following the Earth Summit that was held in Rio-de-Janeiro (Brazil) in 1992. This was aided by the enormous work of Shafik and Bandyopadhyay (1992) serving as an important background work for the World Development Report (1992). It argued that an enhancement in environmental conditions is paramount for sustainable development. Since then, there has been a sizable amount of literature exploring the relationship between growth and environmental quality, but because of contrasting results, generated more uncertainty about the true impact of trade openness on the environment. At the same time, contrasting evidence has given rise to further exploration of the topic by numerous researchers across the world.

For instance, Ang (2007), Soytas *et al*. (2007), Shafik (1994) and Grossman and Krueger (1991) by applying the EKC hypothesis and Kearsley and Riddel (2010) and Copeland and Taylor (2004) applying the pollution haven hypothesis (PHH), were not able to provide any definite conclusions about the environmental effects of trade openness. Grether and De Melo (2003) found that trade openness indirectly causes environmental degradation when it boosts economic expansion in third world countries and directly leads to a deterioration of the environment because of inflows of trade activities from the rich countries. Dinda (2006) argued that polluting activities in rich countries often face stringent environmental standards; as a result, their industries continuously migrate to less developed countries with lower or freer standards, shifting pollution to developing countries. This idea gained popularity and today finds its expression in the well-known pollution haven hypothesis (PHH) and its alternative, the factor endowment hypothesis (FEH). The last mentioned refers to migration of dirty capital-intensive industries away from relatively capital abundant countries, again causing a deterioration in environmental quality of developing countries. Trade openness has been argued to increase carbon emissions in both PHH and FEH because, with trade, a country having a comparative advantage in the production of dirty capital-intensive goods will always increase production to satisfy the growing export market, which intensifies pollution levels (Lopez, 1994; Inglesi-Lotz, 2018; Mapapu and Phiri, 2018).

Methodologically, Antweiler *et al.* (2001), were of the first authors to provide a comprehensive theoretical background highlighting the three trade effects on environmental quality, which are the scale, technique and composition effects. The scale effect refers to a rise in environmental degradation and natural resource depletion brought about by a rise in economic activities and higher consumption (Lopez, 1994; Grossman and Krueger, 1993). The technique effect refers to the possibility of enforcing more stringent environmental standards that lead to a cleaner production process when income rises, and an additional income further stimulates people's inclination for a less carbon-intensive environment and better environmental practices (Grossman and Krueger, 1996; Kebede, 2017). The composition effect, on the other hand, represents how composition of output and structure of industry affect the environment, which is fundamentally driven by the degree of country's openness together with comparative advantage (Cherniwchan, 2017). Depending on the relative size of the capital-labour impact and the effects of environmental regulation, the net impact of the composition effect due to trade openness could be either positive or negative (Kahuthu, 2006; Selden and Song, 1994; Shafik and Bandyopadhyay, 1992).

2.2. Empirical literature

On the empirical front, the trade-environment nexus literature is expansive. However, the evidence reported by these studies is largely conflicting or at best mixed. Some studies find very robust evidence that trade openness improves environmental quality (Frankel and Rose, 2005; Aichele and Felbermayr, 2013; Shahbaz *et al*., 2013c; Ling *et al*., 2015; Jabeen, 2015; Li *et al*., 2015; Zerbo, 2015; Dogan and Seker, 2016; Dogan and Turkekul, 2016; Destek *et al*., 2016; Zerbo, 2017; Roy, 2017; Cherniwchan, 2017; Hasson and Masih, 2017; Iyke and Ho, 2017; Wan *et al*., 2018; Kwakwa *et al*., 2018; Udeagha and Ngepah, 2019a). Other empirical studies, however, have found evidence that trade openness is detrimental to the environment (Twerefou *et al*., 2015; Le *et al*., 2016; Ertugrul *et al*., 2016; Shahbaz *et al*., 2017; Lin, 2017; Jamel and Maktouf, 2017; Kebede, 2017; Balin *et al*., 2017; Fernández-Amador *et al*., 2017; Solarin *et al*., 2017; Raza and Shah, 2018). Contrary to all these empirical works, other studies have suggested that trade openness has no effects on the environment (Gale and Mendez, 1998; Oh and Bhuyan, 2018).

Kwakwa *et al.* (2018) investigate the effect of trade openness in Ghana adopting the STIRPAT model and their results show that trade openness reduces CO_2 emissions in Ghana. Using a two-country trade model, Wan *et al.* (2018) examine the impact of international trade in environmental goods. Their results show that trade openness improves the environmental condition when a country strengthens environmental standards. Using sulphur dioxide (SO_2) and particulate matter (PM10) as proxies of environmental quality, Cherniwchan (2017) examines the environmental consequences of NAFTA on manufacturing firms in the USA. The author finds that trade openness substantially reduces the measures of environmental quality such as particulate matter (PM10) and sulfur dioxide (SO_2) at the affected firms. Similarly, Roy (2017) uses two measures of intra-industry trade (i.e. within-industry specialisation and sector-level trade) and the findings show that both intra-industry trade and overall trade intensity are beneficial to the environment, although intra-industry trade has a larger beneficial impact. Adopting the ARDL framework to investigate the long-run relationship between trade openness and the environment, Zerbo (2017) finds that openness to international goods markets stimulates economic growth and improves environmental conditions in fourteen Sub-Saharan African countries. The author thus advocates the implementation of trade incentives aimed at spurring development since openness is not detrimental to the environment.

In addition, Destek *et al*. (2016), controlling for energy intensity, urbanisation and economic growth in the CO_2 emissions equation using a FMOLS model, find that an increase in trade openness is associated with a reduction in CO_2 emissions in ten selected Central and Eastern European Countries (CEECs).

The results thus suggest that an increase in trade openness improved the environments of CEECs. Similarly, Dogan and Turkekul (2016), while testing for the EKC hypothesis, find evidence that increased trade openness and growth in real GDP improve environmental quality in the USA. Dogan and Seker (2016) furthermore examine the factors that determine CO_2 emissions as well as the effects of international trade. Their findings reveal that openness to international goods markets contributes to mitigate carbon emissions.

In contrast, using the ARDL approach, Raza and Shah (2018) examine the relationship between trade openness and environmental quality in the case of Pakistan and find that increased international trade impedes environmental conditions. Similarly, Solarin *et al.* (2017) employ the ARDL framework to investigate the pollution haven hypothesis (PHH) and the impact of trade openness on Ghana's environment over the period 1980-2012. Their findings reveal that while trade openness has a detrimental effect on Ghana's environment, institutional quality, on the other hand, contributes to boost it. The authors further confirm the existence of PHH in Ghana. Balin *et al.* (2017) obtain similar results for Turkey over the period 1974-2013. The authors conclude that an increase in trade openness deteriorates the Turkish environment. Using the ARDL model to study the dynamic link between trade openness, CO_2 emissions, urbanisation, financial development, affluence, energy intensity and population, Kebede (2017) draws similar conclusions in the case of Ethiopia for the period 1970–2014. The author's results show that an increase in openness leads to an increase in CO_2 emissions, whereas economic growth is stimulated by increases in financial development, urbanisation and population. In addition, Jamel and Maktouf (2017) extend the Kebede (2017) model by using the Cobb-Douglas production function to investigate the relationship between trade openness, environmental quality and other control variables for European countries over the period 1985–2014. Their results, while providing ample evidence of the neutrality hypothesis linking CO_2 emissions to financial development and feedback effects suggesting a bidirectional causality among the variables, show that openness to international trade is harmful to the environment.

Previous work examining the dynamic relationship between trade and the environment extensively used trade intensity (TI) as a proxy for trade openness. This measure of trade openness, traditionally defined as the ratio of trade (sum of imports and exports) to GDP only looks at the trade performance of a country relative to its own domestic economy. The TI-based proxy, which substantially overlooks the country's openness to global trade, is unable to capture the true impact of trade openness on the environment since it penalises bigger economies due to their larger GDP by classifying and portraying them as the closed economies (Squalli and Wilson, 2011). While this measure makes reasonable sense, it is unable to effectively resolve the vagueness surrounding the definition of true trade openness and how it is measured. The key limitation associated with the use of the TI-based measure is that it merely provides a reflection of a country's share of income associated with foreign trade. The weakness of this proxy is further seen by its apparent inability to capture another fundamental part of trade openness, which is a country's trade relative to world trade. The TI-based proxy is thus unable to sufficiently capture the effect of trade openness on the environment, failing to reflect the advantages/disadvantages associated with trading with the rest of the world.

Against this background and drawing on the gaps identified in the empirical literature, the contribution of this paper to the pool of related literature on the trade-environment nexus are fourfold. First, contrary to the previous studies, the study constructs and uses an innovative proxy of trade openness suggested by Squalli and Wilson (2011), which accounts for not only SADC's trade share to GDP, but also size of trade relative to world trade in a given year. Using this proxy of trade openness, as outlined above, we are better able to capture the effects of trade openness on the environment and this distinguishes our paper from similar studies in sub-Saharan countries and SADC, using the TI-based proxy. Second, previous studies especially for the case of SADC region only look at the direct environmental effects of openness in international goods markets (Ziramba, 2015; Sunde, 2020; Mapapu and Phiri, 2018; Shahbaz *et al*., 2013c), while ignoring the indirect consequences such as composition of economic activities and comparative advantage as explained in Cole and Elliott (2003) and Cole (2006). Given this, the paper attempts to fill this gap by using both direct and indirect effects to investigate the trade-environment nexus in the SADC region. The paper achieves this by decomposing the effects into scale, technique, composition and comparative advantage effects to examine the overall environmental impacts (CO_2 emissions) of openness to international goods markets in SADC. Third, this paper contributes to the literature by being the first paper on SADC investigating the relative effects of sector-wise disaggregated GDP on carbon emissions in the presence of trade openness as suggested by Sohag *et al.*(2017) in the case of middle-income countries and Samargandi (2017) for Saudi Arabia. Fourth, it deals with both cross-sectional dependence using tests developed by Pesaran (2007), Pedroni (1997) and Westerlund (2007) and heterogeneous structural breaks using the methods proposed by Clemente-

Montanes-Reyes (1998). To the best of our knowledge, previous studies have not considered the existence of cross-sectional dependence and the presence of structural breaks in the studies of the relationship between trade (openness) and CO_2 emissions for the SADC region. Therefore, this work addresses these shortcomings common in earlier studies dealing with stationarity and panel unit root tests. In this way, the paper considers the presence of multiple structural breaks that may affect the variables and tackles the problem of cross-sectional dependence when panel data-related statistics are computed.

3. Methodology

In this paper, we model the dynamic relationship between trade and environmental quality in the SADC region over the period 1960-2014 by employing second-generation econometric procedures, which take into consideration cross-sectional dependence and multiple heterogeneous structural breaks that have been largely ignored by the previous studies. As a first step, the cross-sectional dependence test proposed by Pesaran (2004) and Pesaran (2007) (the CIPS unit root test), specifically designed to handle the presence of cross-sectional dependence in the hypothesis testing, is used. For robustness, we use a battery of unit root tests to confirm the asymptotic behaviour and order of integration of all variables under consideration. This process enables us to circumvent the issues associated with a spurious regression. In the second step, since structural breaks are very pervasive in empirical literature and a good number of macroeconomic variables, particularly CO_2 emissions and trade openness in our case are affected by these, the present work uses a robust testing strategy proposed by Clemente-Montanes-Reyes (1998) and subsequently controls for these structural breaks in the model. Both trade openness and CO_2 emissions exhibit multiple breaks over the years, and this can be observed from the appropriate tables. In the third step, the estimation of long-run coefficients is done using the Dynamic Ordinary Least Squares (DOLS) approach. Lastly, we perform a number of robustness to test the performance of our model.

3.1. Functional form

Following recent studies by Begum *et al*. (2015); Ling *et al.* (2015); Dogan and Seker (2016); and Bilgili *et al.* (2016), this paper uses the standard environmental Kuznets curve (EKC) hypothesis to investigate the relationship between trade openness and the environment. The EKC hypothesis contends that at the early stages of development of society (particularly during the industrial phase), environmental degradation increases substantially because society places a very high priority on achieving greater material output (economic growth) at the expense of a clean environment. Because more income is preferred to a clean environment at this stage of development, a rise in economic growth is realised to the detriment of environmental quality. This is the intuitive reason behind the positive relationship between economic growth and the environment, which has been widely investigated in empirical literature (Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992; Panayotou, 1993; Selden and Song, 1994; Kaufmann *et al*., 1998; Cole *et al.*, 1997; de Bruyn *et al*., 1998).

However, as income increases and society enforces more stringent environmental standards during more advanced stages of development, environmental quality improves with growth. Hence, in a nutshell, the EKC hypothesis postulates that the association between economic growth and the environment is captured in an inverted U-shaped curve. In its general format, the standard EKC hypothesis, following Begum *et al.* (2015); Ling *et al.* (2015); Dogan and Seker (2016); and Bilgili *et al*. (2016) is shown as follows:

$$CO_2 = F(SE, TE) \tag{1}$$

where CO_2 is CO_2 emissions per capita (in metric tons) used as a measure for the environment, SE represents scale effect proxied by the real GDP per capita and TE captures technique effect derived as the square of real GDP per capita. When Equation (1) is log-linearized, the following is obtained:

$$\text{In}CO_{2it} = \alpha + \varphi InSE_{it} + \beta InTE_{it} + \varepsilon_{it} \tag{2}$$

For the EKC hypothesis to be confirmed in the case of SADC, $\varphi > 0$ and $\beta < 0$. The intuition is that the scale effect (economic growth) contributes to increase environmental degradation while the technique effect reduces it because of enforcement of stringent environmental standards and people's inclination for a less carbon-intensive environment (Cole and Elliott, 2003). Confirmation of the EKC hypothesis suggests that the relationship between economic growth and environmental conditions follows an inverted U-shaped curve.

Brock and Taylor (2005) argue that the existence of the EKC hypothesis is dependent on the level of technological progress which prevails in a country. In this regard, Equation (2) is augmented to include the role of technological innovation and to explore its effect on CO_2 emissions. Also, following Ahmed *et al.* (2016), Sohag *et al.* (2015) and Antweiler *et al*. (2001), by further augmenting Equation (2) to incorporate the impacts of trade openness, energy consumption, composition effect and comparative advantage effect and we obtain:

$$\text{In}CO_{2it} = \alpha + \varphi InSE_{it} + \beta InTE_{it} + \rho InTRE_{it} + \pi InEE_{it} + \delta InCE_{it} + \tau InCPE_{it} + \omega InTECH_{it} + U_{it} \quad (3)$$

where $InTRE_{it}$ represents composite trade intensity (CTI) which captures trade effect; $InEE_{it}$ denotes energy consumption measured in million tonnes of oil equivalent; $InCE_{it}$ is the capital-labour ratio used as a proxy for composition effect; $InCPE_{it}$ is the cross product of capital-labour ratio and trade openness capturing the comparative advantage effect and $InTECH_{it}$ denotes technological innovation measured by total patent applications. All variables are expressed in natural logarithm. φ,β,ρ,π,δ τ and ω are the estimable parameters measuring elasticities while U_t is the stochastic error term with standard properties.

Since theoretical studies connecting trade openness to the environment have generated mixed evidence and remain controversial, a priori expectation is that $\rho > 0$ or < 0. Existing studies have shown that a rise in energy consumption deteriorates environmental quality (Destek *et al*., 2016; Dogan and Turkekul, 2016; and Shahbaz *et al*., 2013c). Therefore, a priori expectation is that $\pi > 0$. The composition effect, as demonstrated by Cole (2006), contributes to worsen environmental degradation when the production structure is dominated by capital-intensive processes. Environmental conditions deteriorate rapidly as a country progressively shifts to those activities involving large-scale capital-intensive processes. Previous studies find a strong positive relationship between emission intensity and capital intensity (Raza and Shah, 2018). Therefore, a priori expectation requires that $\delta > 0$. Furthermore, the composition effect can lead to either an increase or decrease in pollution following openness to international trade (Antweiler *et al*., 2001). In this regard, with trade, countries with a comparative advantage in cleaner industries are most likely to have lesser carbon emissions whereas their counterparts specialising in export and production of dirty and pollution-intensive goods will always have higher carbon emissions. Given this illustration, the expected sign for the coefficient of the comparative advantage effect (τ) can either be negative or positive (i.e. $\tau < 0$ *or* > 0).

Technological innovation is fundamental to enhance energy efficiency. Using a minimum level of energy, advanced technologies enable industries to reduce carbon emissions during production processes and facilitate the shift from non-renewable energy types to alternative sources such as solar power. Therefore, a priori expectation requires that $\omega < 0$. In the same framework, this paper explores the impacts of sector value addition to GDP on the environment by assessing their relative contributions to the rising carbon emissions in the SADC region. Following Al Mamun *et al*. (2014) and Sohag *et al.* (2017), Equation (3) is further augmented to include these variables as follows:

$$\text{In}CO_{2it} = \alpha + \varphi InSE_{it} + \beta InTE_{it} + \rho InTRE_{it} + \pi InEE_{it} + \delta InCE_{it} + \tau InCPE_{it} + \omega InTECH_{it} + \zeta InAGDP_{it} + \vartheta InIGDP_{it} + \phi InSGDP_{it} + U_{it} \quad (4)$$

where $InAGDP_{it}$, $InIGDP_{it}$ and $InSGDP_{it}$ respectively denote the natural logs of sector-wise disaggregated contributions to GDP by agriculture, industry and service sectors.

Previous works have controlled for financial development (FD), Kyoto protocol commitment (KYO), institutional quality (INS) and foreign direct investment (FDI) to resolve the issue of omitted variable bias (Lee, 2013; Nasir and Rehman, 2011; Saboori *et al*., 2012; Shahbaz *et al*., 2012; Lau *et al*., 2014; Shahbaz *et al*., 2015; Sadat and Alom, 2016; Ling *et al*., 2015). We include these variables in Equation (4) and our baseline equation is presented as follows:

$$\text{In}CO_{2it} = \alpha + \varphi InSE_{it} + \beta InTE_{it} + \rho InTRE_{it} + \pi InEE_{it} + \delta InCE_{it} + \tau InCPE_{it} + \omega InTECH_{it} + \zeta InAGDP_{it} + \vartheta InIGDP_{it} + \phi InSGDP_{it} + \varpi InFD_{it} + \psi InFDI_{it} + \sigma InINS_{it} + \lambda KYO_{it} + U_{it} \quad (5)$$

The effect of financial development is not clear because it is dependent on whether the sector has accomplished the maturity level at which it discriminates by committing and reallocating financial resources in favour of those business undertakings with less-polluting technology. It is thought that a mature financial sector is able to distinguish between firms' choice of technology and show a bias in favour of the use of greener technologies that improve environmental quality, when committing funds. However, this becomes problematic to an immature financial sector which is always driven by the sole objective of profit-maximisation at any cost. Given this, a priori expectation requires that $\varpi > 0$ or < 0. Foreign direct investment inflows generate positive externalities through transfer of technology, provide the needed funds for rapid economic expansion, improve managerial skills, increase productivity gains and introduce new production processes that stimulate economic growth (Lee, 2013). Theoretically, studies connecting foreign direct investment to the environment under the pollution haven hypothesis (PHH) have recognised that a rise in foreign direct investment deteriorates environmental conditions. Therefore, the expected sign for the coefficient of foreign direct investment is positive (i.e. $\psi > 0$). Rich countries that have well-developed institutions are able to enforce stringent environmental laws and punish defaulters severely. Consequently, the private sector complies, and this helps to mitigate carbon emissions. This suggests that a country with higher institutional quality tends to have minimum carbon emissions. Hence, it is expected that $\sigma < 0$. The effect of the Kyoto Protocol commitment on carbon emissions will depend on the level of commitment of SADC member countries to reduce CO_2 emissions. In this regard, its expected sign could be positive or negative (i.e. $\lambda < 0$ *or* > 0).

3.2. Measuring trade openness

The measure of trade openness, which is used in this paper is called the composite trade intensity (CTI). The CTI-based proxy was originally introduced by Squalli and Wilson (2011) to overcome the limitations associated with the conventional trade intensity (TI) adopted in the previous literature. The CTI includes more vital information regarding the contribution of a country to the world economy and its influence on the global economy. Intuitively, CTI symbolises trade intensity (TI) adjusted by the share of a country's trade level in relation to average international trade. The novelty of using the CTI-based proxy is that it captures two dimensions of a country's ties with the rest of the world. The CTI is presented as:

$$CTI = \frac{(X+M)_i}{\frac{1}{n}\sum_{j=1}^{n}(X+M)_j} \frac{(X+M)_i}{GDP_i} \tag{6}$$

where: i denotes SADC in this case; j represents its trading partners; the first part of the equation (6) captures world trade intensity (WTI) while the second part represents SADC's trade intensity.

The advantages of the CTI-based measure of trade openness over traditional TI as highlighted by Squalli and Wilson (2011) are as follows: (i) it accounts for both the country's trade share of GDP and relative size of trade in relation to world trade in a specified period of time; (ii) it is more accurate at capturing the exact effect of trade openness on economic growth and the environment; (iii) the adjustment is not often extreme since it takes into consideration both TI and WTI; (iv) it considers two aspects of openness (i.e. TI and WTI) that capture the correct trade openness (while the first aspect measures the proportion of SADC's total income associated with international trade, the second dimension captures the comparative significance of SADC's contribution in world trade; (v) it focuses on real trade flows rather than potential trade flows, as captured by lax or liberal trade policies as well as other important socioeconomic, geographic and demographic factors; (vi) it captures the gains derived from trading quite rigorously with the rest of the world; (vii) as demonstrated by Squalli and Wilson (2011), the TI-based measures penalise large countries by portraying them as closed economies, because their trade share of total economic activities are substantially small by world standards, therefore closed to trade benefits. However, using CTI, the world's largest trading economies such as China, Japan, USA, Germany, etc. are now seen to be open rather than closed economies. So, the proxy classifies more completely the degree of trade openness that countries enjoy.

3.3. Variables and data sources

The paper uses annual data covering the period 1960-2014. In this paper, CO_2 emissions used to represent environmental quality are treated as the dependent variable. While GDP per capita represents scale effect (SE), the square of GDP per capita is used as a proxy of the technique effect (TE) to test the validity of the EKC hypothesis in the case of SADC. The paper uses energy consumption as a measure of the energy effect (EE), trade openness shown above uses the composite trade intensity as a proxy of the trade effect (TRE), capital-labour ratio is used to denote the composition effect (CE) and the comparative advantage effect (CPE) captures the cross product of both composition and trade effects. The other control variables in our model are Kyoto Protocol (KYO), institutional quality (INS), foreign direct investment (FDI), financial development (FD), service sector value addition to GDP (SGDP), industrial value addition to GDP (IGDP), agricultural value addition to GDP (AGDP) and technological innovation (TECH). Table 1 shows a summary of variable definition and data sources.

TABLE 1: DEFINITION OF VARIABLES AND DATA SOURCES

Variable	Description	Expected sign	Source
CO_2	CO_2 emissions (kg per 2010 US$ of GDP)	N/A	WDI
GFCF	Gross fixed capital formation (% of GDP)	N/A	WDI
LAB	Economically active population, population ages 15-64	N/A	WDI
Exports	Total exports (% of GDP)	N/A	WDI
Imports	Total imports (% of GDP)	N/A	WDI
GDP	Gross Domestic Product	N/A	WDI
EMP	Number of persons engaged (in millions)	N/A	PWT
POP	Total population (in millions)	N/A	WDI
EE	Energy consumption, million tonnes oil equivalent	Positive	BP Statistical Review of World Energy
TRE	Trade openness computed as composite trade intensity introduced by Squalli & Wilson (2011) capturing trade effect	Positive or negative	WDI, Authors
SE	Real GDP per capita capturing scale effect	Positive	WDI
TE	Real GDP per capita squared capturing technique effect	Negative	WDI, Authors
CE	Capital-labour ratio capturing composition effect	Positive	WDI, PWT, Authors
CPE	Cross product of capital-labour ratio and trade openness variable representing comparative advantage effect	Positive or negative	WDI, PWT, Authors
FD	Financial development measured by domestic credit to private sector (% of GDP)	Positive or negative	WDI
FDI	Foreign direct investment, net inflows (% of GDP)	Positive	WDI
INS	Institutional quality is estimated by calculating the average of political rights and civil liberties score.	Negative	WDI
KYO	Kyoto protocol is a dummy variable constructed which takes a value of one from year 2002 onward when SADC member countries have ratified the Kyoto protocol commitments and a value of zero otherwise.	Positive or negative	Authors
TECH	Technological innovation measured by total patent applications	negative	WDI
AGDP	Agriculture, value added (% of GDP)	Positive or negative	WDI
IGDP	Industry, value added (% of GDP)	Positive or negative	WDI
SGDP	Services, value added (% of GDP)	Positive or negative	WDI

Note: N/A: Not available; WDI: World Development Indicator; PWT: Penn World Table

3.4. Empirical framework

In this paper, we investigate the long-run relationship between trade and environmental quality (CO_2 emissions) by using the dynamic ordinary least squares (DOLS) estimation method in a panel cointegration framework.

3.4.1. CD, CIPS tests and unit root test with structural breaks

Previous studies applying the traditional unit root tests, did not account for cross-sectional dependence.[1] As widely acknowledged in empirical literature, when the root is close to one, the power of conventional unit root tests becomes very low particularly in small samples and in the presence of cross-sectional dependence (Shiller and Perron, 1985). Thus, failure to tackle this problem when panel data-related statistics are computed may cause a serious bias leading to spurious inference. This paper therefore uses a testing strategy which is able to deal with the cross-sectional dependence and utilising macroeconomic variables with a cross-country relationship. To this end, the paper uses the cross-sectional dependence test proposed by Pesaran (2004). After establishing the presence of cross-sectional dependence in the panel dataset, the paper accommodates this by using the Pesaran (2007) CIPS unit root test specifically designed to handle the presence of cross-sectional dependence in the hypothesis testing.

Recent studies have shown that infrequent shifts in the mean of macroeconomic variables such as trade and CO_2 emissions are a stylized fact; as a result, the presence of structural breaks should be properly accounted for. Previous studies have relied on the use of conventional unit root and stationarity tests to determine whether the variables are stationary. In the presence of unattended structural breaks, the conventional stationarity tests are biased towards non-rejection (Perron, 1989; Lee *et al.*, 1997). Thus, it is evidently seen that the application of the traditional stationarity tests may bring about spurious inference in the presence of structural breaks and further empirical refinements may be crucial. The paper contributes by using a testing strategy which is able to account for not only cross-sectional dependence but also heterogenous structural breaks in the model. To this end, the paper uses the Clemente-Montanes-Reyes (1998) detrended unit root test.

3.4.2. Panel cointegration technique

Cointegration tests are essential in empirical literature because it enables us to investigate the long-run equilibrium relationship among series under

[1] In this paper, the classical unit root and stationarity tests are also used, and the results are reported accordingly in the results section.

review. In this work, the bootstrap panel cointegration framework suggested by Westerlund (2007) is used to examine the long-run association among variables under examination. Conventional cointegration tests have failed to reject the null hypothesis even when cointegration is not supported by theories. Westerlund (2007) develops a new approach based on structural rather than residual dynamics. Because of the restricting normal distribution, ample evidence exists that this approach is more robust and consistent than the traditional techniques. Furthermore, its outcome provides good accuracy as well as additional power when compared to the residual-based techniques proposed by Pedroni (2000, 2001a, b).[2] Based on this evidence, this research uses the bootstrap panel cointegration framework to analyse the cointegrating relationship between trade openness and the environment for SADC.

3.4.3. Long-run elasticities

Once a cointegrating relationship is established, the next step involves the estimation of long-run coefficients of the model. To this end, the study uses the dynamic ordinary least squares (DOLS) framework proposed by Stock and Watson (1993) to establish the magnitude of long-run equilibrium. Thus, the application of the DOLS framework in this work is motivated because of the following reasons: (1) the DOLS model can be estimated notwithstanding the order of integration of series (regardless of whether the variables are purely I(0), purely I(1) or mutually cointegrated); although the dependent variable should be integrated of order one; (2) it circumvents the problems of serial correlation associated with the model estimation and other internalities; thus, it provides robust and reliable estimates (Esteve and Requena 2006); (3) lastly, the primary benefit of the DOLS approach is that it also considers the presence of a mix order of integration of the respective variables in the co-integrated framework. Hence, the estimation of DOLS involves regressing one of the I(1) variables against other I(1) and I(0) variables by including leads (p) and lags (-p) in the framework. Thus, this estimator solves possible endogeneity and small sample bias problems. Moreover, the co-integrating vectors obtained from the DOLS estimators are asymptotically efficient.

The DOLS framework is presented as follows:

---

[2] We further reported the results of cointegration tests proposed by Pedroni (2000) for robustness check.

$$InCO_{2it} = \pi_0 + \pi_1 InSE_{it} + \pi_2 InTE_{it} + \pi_3 InTRE_{it} + \pi_4 InEE_{it} + \pi_5 InCPE_{it} + \pi_6 InTECH_{it} + \pi_7 InCE_{it} + \pi_8 InFD_{it} + \pi_9 InFDI_{it} + \pi_{10} InAGDP_{it} + \pi_{11} InIGDP_{it} + \pi_{12} InSGDP_{it} + \pi_{13} InINS_{it} + \pi_{14} InKYO_{it} + \sum_{k=-n}^{n} \gamma_{1i} \Delta InSE_{it-k} + \sum_{k=-n}^{n} \gamma_{2i} \Delta InTE_{it-k} + \sum_{k=-n}^{n} \gamma_{3i} \Delta InTRE_{it-k} + \sum_{k=-n}^{n} \gamma_{4i} \Delta InEE_{it-k} + \sum_{k=-n}^{n} \gamma_{5i} \Delta InCPE_{it-k} + \sum_{k=-n}^{n} \gamma_{6i} \Delta InTECH_{it-k} + \sum_{k=-n}^{n} \gamma_{7i} \Delta InCE_{it-k} + \sum_{k=-n}^{n} \gamma_{8i} \Delta InFD_{it-k} + \sum_{k=-n}^{n} \gamma_{9i} \Delta InFDI_{it-k} + \sum_{k=-n}^{n} \gamma_{10i} \Delta InAGDP_{it-k} + \sum_{k=-n}^{n} \gamma_{11i} \Delta InIGDP_{it-k} + \sum_{k=-n}^{n} \gamma_{12i} \Delta InSGDP_{it-k} + \sum_{k=-n}^{n} \gamma_{13i} \Delta InINS_{it-k} + \sum_{k=-n}^{n} \gamma_{14i} \Delta KYO_{it-k} + \omega D_i + \varepsilon_t \quad (7)$$

Here, n denotes the optimal lag level to be determined by Schwarz Information Criterion (SIC), i denotes cross-sectional units (countries) and t represents time trend in the current research. D_i is the dummy variable used to account for the structural break in the models. Modelling this way, we are able to observe whether the breaking year actually has any statistically significant effect in the model in the long run.

3.5. Robustness checks

The paper has implemented a number of robustness checks to ensure that the results of the DOLS estimation method are consistent and robust. As expected, our data contains heteroscedasticity arising from time and cross-sectional units as well as zero trade flows characterising the African dataset.[3] For a robustness check, the paper uses the Eicker-White covariance Poisson Pseudo-Maximum Likelihood (PPML) method (Eicker, 1963; White, 1980). Earlier studies have extensively used the PPML method as a better tool to address these problems (Ngepah and Udeagha, 2018, 2019; Udeagha and Ngepah, 2019a, b). In the presence of heteroscedasticity, the PPML method provides consistent estimates and performs much better than the conventional Ordinary Least Square (OLS) and Nonlinear Least Square (NLS) methods (Frankel & Wei, 1993; Santos Silva & Tenreyro, 2006). Apart from the problems of heteroscedasticity and zero trade flows, the paper adopts a good number of other econometric strategies to address other potential econometric problems that may affect our results. For instance, economic agents make decisions causing interdependence and co-movement among individual unobservable variables. This potentially causes

[3] The results of the preliminary test of heteroscedasticity show evidence of heteroscedasticity. The results can be made available from the authors upon request.

correlation of disturbances across space. To address this problem, the research utilises the approach proposed by Conley (1999), by providing accurate standard errors that take into consideration these expected cross-sectional dependencies. The strategy estimates non-parametrically the covariance matrices to ensure that there is no imposition of an extraneous restriction on the shape of spatial autocorrelation.

Furthermore, the paper controls for individual heterogeneity. Panel data suggests that countries are heterogeneous and not controlling for this heterogeneity may lead to biased results (Moulton, 1986, 1987). To this end, both country and time fixed effects are properly accounted for by extending our basic specification to include them as well as taking into consideration the effects of mis-measured variables and omitted variable bias (Hsiao, 1986). Also, to fix the issues of contemporaneous correlation and group-wise heteroscedasticity across panels, we adopt the estimation method suggested by Beck and Katz (1996) by using the Prais-Winsten transformation technique. This approach removes autocorrelation from the data and uses the panel-correlated standard errors. Therefore, owing to the possibility of various econometric problems enumerated above, this work has implemented a good number of robustness checks to ensure that the results of the DOLS estimation method (the benchmark strategy) are consistent and robust. This further enables us to make comparison with other estimation strategies.

4. Results and discussion

4.1. Summary statistics

Before we start discussing the results, the summary statistics of the variables used are presented in Table 2. CO_2 emissions have an average value of 0.7461 (kg per 2010 US$ of GDP) and reaches a peak of 1.6111 (kg per 2010 US$ of GDP) over the period 1960 to 2014. Over the same period, trade openness (TRE) has an average value of 16.3304 and reaches a peak of 480.7926. Similarly, the average values of energy consumption (million tonnes oil equivalent), financial development (% of GDP) and technological innovation (total patent applications) are 1205.272, 49.5195 and 6433.539 respectively. The average values of agricultural value added (% of GDP), industry value added (% of GDP) and services value added (% of GDP) are 12.9212, 27.1973 and 50.4862 respectively. Technique effect (TE) has the highest mean value of 9995.191 over the selected period for SADC countries. The difference between minimum and maximum values of all the variables ranges in between -0.4525 to 8458.6305 and technique effect (TE) has the highest difference. The variations are more in technological innovation (TECH) and scale effect (SE) compared with CO2 emissions (CO_2) and Kyoto Protocol dummy (KYO). The variations of technique effect (TE) and comparative advantage effect (CPE) are also relatively higher as they have the third and fourth highest standard deviations. The variations are less for institutional quality (INS), foreign direct investment (FDI), industrial value added (% of IGDP) and service value added (% of SGDP), which make these variables less unstable in relation to others. Furthermore, the Jarque-Bera statistics affirms the normality of our data series which indicates the suitability of the data for any empirical analysis.

Table 2: Descriptive Statistics

Variables	Mean	Median	Maximum	Minimum	Std. Dev	Skewness	Kurtosis	J-B Stat	Probability
CO_2	0.7461	0.4127	1.6111	0.0989	0.5282	0.2950	1.3660	2.8269	0.120
SE	2298.183	1456.008	9197.027	135.7371	2181.792	1.3088	4.0324	3.6552	0.113
TE	9995.191	2121.078	8458.6305	1842.457	1711.6073	2.4340	8.4634	2.5804	0.319
TRE	16.3304	3.5104	480.7926	0.0046	56.2202	6.4050	49.0770	2.5461	0.251
EE	1205.272	833.9564	2950.154	305.9067	913.6746	0.7987	1.8600	3.3694	0.221
CE	15.4073	2.7615	87.8878	0.4702	22.9373	1.3788	3.4601	3.2225	0.201
CPE	321.0150	9.7699	10080.03	0.2113	1538.64	5.5118	32.1456	1.6701	0.103
FD	49.5195	29.6290	160.1248	1.0568	44.9674	0.9731	2.6719	1.5558	0.152
FDI	2.2050	0.8863	27.9026	-0.4525	3.5773	4.1559	27.8609	2.4110	0.254
INS	3.2696	3.5000	6.5000	1.5000	1.4753	0.3077	1.8384	1.3444	0.305
KYO	0.3039	0.0000	1.0000	0.0000	0.4622	0.8526	1.7269	1.2458	0.210
AGDP	12.9212	10.5798	56.5440	2.2854	10.2366	1.6490	7.3229	3.6494	0.120
IGDP	27.1973	27.1941	45.2775	15.8719	6.6629	0.6428	2.9554	1.0338	0.131
SGDP	50.4862	49.0907	63.1945	25.7920	6.9135	-0.5771	4.7882	1.2545	0.172
TECH	6433.539	1668.500	3501.06	1.0000	9376.222	1.6173	4.3343	2.0339	0.363

Source: Authors' calculations.

Table 3: Pearson Correlation Estimates

	$lnCO_2$	lnSE	lnTE	lnTRE	lnEE	lnCE	lnCPE	lnFD	lnFDI	lnINS	KYO	lnAGDP	lnIGDP	lnSGDP	lnTECH
$lnCO_2$	- -														
lnSE	0.09* (0.00)	- -													
lnTE	0.39* (0.00)	0.12* (0.00)	- -												
lnTRE	0.19* (0.00)	0.12* (0.00)	0.07 (0.06)	- -											
lnEE	0.34* (0.00)	0.14* (0.00)	-0.16* (0.00)	-0.03 (0.45)	- -										
lnCE	0.15* (0.00)	0.17* (0.00)	0.05* (0.00)	0.49* (0.00)	-0.15* (0.00)	- -									
lnCPE	0.35* (0.00)	0.26* (0.00)	0.18* (0.00)	0.95* (0.00)	0.04 (0.24)	0.03* -(0.00)	- -								
lnFD	0.09* (0.00)	0.55* (0.00)	0.11* (0.00)	0.29* (0.00)	0.19* (0.00)	0.25* (0.00)	0.40* (0.00)	- -							
lnFDI	0.47* (0.00)	0.37* (0.00)	0.28* (0.00)	0.09* (0.00)	0.23* (0.00)	0.19* (0.00)	0.18* (0.00)	0.45* (0.00)	- -						
lnINS	0.47* (0.00)	0.34* (0.00)	0.11* (0.00)	0.12* (0.00)	0.05* (0.00)	0.05 (0.19)	0.23* (0.00)	0.48* (0.00)	0.33* (0.00)	- -					
KYO	0.29* (0.00)	0.23* (0.00)	0.06 (0.08)	0.24* (0.00)	0.11* (0.00)	0.27* (0.00)	0.28* (0.00)	0.34* (0.00)	0.45* (0.00)	0.15* (0.00)	- -				
lnAGDP	0.26* (0.00)	0.62* (0.00)	0.49* (0.00)	0.55* (0.00)	0.04* (0.20)	0.45* (0.00)	0.06* (0.00)	0.59* (0.00)	0.34* (0.00)	0.35* (0.00)	0.28* (0.00)	- -			
lnIGDP	0.12* (0.00)	0.59* (0.00)	0.41* (0.00)	0.38* (0.00)	0.26* (0.00)	0.34* (0.00)	0.12* (0.00)	0.17* (0.00)	0.44* (0.00)	0.33* (0.00)	0.33* (0.00)	0.11* (0.00)	- -		
lnSGDP	0.54* (0.00)	0.57* (0.00)	0.49* (0.00)	0.58* (0.00)	0.05 (0.16)	0.49* (0.00)	0.69* (0.00)	0.61* (0.00)	0.41* (0.00)	0.29* (0.00)	0.39* (0.00)	0.13* (0.00)	0.16* (0.00)	- -	
lnTECH	0.35* (0.00)	0.23* (0.00)	-0.01 (0.88)	0.20* (0.00)	0.17* (0.00)	0.07* (0.04)	0.23* (0.00)	0.38* (0.00)	0.27* 0.00)	0.28* (0.00)	0.26* (0.00)	0.24* (0.00)	0.33* (0.00)	0.29* (0.00)	- -

Source: Authors' calculations. *Note:* * denote statistical significance at 5%.

4.2. The cross-sectional dependence, unit root tests and structural breaks

Table 4 presents the results of both CD and CIPS unit root tests. The results of the CD test show the rejection of the null hypothesis of cross-sectional independence CD ~ N(0,1) at the 1% level of significance for all variables under review. This provides ample evidence suggesting the existence of cross-sectional dependence among the cross-sectional units (countries). Given this evidence, the newly introduced CIPS unit root test is implemented to adequately account for this cross-sectional dependence in the data series. The results of the CIPS unit root test show that all variables are stationary at the level apart from InEE and InCE. However, after first differencing, all variables become stationary at the first differences. In simple words, all variables are integrated of order I(1).

TABLE 4: RESULTS OF CROSS-SECTIONAL DEPENDENCE AND CIPS UNIT ROOT TEST

Variable	**CD test**	**p-value**	**CIPS test**	
			level	**1st difference**
InCO2	32.02	0.000	-2.340**	-5.987***
InSE	7.16	0.000	-2.877***	-6.175***
InTE	10.62	0.000	-3.317***	-6.190***
InTRE	7.78	0.000	-2.712***	-6.178***
InEE	11.52	0.000	-1.708	-4.766***
InCE	29.79	0.000	-2.061	-6.190***
InCPE	17.52	0.000	-2.552***	-6.190***
InFD	32.42	0.000	-2.849***	-6.190***
InFDI	31.84	0.000	-3.583***	-6.190***
InINS	60.70	0.000	-3.878***	-5.903***
KYO	61.76	0.000	-3.713***	-6.190***
InTECH	24.71	0.000	-3.388***	-5.603***
InAGDP	15.40	0.000	-3.013***	-6.190***
InIGDP	20.13	0.000	-2.486***	-6.096***
InSGDP	37.12	0.000	-2.286**	-6.127***

Source: Authors' calculations.

Note: *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

Furthermore, for robustness, a battery of conventional unit root tests, which do not account for cross-sectional dependence in the data series are also used and the results reported in Table 5.

TABLE 5: PANEL UNIT ROOT TESTS

Variable	LLC	IPS	HT	ADF-Fisher	Breitung	Test results
InCO2	-6.6527***	-2.0264**	-1.7533**	-1.0429	-2.0899**	Stationary
D(InCO2)	-13.3925	-7.2226***	-0.0231***	-24.2853***	-16.8466***	Stationary
InSE	-6.5568***	-2.4619***	-5.5440***	-1.8027**	-2.3595***	Stationary
D(InSE)	-16.7290***	-8.4085***	-0.1489***	-26.5859***	-20.6677***	Stationary
InTE	-7.7001***	-2.7975***	-7.6625***	-3.7179***	-2.8924***	Stationary
D(InTE)	-18.5783***	-8.8312***	-0.2131***	-27.9637***	-23.2062***	Stationary
InTRE	-6.3799**	-2.3727***	-4.4849***	-3.3717***	-4.3268***	Stationary
D(InTRE)	-18.6521***	-8.4277***	-0.2141***	-27.7770***	-25.0133***	Stationary
InEE	-6.9268**	-3.5617	-3.5780	-3.0547***	-2.1853**	Stationary
D(InEE)	-10.1756***	-5.2815***	-0.1431***	-24.0598***	-14.7119***	Stationary
InCE	-2.9714	-0.9664	-0.5526	-1.5829*	-3.2613***	Unit root
D(InCE)	-14.5038***	-7.6426***	-0.0679***	-24.9101***	-21.2637***	Stationary
InCPE	-5.6421*	-2.0143**	-2.3487***	-2.4494***	-4.5440***	Stationary
D(InCPE)	-17.7051***	-8.4854***	-0.1740***	-27.7394***	-25.2221***	Stationary
InFD	-7.1454***	-2.3301***	-5.0181***	-4.0722***	-6.3857***	Stationary
D(InFD)	-17.3994***	-8.3689***	-0.2041***	-27.0434***	-26.5877***	Stationary
InFDI	-5.8984***	-2.7077***	-15.1195***	-10.3473***	-10.0831***	Stationary
D(InFDI)	-20.5944***	-10.2347***	-0.3790***	-29.9659***	-29.2266***	Stationary
InINS	-7.2076***	-1.8082*	-3.1470***	-4.1509***	-3.7850***	Stationary
D(InINS)	-14.3492***	-7.0748***	-0.0508***	-24.6323***	-13.4037***	Stationary
KYO	-1.9559	-0.5002	-7.4070***	-8.2057***	-6.6802***	Stationary
D(KYO)	-14.6413***	-7.2801***	-0.0714***	-25.7447***	-20.5248***	Stationary
InTECH	-6.1693	-2.6731	-13.8291***	-8.2260***	-9.0272***	Stationary
D(InTECH)	-19.3167***	-6.9814***	-0.4280***	-30.5125***	-30.7116***	Stationary
InAGDP	-6.3867***	-2.3790***	-5.2555***	-2.7307***	-4.2898***	Stationary
D(InAGDP)	-17.3705***	-8.9301***	-0.2881***	-28.2085***	-24.7886***	Stationary
InIGDP	-5.0925*	-1.8980**	-2.5655***	-1.5955*	-2.6478***	Stationary
D(InIGDP)	-21.7239***	-7.7151***	-0.0694***	-25.1620***	-4.4162***	Stationary
InSGDP	-5.0773*	-1.6540	-1.5580*	-1.6230*	-2.6608***	Stationary
D(InSGDP)	-15.7687***	-7.6259***	-0.0892***	-26.1347***	-21.7547***	Stationary

Source: Authors' calculations.
Note: (i) LLC denotes the Levin, Lin & Chu (1992, 2002) panel unit root; IPS represents the Im, Pesaran & Shin (1997, 2003) panel unit root; HT means the Harris & Tzavalis (1999) panel unit root. (ii) *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively.

The results presented in Table 5 are consistent with those reported in Table 4. Both results show that after first differencing, any series that is non-stationary in levels becomes stationary at first difference in all tests. Therefore, the robustness of the results is confirmed by the similarities of conclusions among these panel unit root tests. The evidence suggests absence of I(2) variables in the data series. Furthermore, failure of conventional unit root tests to capture the presence of structural breaks in the variables has motivated us to implement a testing strategy which is able to account for two structural breaks in the model. The paper hence uses the Clemente-Montanes-Reyes (1998) detrended unit root test and the results are reported in Table 6.

Table 6: Clemente-Montanes-Reyes Detrended Unit Root Test

	Innovative outliers			**Additive outlier**		
	T-statistic	**TB1**	**TB2**	**T-statistic**	**TB1**	**TB2**
Panel A: CO_2 individual information						
Angola	-4.371	1978	1993	-1.208	1977	1992
Botswana	-5.715*	1974	2008	-2.584	1973	1984
Comoros	-3.270	1978	1994	-1.693	1992	2008
DRC	-2.792	1973	1995	-3.841	1977	1995
Lesotho	-3.830	1988	1999	-1.300	1987	2002
Madagascar	-4.387	1965	1992	-2.792	1973	1995
Malawi	-5.538*	1979	2008	-3.860	1978	2008
Mauritius	-4.883	1987	1997	-4.113	1986	2008
Mozambique	-7.640*	1978	2008	-1.625	1977	1995
Namibia	-2.543	1991	2006	-1.514	1992	1996
Seychelles	-3.408	1968	1983	-3.324	1980	1998
South Africa	-4.443	1980	1999	-3.414	1980	1999
Tanzania	-4.534	1986	2002	-3.373	1985	2008
Zambia	-2.350	1979	1997	-3.583	1981	2008
Zimbabwe	-4.240	1984	1993	-4.065	1966	1996
Panel B: Trade openness individual information						
Angola	-3.578	1998	2006	-2.716	1997	2005
Botswana	-3.479	1973	1986	-3.753	1973	1985
Comoros	-4.899	1978	2008	-6.713	1977	2008
DRC	-3.530	1992	2005	-5.864*	1991	2008
Lesotho	-9.504*	1980	2008	-6.076*	1983	2004
Madagascar	-5.503*	1992	2008	-1.172	1990	1996
Malawi	-3.837	1992	2000	-1.451	1991	2008
Mauritius	-5.503*	1983	2008	-1.945	1984	2008
Mozambique	-5.824*	1979	2008	-2.510	1978	1991
Namibia	-6.445*	1978	1988	-3.077	1977	1989
Seychelles	-5.937*	1974	1994	-2.092	1973	1997
South Africa	-3.899	1987	2008	-3.188	1990	1997
Tanzania	-6.183*	1990	2008	-2.547	1989	2008
Zambia	-3.407	1992	2002	-0.216	1991	2003
Zimbabwe	-3.792	1973	1990	-4.025	1972	1988

Source: Authors' calculations.
Note: (i)* denotes statistical significance at 5% level. (ii) Critical value is –5.490 at 5% level of significance.

Table 6 shows that the variables have at least one structural break in different years. For robustness, a dummy variable (D2008) is created for the break year of 2008 to account for the presence of structural break in the variables. This year is attributed to the influence of 2008 global crisis that significantly affected the region.

4.3. Findings of panel cointegration tests

Table 7 reports the results of the panel cointegration test proposed by Pedroni (1997), where the null hypothesis of no cointegration is rejected by all the statistics of the Pedroni cointegration test at the various levels (10%, 5% and 1%) of significance. The rejection of the null hypothesis is thus supported by the four tests of the within measurement (namely: Panel v-statistic, Panel rho-statistic, Panel PP statistic and Panel ADF statistic) as well as three tests of the between dimension (namely: Group rho-statistic, Group PP statistic and Group ADF statistic). Hence, all seven tests indicate that the variables move together in the long run. This evidence therefore validates the existence of a cointegrating relationship among the variables under review.

Table 7: Results of Pedroni (Engle-Granger based) Panel Cointegration

Estimates	Statistic	Probability
Panel v-statistic	-2.8908***	0.0019
Panel rho-statistic	1.7102**	0.0436
Panel PP statistic	-1.4429*	0.0745
Panel ADF statistic	-2.4823***	0.0065
Alternative Hypothesis: Individual AR Coefficient		
Group rho-statistic	2.4680***	0.0068
Group PP statistic	-1.2937*	0.0979
Group ADF statistic	-2.5242***	0.0058

Source: Authors' calculations.
Note: (i) *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively. (ii) The null hypothesis of Pedroni's (1997) panel cointegration procedure is no cointegration.

Using the second-generation co-integration test that accounts for cross-sectional dependence in the data series, we provide further evidence of a long-run relationship among the variables under examination. The bootstrap panel cointegration test suggested by Westerlund (2007) is used and the results are reported in Table 8. Table 8 reports both the with-dimension and within dimension results while confirming the acceptance of the alternative hypothesis and the rejection of the null hypothesis. Therefore, the existence of a long-run relationship among the variables under consideration is further supported by the results of the second-generation test. This evidence suggests that our previous results are robust, consistent and do not change profoundly.

Table 8: Results of Westerlund (2007) Bootstrap Panel Cointegration

Statistic	Value	Z value	P-value	Robust p value
Gt	-8.448	-25.533	0.000	0.000
Ga	-15.795	-2.658	0.004	0.001
Pt	-10.431	-2.832	0.002	0.001
Pa	-10.708	-1.918	0.028	0.040

Source: Authors' calculations.
Note: (i) The null hypothesis of Westerlund [2007] panel cointegration procedure is no Cointegration; (ii) Using the bootstrap approach of Westerlund [2007] to account for cross-sectional dependence, the number of replications is 300; (iii) The p-values are for a one-sided test based on normal distribution; (iv)The robust p-value are for a one-sided test based on 300 bootstrap replications.

4.4. Findings from dynamic ordinary least squares (DOLS)

Having established the presence of a cointegrating equilibrium relationship among the variables, the paper uses the DOLS technique as the basic framework to investigate the long run relationship among the variables. Also, the battery of other estimation techniques such as PPML, FGLS, OLS, FMOLS, PW-PCSE, OLS-PCSE and OLS-CSD as alternative frameworks is used for robustness checks.

TABLE 9A: RESULTS OF LONG RUN ANALYSIS THROUGH DOLS, PPML, FGLS AND OLS

Model 1 Country and time fixed effects uncontrolled				
Regressor	**DOLS (1)**	**PPML (2)**	**FGLS (3)**	**OLS (4)**
Dependent variable	**($InCO_2$)**	**(CO_2)**	**($InCO_2$)**	**($InCO_2$)**
InSE	0.343***	0.183***	0.316***	0.329***
	(7.03)	(10.25)	(18.26)	(8.81)
InTE	-0.073***	-0.024***	-0.035***	-0.029*
	(-2.66)	(-4.69)	(-4.72)	(-1.97)
InTRE	-0.584***	-0.133***	-0.330***	-0.391***
	(-8.64)	(-7.47)	(-17.29)	(-8.43)
InEE	0.089**	0.018**	0.074***	0.091***
	(2.25)	(2.57)	(7.31)	(3.95)
InCPE	0.559***	0.127***	0.295***	0.358***
	(9.91)	(8.47)	(17.42)	(8.98)
InTECH	-0.073**	-0.017***	-0.043***	-0.062**
	(-2.71)	(3.07)	(-3.81)	(-2.44)
InCE	-0.294***	-0.073***	-0.158***	-0.174***
	(-8.11)	(-8.26)	(-13.71)	(-6.85)
InFD	-0.273***	-0.080***	-0.243***	-0.297***
	(-7.99)	(-7.66)	(-20.66)	(-10.95)
InFDI	0.356***	0.059***	0.182***	0.242***
	(4.88)	(4.12)	(7.12)	(4.02)
InAGDP	-0.035	-0.005	-0.077***	-0.075
	(-0.58)	(-0.34)	(-3.68)	(-1.60)
InIGDP	0.060	0.024**	0.125***	0.097***
	(1.07)	(2.08)	(7.45)	(2.63)
InSGDP	-0.150***	-0.005	-0.057***	-0.020
	(-2.71)	(-0.38)	(-3.20)	(-0.52)
InINS	0.349***	0.079***	0.084*	0.011
	(2.76)	(2.60)	(1.97)	(0.13)
KYO	-0.031	-0.022	-0.112	-0.107
	(-0.15)	(-0.66)	(-1.44)	(-0.76)
D2008	-	-	-	-
	-	-	-	-
Constant	-0.23***	-0.013*	0.883***	-0.623
	(-4.16)	(-1.97)	(3.40)	(-1.11)
Country fixed effects	No	No	No	No
Year fixed effects	No	No	No	No
R^2	0.879	0.797	-	0.707
Adjusted R^2	0.579	-	-	0.702

Source: Authors' calculations.
Note: (i) *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively. T-ratios are in parentheses ( ). (ii) Since year 2008 attributed to global crisis is a valid breakpoint based on Clemente-Montanes-Reyes detrended unit root test for SADC countries, we have attempted to account for it by including it in the regression models.

TABLE 9B: RESULTS OF LONG RUN ANALYSIS THROUGH DOLS, PPML, FGLS AND OLS

	Model 2 Controlling country and time fixed effects			
Regressor	**DOLS (5)**	**PPML (6)**	**FGLS (7)**	**OLS (8)**
Dependent variable	**($lnCO_2$)**	**(CO_2)**	**($lnCO_2$)**	**($lnCO_2$)**
lnSE	0.341***	0.146***	0.210***	0.221***
	(7.01)	(9.12)	(11.12)	(5.58)
lnTE	-0.050*	-0.046***	-0.060***	0.049**
	(-1.98)	(-5.06)	(-5.93)	(2.27)
lnTRE	-0.572***	-0.258***	-0.351***	-0.352***
	(-5.95)	(-9.37)	(-11.41)	(-6.54)
lnEE	0.228***	0.050***	0.099***	0.117***
	(5.32)	(4.12)	(5.70)	(3.75)
lnCPE	0.435***	0.236***	0.284***	0.275***
	(4.92)	(8.79)	(9.70)	(5.37)
lnTECH	-0.064*	-0.009**	-0.012	-0.026
	(-1.95)	(-2.41)	(-0.95)	(-0.94)
lnCE	-0.249***	-0.187***	-0.198***	-0.200***
	(-3.42)	(-8.54)	(-8.07)	(-5.03)
lnFD	-0.267***	-0.059***	-0.226***	-0.264***
	(-7.71)	(-6.77)	(-17.01)	(-10.23)
lnFDI	0.451***	0.078***	0.183***	0.286***
	(5.97)	(4.98)	(5.59)	(4.78)
lnAGDP	-0.227***	-0.018	-0.015	-0.024***
	(-3.80)	(-1.18)	(-0.67)	(-3.52)
lnIGDP	0.025	0.047***	0.108***	0.132***
	(0.45)	(3.91)	(5.07)	(3.30)
lnSGDP	-0.217***	-0.014	-0.047**	-0.090**
	(-3.88)	(-0.97)	(-2.21)	(-2.19)
lnINS	0.022	0.057	0.036	0.163
	(0.13)	(1.03)	(0.50)	(1.24)
KYO	-0.257***	-0.048***	-0.001	-0.335
	(-4.49)	(-3.08)	(-0.01)	(-1.40)
D2008	-	-	-	-
	-	-	-	-
Constant	-0.61**	-0.350	-0.503	-0.165
	(-2.74)	(-0.70)	(-1.18)	(-0.21)
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
R^2	0.892	0.700	-	0.803
Adjusted R^2	0.618	-	-	0.782

Source: Authors' calculations.

Note: (i) *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively. T-ratios are in parentheses ( ). (ii) Since year 2008 attributed to global crisis is a valid breakpoint based on Clemente-Montanes-Reyes detrended unit root test for SADC countries, we have attempted to account for it by including it in the regression models.

Table 9c: Results of long run analysis through DOLS, PPML, FGLS and OLS

Model 3 Controlling structural breaks				
Regressor	**DOLS (9)**	**PPML (10)**	**FGLS (11)**	**OLS (12)**
Dependent variable	**($lnCO_2$)**	**(CO_2)**	**($lnCO_2$)**	**($lnCO_2$)**
lnSE	0.341*** (7.01)	0.146*** (9.12)	0.210*** (11.12)	0.220*** (5.58)
lnTE	-0.049* (-1.96)	-0.046*** (-5.06)	-0.059*** (-5.93)	0.048** (2.27)
lnTRE	-0.572*** (-5.95)	-0.258*** (-9.37)	-0.350*** (-11.41)	-0.352*** (-6.54)
lnEE	0.228*** (5.32)	0.049*** (4.12)	0.096*** (5.71)	0.116*** (3.75)
lnCPE	0.435*** (4.92)	0.236*** (8.79)	0.284*** (9.70)	0.274*** (5.37)
lnTECH	-0.064* (-1.98)	-0.007* (-1.98)	-0.012 (-0.95)	-0.025 (-0.94)
lnCE	-0.249*** (-3.42)	-0.187*** (-8.54)	-0.197*** (-8.07)	-0.200*** (-5.03)
lnFD	-0.267*** (-7.71)	-0.058*** (-6.77)	-0.225*** (-17.01)	-0.263*** (-10.23)
lnFDI	0.450*** (5.97)	0.077*** (4.98)	0.183*** (5.59)	0.285*** (4.78)
lnAGDP	-0.227 (-3.80)	-0.017 (-1.18)	-0.015 (-0.67)	-0.024*** (-3.52)
lnIGDP	0.025 (0.45)	0.047*** (3.91)	0.107*** (5.07)	0.132*** (3.30)
lnSGDP	-0.216*** (-3.88)	-0.013 (-0.97)	-0.046** (-2.21)	-0.090** (-2.19)
lnINS	0.022 (0.13)	0.057 (1.03)	0.036 (0.50)	0.163 (1.24)
KYO	-0.257*** (-4.49)	-0.047** (-2.12)	-0.002 (-0.01)	-0.334 (-1.40)
D2008	-0.387 (-0.42)	1.380*** (3.15)	2.650*** (12.37)	1.585*** (2.74)
Constant	-0.63* (-1.96)	-0.350 (-0.70)	-.436 (-1.31)	-0.164 (-0.21)
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
R^2	0.800	0.704	-	0.803
Adjusted R^2	0.724	-	-	0.781

Source: Authors' calculations.

Note: (i) *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively. T-ratios are in parentheses ( ). (ii) Since year 2008 attributed to global crisis is a valid breakpoint based on Clemente-Montanes-Reyes detrended unit root test for SADC countries, we have attempted to account for it by including it in the regression models.

Table 9 reports the results of the DOLS model and other estimation approaches for robustness checks. The results show that the scale effect (InSE) has the hypothesised sign of positive impact on CO_2 emissions and is statistically significant. Holding other things constant, a 1% increase in real GDP per capita (InSE) causes a 0.343% rise in per capita CO_2 emissions in the long run. The result suggests that as SADC attains better higher levels of output, this brings about more environmental degradation. Similarly, the technique effect (InTE) has the expected sign of a negative impact on CO_2 emissions and is statistically significant. The net impact (of scale and technique effects) on CO_2 emissions is thus negative since the positive scale effect is dominated by the negative technique effect as income increases. This suggests that if economic transition takes place with progress in technology and people's inclination for a less carbon-intensive environment improves, the overall positive effect brought about by an increase in per capita income then gradually becomes negative as the technique effect starts dominating the scale effect, thereby improving environmental quality. The negative effect of InTE reflects this. Hence, a 1% increase in income resulting from a change in technology and people's inclination for a less carbon-intensive environment is associated with a reduction in CO_2 emissions by 0.073%. This evidence suggests that there is an inverted U-shaped relationship between the linear impact (of scale effect) and the non-linear impact (of technique effect) on CO_2 emissions; thus, providing support for the existence of the EKC hypothesis for the SADC region. Similar results have been derived by Nasir and Rehman (2011); Saboori *et al.* (2012); Shahbaz *et al.* (2012); Lau *et al.* (2014); Shahbaz *et al.* (2015); Sadat and Alom (2016); Ling *et al.* (2015); Copeland and Taylor (1994); Fodha and Zaghdoud (2010); Jayanthakumaran *et al.* (2012) and Shahbaz *et al*. (2013c). The impact of composition effect (InCE) on CO_2 emissions is negative and statistically significant at the 1% level implying that a 1% rise in the capital-labour ratio is related to a 0.421% decline in CO_2 emissions, *ceteris paribus*. Our result is supported by Ling *et al* (2015); Feridun *et al*. (2006); Tsurumi and Managi (2010) and Sadat and Alom (2016) but in contradiction with Managi *et al*. (2009) and Cole (2006).

Concerning the trade openness variable (InTRE), the estimated coefficient is negative and statistically significant. The result suggests that a 1% increase in trade openness leads to a 0.584% decrease in CO_2 emissions at 1% level of significance holding other things constant. This shows that trade openness is environmentally friendly in the long run for the case of SADC region because it facilitates technology and capital inflows that ultimately bring about greener development. This association between trade openness and CO_2 emissions can be justified by scale, technique and composition effects. The scale effect suggests that trade openness facilitates export volume, which leads to an increase in economic growth. The increase in economic growth in turn improves the income level, thereby enabling the SADC region to import environmentally friendly technology to increase output volume (i.e. technique effect). In addition, trade openness is a source of competition among local producers encouraging them to adopt greener technology to lower CO_2 emissions during production. The composition effect suggests that trade openness changes the industrial structure of a country such that it specialises in production of goods in which it has a comparative advantage. Hence, the composition effect improves environmental quality only when a country has a comparative advantage in environment friendly industries. Also, our result implies that openness to international goods markets adequately stimulates institutional development, capital formation and technological spill-over in the SADC region. The long-term national policies to enhance trade openness improve environmental quality in these countries. Our findings are in line with Shahbaz *et al*. (2012, 2013b); Sadat and Alom (2016) and Ling *et al*. (2015) but contradict with Omri *et al.* (2014); Feridun *et al.* (2006); Le *at al.* (2016); Solarin *et al*. (2017); Shahbaz *et al.* (2013a, c, 2014a, b).

The coefficient of the energy variable (InEE) is positive and statistically significant. Our results show that energy consumption contributes to increase CO_2 emissions in the SADC region since these countries heavily depend on the energy sector for production. This finding is in harmony with Shahbaz *et al.* (2013c). The estimated coefficient of the comparative advantage effect (InCPE) is positive and statistically significant. Similar to Ling *et al.* (2015) and Sadat and Alom (2016), we find that a 1% rise in this variable causes a 0.559% corresponding increase in CO_2 emissions at the 1% level of significance, *ceteris paribus*. The result suggests that when production is shifted to sectors in which SADC has a comparative advantage, it leads to an increase in CO_2 emissions. This may be caused by a loss in technical competitiveness arising from shifting physical and human capital, which has a positive impact on energy demand, thereby worsening environmental degradation. The results are in line with Sadat and Alom (2016) and Ling *et al*. (2015), but in contrast to Managi *et al.* (2009). The coefficient of financial development (InFD) is negative and statistically significant at the 1% level, implying that the financial sector contributes in reducing CO_2 emissions by directing banks to support investment projects that are less carbon intensive. The finding further reveals that the financial sector, while enabling businesses to utilise greener technology during production, has reached the maturity level in which it is able to prudently allocate scarce funds, thereby promoting environmentally friendly projects. This empirical evidence is consistent with Shahbaz *et al.* (2013c) and Tamazian and Rao (2010).

The impact of foreign direct investment (InFDI) on environmental degradation is positive and statistically significant. The result thus posits that InFDI worsens CO_2 emissions in the SADC region. Similar results were obtained by Ming Qing and Jia (2011) and Lee (2013). However, the result contradicts with Abdouli and Hammami (2017) and Omri *et al.* (2014). Regarding the coefficient of the institutional quality variable (InINS), it is found to be positive and statistically significant suggesting that an increase in institutional quality promotes economic expansion which leads to a significantly unfavourable impact on environmental quality. Therefore, an increase in institutional quality negatively affects environmental quality via economic growth. Our finding is in line with Sjöstedt and Jagers (2014) and Abid (2016). The coefficient of the Kyoto dummy is negative and statistically significant under FMOLS and few other estimation techniques. This suggests that the Kyoto Protocol initiative has contributed substantially to reduce CO_2 emissions in the SADC region. Our finding is supported by Iwata and Okada (2014), Grunewald and Martinez-Zarzoso (2015) and Aichele and Felbermayr (2013). The relationship between technological innovation (InTECH) and CO_2 emissions is negative and statistically significant at the 5% level, suggesting that technological innovation helps to improve environmental quality by promoting the efficiency of energy utilisation and producing renewable energy sources at minimum costs. Similar results have been derived by Ahmed *et al.* (2016); Sohag *et al.* (2015); Yii and Geetha (2017) and Chen and Lei (2018).

Lastly, the paper contributes by examining the effects of sector value addition to GDP on carbon emissions in the SADC region. To this end, our findings reveal that the expansion of the agricultural and service sectors has substantially reduced carbon emissions, whereas industrial sector expansion significantly worsened environmental quality. Our empirical evidence is supported by Al Mamun *et al.* (2014), Samargandi (2017) and Sohag *et al.* (2017).

4.5. Robustness check

As earlier pointed out, our estimation results may suffer from numerous econometric problems leading to spurious results. Therefore, to check the robustness of results produced by the DOLS technique and address previously highlighted problems, we have used a battery of alternative estimation methods such as PPML, FGLS, OLS, FMOLS, PW-PCSE, OLS-PCSE and OLS-CSD and their results are reported in both Tables 9 and 10. Panel data suggests that countries are heterogeneous and not controlling for this heterogeneity one runs the risk of obtaining biased results (Moulton, 1986, 1987). To this end, both country and time fixed effects are properly accounted for by extending our basic specification to include them as well as taking into consideration the effects of mis-measured variables and omitted variable bias (Hsiao, 1986). In light of this, we have implemented an estimation strategy taking account of fixed effects across countries and years in the estimations. The results are reported in columns for Model 2 in both Tables 9 and 10. These results for Model 2 (controlling country and time fixed effects) when compared with those of Model 1 (country and time fixed effects uncontrolled) produce the same message. This is because the estimated coefficients are similar in both the signs and magnitudes across both models. Given this evidence, we can conclude that, following the robustness checks by controlling both country fixed effects and time fixed effects, our main results are robust, consistent and do not change profoundly.

Second, the possibility of spatial dependence in the model is controlled for by implementing the strategy proposed by Conley (1999). This is done by replicating the initial estimation exercise to correct the standard errors for spatial dependence. The results are reported in columns (4), (8) and (12) of Table 10. Regarding the impact of trade openness on the environment, the major conclusion remains unaffected after controlling for the presence of cross-sectional spatial interdependencies in the model. Empirical evidence shows that under the OLS-CSD estimation strategy, the estimated coefficients for most variables are still statistically significant and maintain their signs in most cases, although a very slight difference exits in terms of magnitudes of the coefficients. Overall, the estimated effects are robust; hence, our conclusion is not fundamentally affected.

Third, recent studies have shown that infrequent shifts in the mean of macroeconomic variables such as trade and CO_2 emissions are a stylized fact, as a result, the presence of structural breaks should be properly accounted for. This paper further uses an estimation strategy which is able to account for heterogeneous structural breaks in the model and the results are reported in columns for Model 3 (controlling structural breaks) of both Tables 9 and 10. Empirical evidence shows that there is little or no difference in the estimated coefficients of most variables in Models 1 and 2 (without controlling structural breaks) and Model 3 (controlling structural breaks). In all models, we find no significant difference in the results, and we can comfortably conclude that our main results are consistent and have not changed noticeably in the presence of structural breaks.

In summary, when the results of the DOLS technique are compared with alternative estimation strategies, there is little or no difference regarding the estimated coefficients in terms of their signs and magnitudes. Most variables, while retaining their signs, are statistically significant, even though there is a slight difference in their magnitudes in some cases. The existence of the EKC hypothesis is confirmed in all estimation techniques.

TABLE 10A: RESULTS OF LONG RUN ANALYSIS THROUGH FMOLS, PW-PCSE, OLS-PCSE AND OLS-CSD

Model 1 Country and time fixed effects uncontrolled				
Regressor	**FMOLS** **(1)**	**PW-PCSE** **(2)**	**OLS-PCSE** **(3)**	**OLS-CSD** **(4)**
Dependent variable	**(InCO_2)**	**(InCO_2)**	**(InCO_2)**	**(InCO_2)**
InSE	0.260*** (28.71)	0.225*** (8.16)	0.329*** (9.12)	0.216*** (7.73)
InTE	-0.091*** (-10.17)	-0.050*** (3.73)	-0.029* (-1.97)	-0.047*** (-3.48)
InTRE	-0.462*** (-3.42)	-0.120*** (-2.84)	-0.391*** (-7.69)	-0.133*** (-3.27)
InEE	0.042* (1.98)	0.076*** (3.24)	0.091*** (4.08)	0.092*** (4.00)
InCPE	0.320*** (4.97)	0.103*** (2.62)	0.358*** (7.80)	0.118*** (3.20)
InTECH	-0.020 (-0.10)	-0.007 (-0.40)	-0.062** (-2.24)	-0.003*** (-2.61)
InCE	-0.421*** (-10.92)	-0.056* (-1.99)	-0.174*** (-6.14)	-0.062** (-2.42)
InFD	-0.070*** (-4.15)	-0.119*** (-5.07)	-0.297*** (-10.76)	-0.092*** (-4.05)
InFDI	0.261*** (16.85)	0.097*** (2.88)	0.242*** (4.07)	0.099*** (3.02)
InAGDP	-0.130*** (-15.50)	-0.022 (-0.69)	-0.075** (-2.50)	-0.010 (-0.03)
InIGDP	0.347*** (27.16)	0.070* (1.97)	0.097** (2.54)	0.062 (1.52)
InSGDP	-0.291*** (-9.23)	-0.119*** (-3.20)	-0.020 (-0.44)	-0.136*** (-3.45)
InINS	0.150 (0.91)	0.316*** (2.74)	0.011* (1.96)	0.262*** (2.97)
KYO	-0.674*** (-38.22)	-0.053 (-0.30)	-0.107** (-2.17)	-0.292* (-1.99)
D2008	- -	- -	- -	- -
Constant	1.073 (0.68)	2.052*** (4.49)	0.623 (1.11)	1.919*** (4.20)
Country fixed effects	No	No	No	No
Year fixed effects	No	No	No	No
R^2	0.743	0.629	0.707	0.681
Adjusted R^2	0.715	-	-	-

Source: Authors' calculations.

Note: (i) *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively. T-ratios are in parentheses ( ). (ii) Since year 2008 attributed to global crisis is a valid breakpoint based on Clemente-Montanes-Reyes detrended unit root test for SADC countries, we have attempted to account for it by including it in the regression models.

TABLE 10B: RESULTS OF LONG RUN ANALYSIS THROUGH FMOLS, PW-PCSE, OLS-PCSE AND OLS-CSD

	Model 2 Controlling country and time fixed effects			
Regressor	**FMOLS (5)**	**PW-PCSE (6)**	**OLS-PCSE (7)**	**OLS-CSD (8)**
Dependent variable	**(InCO_2)**	**(InCO_2)**	**(InCO_2)**	**(InCO_2)**
InSE	0.287*** (3.34)	0.206*** (7.15)	0.221*** (5.83)	0.194*** (6.89)
InTE	-0.015* (-1.96)	-0.071*** (4.86)	-0.049** (-2.37)	-0.070*** (4.69)
InTRE	-0.412*** (-3.52)	-0.078* (-1.98)	-0.352*** (-6.63)	-0.145*** (-2.63)
InEE	0.146*** (2.16)	0.071** (2.58)	0.117*** (3.40)	0.069*** (2.60)
InCPE	0.281** (2.52)	0.062 (1.09)	0.275*** (5.52)	0.125** (2.36)
InTECH	-0.070 (-1.17)	-0.039** (-2.18)	-0.026* (-1.96)	-0.034* (-1.98)
InCE	-0.169* (-1.98)	-0.022 (-0.44)	-0.201*** (-5.34)	-0.089* (-1.97)
InFD	-0.401*** (-7.17)	-0.106*** (-4.68)	-0.264*** (-10.13)	-0.087*** (-4.08)
InFDI	0.431*** (3.33)	0.089*** (2.68)	0.286*** (5.02)	0.085*** (2.59)
InAGDP	-0.132** (-2.29)	-0.007 (-0.23)	-0.024 (-0.54)	-0.017 (-0.55)
InIGDP	0.107 (1.23)	0.058* (1.99)	0.132*** (3.06)	0.044* (1.98)
InSGDP	-0.208** (-2.32)	-0.058 (-1.60)	-0.090** (-2.02)	-0.056 (-1.47)
InINS	0.178 (0.62)	0.117*** (3.95)	0.163 (1.40)	0.047** (2.43)
KYO	-0.565 (-1.09)	-0.013** (-2.07)	-0.335 (-1.51)	-0.094 (-0.52)
D2008	- -	- -	- -	- -
Constant	-2.824* (-1.99)	1.270** (2.34)	-0.165 (-0.23)	1.389** (2.37)
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
R^2	0.813	0.735	0.803	0.704
Adjusted R^2	0.780	-	-	-

Source: Authors' calculations.

Note: (i) *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively. T-ratios are in parentheses ( ). (ii) Since year 2008 attributed to global crisis is a valid breakpoint based on Clemente-Montanes-Reyes detrended unit root test for SADC countries, we have attempted to account for it by including it in the regression models.

ABLE 10C: RESULTS OF LONG RUN ANALYSIS THROUGH FMOLS, PW-PCSE, OLS-PCSE AND OLS-CSD

Model 3 Controlling structural breaks				
Regressor	**FMOLS (9)**	**PW-PCSE (10)**	**OLS-PCSE (11)**	**OLS-CSD (12)**
Dependent variable	**(lnCO$_2$)**	**(lnCO$_2$)**	**(lnCO$_2$)**	**(lnCO$_2$)**
lnSE	0.286***	0.205***	0.220***	0.194***
	(3.34)	(7.15)	(5.83)	(6.89)
lnTE	-0.014*	-0.070***	-0.048**	-0.069***
	(-1.96)	(4.86)	(-2.37)	(4.69)
lnTRE	-0.411***	-0.077*	-0.352***	-0.145***
	(-3.52)	(-1.98)	(-6.63)	(-2.63)
lnEE	0.145***	0.070**	0.116***	0.068***
	(2.16)	(2.58)	(3.40)	(2.60)
lnCPE	0.280**	0.061	0.274***	0.124**
	(2.52)	(1.09)	(5.52)	(2.36)
lnTECH	-0.069	-0.039**	-0.025*	-0.033*
	(-1.17)	(-2.18)	(-1.96)	(-1.98)
lnCE	-0.168*	-0.022	-0.200***	-0.088*
	(-1.98)	(-0.44)	(-5.34)	(-1.97)
lnFD	-0.401***	-0.105***	-0.263***	-0.087***
	(-7.17)	(-4.68)	(-10.13)	(-4.08)
lnFDI	0.430***	0.088***	0.285***	0.085***
	(3.33)	(2.68)	(5.02)	(2.59)
lnAGDP	-0.132**	-0.007	-0.024	-0.016
	(-2.29)	(-0.23)	(-0.54)	(-0.55)
lnIGDP	0.106	0.057*	0.132***	0.044*
	(1.23)	(1.99)	(3.06)	(1.98)
lnSGDP	-0.208**	-0.057	-0.090**	-0.055
	(-2.32)	(-1.60)	(-2.02)	(-1.47)
lnINS	0.177	0.117***	0.163	0.046**
	(0.62)	(3.95)	(1.40)	(2.43)
KYO	-0.565	-0.012**	-0.335	-0.093
	(-1.09)	(-2.07)	(-1.51)	(-0.52)
D2008	0.645	1.914***	1.586***	3.251***
	(0.51)	(6.15)	(4.32)	(6.68)
Constant	-1.321	1.269	-0.164	1.389**
	(-1.69)	(2.34)	(-0.23)	(2.37)
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
R^2	0.862	0.754	0.803	0.817
Adjusted R^2	0.804	-	-	-

Source: Authors' calculations.
Note: (i) *, ** and *** denote statistical significance at 10%, 5% and 1% levels respectively. T-ratios are in parentheses ( ). (ii) Since year 2008 attributed to global crisis is a valid breakpoint based on Clemente-Montanes-Reyes detrended unit root test for SADC countries, we have attempted to account for it by including it in the regression models.

6. Conclusion and policy implications

The paper contributes new evidence on the relationship between trade openness and environmental quality in SADC by constructing a novel proxy of trade openness that accurately captures trade openness. The innovative proxy considers both the SADC region's trade share of GDP and its size of trade relative to the rest of the world in a specified period of time. Using this measure of trade openness, we examine the role of trade openness on environmental degradation in a multivariate structure and panel dataset for the SADC region over the period 1960-2014, while decomposing the effects of trade into scale, technique, composition, comparative advantage, energy usage and technological innovation effects. In the same framework, we explore the role of sector value addition to GDP on the environmental quality in the presence of trade openness. We use other control variables such as financial development, foreign direct investment, institutional quality and a Kyoto Protocol dummy. We have used the second-generation econometric procedure such as Clemente-Montanes-Reyes detrended unit root test, which takes into consideration the heterogeneous structural breaks that have been largely ignored by the previous studies and a testing strategy which is able to account for cross-sectional dependence (Pesaran CIPS unit root test) in the panel dataset. In this way, the paper leverages on fairly new econometric techniques that thrive in the presence of structural breaks and also gives robust and reliable estimates. For robustness checks, we have further used a battery of panel unit root tests to investigate the panel unit roots of the series under review and SBIC is used to identify the optimal lag length. The existence of a cointegrating equilibrium among the variables is examined using the strategies suggested by Westerlund and Pedroni. Our empirical results confirm the presence of a cointegrating relationship among the variables.

To investigate the long run relationship among the variables, the paper uses the estimation approach proposed by Stock and Watson, which was further refined by Pedroni. Empirical evidence shows that the scale effect contributes to increase CO2 emissions while the technique effect reduces it. This evidence suggests an inverted U-shaped curve in the relationship between openness and environmental quality, confirming that the EKC hypothesis holds for SADC. Technological innovation, the composition effect, financial development, agriculture GDP, service sector GDP and Kyoto Protocol Commitment contribute to improve environmental quality; however, energy consumption, the comparative advantage effect, foreign direct investment, industrial GDP and institutional quality increase CO_2 emissions. Furthermore, the long-run relationship between trade openness and CO_2 emissions is investigated and the evidence shows that trade openness substantially improves environmental quality in the SADC countries.

Our empirical results are robustly supported by the results of PPML, FGLS, OLS, FMOLS, PW-PCSE, OLS-PCSE and OLS-CSD estimation strategies as alternative frameworks. Based on the empirical evidence, the positive long-run relationship between foreign direct investment and CO_2 emissions confirms the existence of pollution haven hypothesis (PHH) for the SADC countries. This is because SADC countries (especially South Africa) have a comparative advantage in the export and production of dirty goods, which transform these countries into "havens" for highly pollution-intensive industries. Our empirical evidence is in line with the conclusion reached by previous studies that industries characterised with the production of highly pollution-intensive and dirty goods have substantially shifted to less developed countries. This migration in the form of foreign direct investment has resulted to transferring the pollution problems of industrial countries to these poor countries, thereby contributing significantly to deteriorate their environmental quality. In addition, given SADC's less stringent environmental standards and weaker institutions owing to corruption and lawlessness, have left them with deteriorating environments as they continue to specialise in the production of dirty products that harm the environment.

The policy implication of these findings is that the SADC member countries should strive to reform and strengthen their trade policy when seeking to reduce carbon emissions. Part of our central finding that foreign direct investment harms the environment in the region is consistent with the popular notion that rich countries dump the pollution associated with their consumption on poor countries. For example, foreign direct investment from advanced economies has helped to transform the region into a highly polluted factory of the world, which exports much of what it produces back to the advanced economies. Therefore, our evidence lends some support to calls for rich countries to provide assistance for the efforts of rich countries to tackle pollution. To the extent that rich countries are outsourcing pollution, there is a case for their contributing to the clean-up of the outsourced pollution. Meanwhile, due to significant benefits of foreign direct investment in the region, the region should devise better measures to ensure that the foreign direct investment contributes towards improving their environmental quality. In this light, policymakers should intensify efforts to ensure that foreign investors adopt updated, greener and cleaner technologies.

Ultimately, this will enable the region to shift from non-renewable energy sources to renewable or less carbon-intensive sources, while ensuring proficiency in the production processes. In addition, replacement of non-renewable energy sources with better substitutes such as solar power will remarkably improve the region's environmental quality.

Furthermore, the global partnership to mitigate the growing trans-boundary environmental degradation as well as various spillover effects is significantly important. In this light, the region's policymakers and governments should effectively collaborate with the rest of the world to enhance strong partnership in sharing technology that can reduce carbon emissions. More essentially, the SADC member countries should integrate all-inclusive environmental chapters into their trade agreement policies to facilitate an easier transition into cleaner industries and low-carbon economy. Trade agreements can strengthen the capacity for governments to address environmental issues. In particular, the reduction of trade barriers on environmental goods can lead to increased access to green technologies at lower cost. For instance, the Trans-Pacific Partnership (TPP) agreement is expected to help developing countries shift into cleaner industries and transition to low-carbon pathways by providing access to green goods, services, and investments. Also, strengthening socio-economic and governance-related factors could play a significant role in achieving environmental sustainability in the long-run.

In principle, policies can be designed as if the world was a single country, using a common charge per unit of emissions that reflects the cost of global warming. Though such international agreements might be fraught with free-riding and monitoring problems, these could be solved by trade sanctions. However, a more effective way is to provide stronger incentives to cooperate through international transfers, which introduce a tangible cost for non-compliance. For instance, the TPP parties have adopted a range of renewable energy subsidies. The TPP also allows for subsidies for research and development on green energy. However, green subsidies might distort resource allocation, so it is important to take such inefficiencies into account.

In sum, successful negotiation of environmental provisions in trade agreements requires extensive preparation, close coordination among trade and environmental actors, setting of priorities, and reconciling conflicting interests. Environmental provisions are not a one-off but instead require continuous efforts to ensure effective integration of trade and environmental issues throughout the trade agreement. In this connection, SADC member countries would benefit from external support, especially in terms of financial resources and capacity building, either from their developed country trade partners or from other institutions such as development co-operation agencies. Lastly, trade policy reforms could be accompanied with other developmental policies aimed at promoting enduring value for minimisation of GHG emissions and continuously support the development of new technologies that improve the region's environmental quality and protect the global environment.

Biographical Notes

Maxwell Chukwudi Udeagha holds a Master's degree in Development Economics from the University of Johannesburg, South Africa. He is an editorial board member of several Journals including *American Journal of Environmental Sciences and Engineering*, *Economics Bulletin*, *Global Economics Science*, *Journal of Contemporary African Studies*, *Journal of Economics and International Business Managemen*t. He has research interest in emerging market economies, development economics, international trade, African environment, regional economic integration, applied economics and applied econometrics. He is currently working toward his PhD and has published a few papers in top, high-ranking and high-profile Journals.

Marthinus Christoffel Breitenbach holds a PhD in Economics from the University of Pretoria, South Africa. He is an associate professor in the School of Economics at the University of Pretoria and his research interests vary from development issues, including environmental and agricultural issues to open-economy macroeconomic issues, especially exchange rate dynamics, international trade and finance. He recently also authored and co-authored papers relating to non-parametric measurement of efficiency in the public domain.

Acknowledgement

This work is based on the research supported in part by the National Research Foundation of South Africa (Grant Number: 121822).

References

Abdouli, M., & Hammami, S. (2017). Investigating the causality links between environmental quality, foreign direct investment and economic growth in MENA countries. *International Business Review*, 26(2):264-278.

Abid, M. (2016). Impact of economic, financial, and institutional factors on CO_2 emissions: Evidence from Sub-Saharan Africa economies. *Utilities Policy*, 41:85-94.

Ahmed, A., Uddin, G. S., & Sohag, K. (2016). Biomass energy, technological progress and the environmental Kuznets curve: Evidence from selected European countries. *Biomass and Bioenergy*, 90, 202-208.

Aichele, R., & Felbermayr, G. (2013). The effect of the Kyoto protocol on carbon emissions. *Journal of Policy Analysis and Management*, 32(4):731-757.

Al Mamun, M., Sohag, K., Mia, M. A. H., Uddin, G. S., & Ozturk, I. (2014). Regional differences in the dynamic linkage between CO_2 emissions, sectoral output and economic growth. *Renewable and Sustainable Energy Reviews*, 38, 1-11.

Ang, J.B. (2007). CO_2 emissions, energy consumption, and output in France. *Energy Policy*, 35 (10), 4772–4778.

Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment? *American Economic Review*, 91(4):877-908.

Armah, F. A., Odoi, J. O., & Luginaah, I. (2015). Indoor air pollution and health in Ghana: Self-reported exposure to unprocessed solid fuel smoke. *EcoHealth*, 12(2), 227–243.

Balin, B. E., Akan, H. D. M., & Altayligil, Y. B. (2017). Trade Liberalization and Environmental Degradation: A Time Series Analysis for Turkey. Paper prepared for the 19th Annual Conference of ETSG, Florence-Italy.

Beck, N. and J. Katz. (1996). Nuisance vs. Substance: Specifying and Estimating Time-Series-Cross-Section Models. *Political Analysis*, 6(1), 1–36.

Beeson M (2010) The coming of environmental authoritarianism. *Environmental Politics* 19(2):276–294.

Begum, R. A., Sohag, K., Abdullah, S. M. S., & Jaafar, M. (2015). CO_2 emissions, energy consumption, economic and population growth in Malaysia. *Renewable and Sustainable Energy Reviews*, 41, 594-601.

Bilgili, F., Koçak, E., Bulut, Ü. (2016). The dynamic impact of renewable energy consumption on CO_2 emissions: a revisited Environmental Kuznets Curve approach. *Renew. Sustain. Energy Rev*. 54: 838-845.

Brock, W. A., & Taylor, M. S. (2005). Economic growth and the environment: a review of theory and empirics. In *Handbook of Economic Growth* (Vol. 1, pp. 1749-1821). Elsevier.

Canadell, J.G., Raupach, M.R., Houghton, R.A. (2009). Anthropogenic CO_2 emissions in Africa. *Biogeosciences* 6(3):463–468.

Chen, W., Lei, Y. (2018). The impacts of renewable energy and technological innovation on environment-energy-growth nexus: new evidence from a panel quantile regression. *Renew Energy* 123:1–14.

Cherniwchan, J. (2017). Trade liberalization and the environment: Evidence from NAFTA and US manufacturing. *Journal of International Economics*, 105:130-149.

Clemente, J., Montañés, A., & Reyes, M. (1998). Testing for a unit root in variables with a double change in the mean. *Economics Letters*, 59(2), 175-182.

Cole, M. A. (2006). Does trade liberalization increase national energy use? *Economics Letters*, 92(1):108-112.

Cole, M. A., & Elliott, R. J. (2003). Determining the trade–environment composition effect: the role of capital, labour and environmental regulations. *Journal of Environmental Economics and Management*, 46(3):363-383.

Cole, M., Rayner, A., Bates, J., (1997). The environmental Kuznets curve: An empirical analysis. *Environment and Development Economics* 2 (4), 401–416.

Conley, T. (1999). GMM estimation with cross-sectional dependence. *Journal of Econometrics* 92 (1), 1–45.

Copeland, B.R., Taylor, M.S. (2004). Trade, growth, and the environment. *J Econ Lit* 42(1):7–71.

Copeland, B. R., & Taylor, M. S. (1994). North-South trade and the environment. *The Quarterly Journal of Economics*, 109(3):755-787.

Copeland, B. R., & Taylor, M. S. (2005). Free trade and global warming: a trade theory view of the Kyoto Protocol. *Journal of Environmental Economics and Management*, 49(2):205-234.

Copeland, B. R., & Taylor, M. S. (2013). Trade and the environment: Theory and evidence. Princeton University Press, New Jersey.

Copeland, B.R., Taylor, M.S. (2004). Trade, Tragedy, and the Commons (No. w10836). National Bureau of Economic Research.

Cotula, L., (2011). Land Deals in Africa: What is in the Contracts? International Institute of Environment and Development (IIED) London.

de Bruyn, S. M., van den Bergh, J. C. J. M., Opschoor, J. B. (1998). Economic growth and emissions: Reconsidering the empirical basis of environmental Kuznets curves. *Ecological Economics* 25 (2), 161–175.

Destek, M. A., Balli, E., & Manga, M. (2016). The relationship between CO_2 emission, energy consumption, urbanization and trade openness for selected CEECs. Research in World Economy, 7(1):52.

Deutsche GesellschaftfürTechnischeZusammenarbeit (GTZ) GmbH, 2009. Foreign Direct Investment (FDI) in Land in Developing Countries. GTZ, Germany. http://www.responsibleagroinvestment.org/rai/sites/responsibleagroinvestment.org/files/gtz-foreign-direct-investment.pdf (accessed 06.03.2020).

Dinda, S. (2006). Globalization and Environment: Can Pollution Haven Hypothesis alone explain the impact of Globalization on Environment? MPRA working Paper 50590.

Dogan, E. and F. Seker, F. (2016). Determinants of CO_2 emissions in the European Union: the role of renewable and non-renewable energy, *Renew. Energy* 94: 429-439.

Dogan, E., & Turkekul, B. (2016). CO_2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. *Environmental Science and Pollution Research*, 23(2):1203-1213.

Ehrilch, P.R., Ehrilch, A.H. and Daily, G.C. (1993). 'Food Security, Population, and Environment'. *Population and Development Review*, Vol. 19 (1 (March), pp.1–32.

Eicker, F. (1963). Asymptotic Normality and Consistency of the Least Squares Estimators for Families of Linear Regressions". *The Annals of Mathematical Statistics* 34: 447–456.

Ertugrul, H. M., Cetin, M., Seker, F., & Dogan, E. (2016). The impact of trade openness on global carbon dioxide emissions: evidence from the top ten emitters among developing countries. *Ecological Indicators*, 67, 543-555.

Esteve, V., Requena, F. (2006). A cointegration analysis of car advertising and sales data in the presence of structural change. *Int J Econ Bus* 13(1):111–128.

Feridun, M., Ayadi, F. S., & Balouga, J. (2006). Impact of trade liberalization on the environment in developing countries: the case of Nigeria. *Journal of Developing Societies*, 22(1):39-56.

Fernández-Amador, O., Francois, J. F., Oberdabernig, D. A., & Tomberger, P. (2017). Carbon dioxide emissions and economic growth: An assessment based on production and consumption emission inventories. *Ecological Economics*, 135:269-279.

Fodha, M., & Zaghdoud, O. (2010). Economic growth and pollutant emissions in Tunisia: an empirical analysis of the environmental Kuznets curve. *Energy Policy*, 38(2):1150-1156.

Frankel, J. A., & Rose, A. K. (2005). Is trade good or bad for the environment? Sorting out the causality. *Review of Economics and Statistics*, 87(1):85-91.

Frankel, J., and S. Wei. (1993). Trade Blocs and Currency Blocs". NBER working paper no. 4335.

Gale, L. R., & Mendez, J. A. (1998). The empirical relationship between trade, growth and the environment. *International Review of Economics & Finance*, 7(1):53-61.

Garrison, V. H., Majewski, M. S., Konde, L., Wolf, R. E., Otto, R. D., & Tsuneoka, Y. (2014). Inhalable desert dust, urban emissions and potentially biotoxic metals in urban Saharan-Sahelian air. *Science of the Total Environment*, 500–501, 383–394.

Gaspar, F. W., Chevrier, J., Bornman, R., Crause, M., Obida, M., Barr, D. (2015). Undisturbed dust as a metric of long term indoor insecticide exposure: Residential DDT contamination from indoor residual spraying and its association with serum levels in the VHEMBE cohort. *Environment International*, 85, 163–167.

Grether, J. M., & De Melo, J. (2003). Globalization and dirty industries: Do pollution havens matter? (No. w9776). National Bureau of Economic Research.

Grossman, G., Krueger, A. (1995). Economic growth and the environment? *Q J Econ* 110(2):353–377.

Grossman, G.M., Krueger, A.B. (1993). Environmental Impacts of a North American Free Trade Agreement. In: Barber, P. (Ed.), The US-Mexico Free Trade Agreement. MIT Press, Cambridge, MA.

Grossman, G.M., Krueger, A.B., (1991). Environmental Impacts of a North American Free Trade Agreement (No. w3914). National Bureau of Economic Research.

Grossman, G.M., Krueger, A.B., (1996). The inverted-U: what does it mean? *Environ. Dev. Econ.* 1 (01), 119–122.

Grunewald, N., Martinez-Zarzoso, I. (2015). Did the Kyoto Protocol fail? An evaluation of the effect of the Kyoto Protocol on CO2 emissions. *Environment and Development Economics*, 21:1–22.

Hasson, A., & Masih, M. (2017). Energy consumption, trade openness, economic growth, carbon dioxide emissions and electricity consumption: evidence from South Africa based on ARDL. Munich Personal RePEc Archive (MPRA) Paper No. 79424.

Hsiao, C. (1986). Analysis of Panel Data. Cambridge: Cambridge University Press.

Inglesi-Lotz, R. (2018). Decomposing the South African CO_2 emissions within a BRICS countries context: Signalling potential energy rebound effects. Energy, 147:648-654.

Iwata, H., & Okada, K. (2014). Greenhouse gas emissions and the role of the Kyoto Protocol. *Environmental Economics and Policy Studies*, 16(4):325-342.

Iyke, B. N., & Ho, S. Y. (2017). Trade openness and carbon emissions: Evidence from Central and Eastern Europe. MPRA Paper, 80399.

Jabeen, A. (2015). Is trade liberalization, economic growth, energy consumption good for the environment? *Romanian Journal of Fiscal Policy* (RJFP), 6(2):1-13.

Jamel, L., & Maktouf, S. (2017). The nexus between economic growth, financial development, trade openness, and CO_2 emissions in European countries. *Cogent Economics & Finance*, 5(1):1341456.

Jayanthakumaran, K., Verma, R., & Liu, Y. (2012). CO_2 emissions, energy consumption, trade and income: a comparative analysis of China and India. *Energy Policy*, 42:450-460.

Kahuthu, A. (2006). Economic growth and environmental degradation in a global context. *Environ. Dev. Sustain*. 8 (1), 55–68.

Kaufmann, R. K., Davidsdottir, B., Garnham, S., Pauly, P. (1998). The determinants of atmospheric SO_2 concentrations: Reconsidering the environmental Kuznets curve. *Ecological Economics*, 25 (2), 209–220.

Kearsley, A., Riddel, M. (2010). A further inquiry into the pollution haven hypothesis and the environmental Kuznets curve. *Ecological Economics*, 69 (4), 905–919.

Kebede, S. (2017). Modeling Energy Consumption, CO2 Emissions and Economic Growth Nexus in Ethiopia: Evidence from ARDL Approach to Cointegration and Causality Analysis. Munich Personal RePEc Archive (MPRA) Paper No. 83214.

Khan Z, Ali S, UmarM, Kirikkaleli D, & Jiao, Z. (2020). Consumption-based carbon emissions and international trade in G7 countries: The role of environmental innovation and renewable energy. *Sci Total Environ*. https://doi.org/10.1016/j.scitotenv.2020.138945

Kugelman, M., Levelstein, S.L. (Eds.), (2012). The Global Farms Race: Land Grabs, Agricultural Investment, and the Scramble for Food Security. Island Press, Washington, D.C.

Kwakwa, P. A., Alhassan, H., & Adu, G. (2018). Effect of natural resources extraction on energy consumption and carbon dioxide emission in Ghana. Munich Personal RePEc Archive (MPRA) Paper No. 85401.

Lau, L. S., Choong, C. K., & Eng, Y. K. (2014). Carbon dioxide emission, institutional quality, and economic growth: Empirical evidence in Malaysia. *Renewable Energy*, 68:276-281.

Le, T. H., Chang, Y., & Park, D. (2016). Trade openness and environmental quality: International evidence. *Energy Policy*, 92:45-55.

Lee, J., Huang, C. J. and Shin, Y. (1997). On stationary tests in the presence of structural breaks. *Economics Letters*, 55, pp. 165–72.

Lee, W. J. (2013). The contribution of foreign direct investment to clean energy use, carbon emissions and economic growth. *Energy Policy*, 55:483–489.

Li, Z., Xu, N., & Yuan, J. (2015). New evidence on trade-environment linkage via air visibility. *Economics Letters*, 128:72-74.

Lin, F. (2017). Trade openness and air pollution: City-level empirical evidence from China. *China Economic Review*, 45:78-88.

Ling, C. H., Ahmed, K., Muhamad, R. B., & Shahbaz, M. (2015). Decomposing the trade-environment nexus for Malaysia: what do the technique, scale, composition, and comparative advantage effect indicate? *Environmental Science and Pollution Research*, 22(24):20131-20142.

Lopez, R. (1994). The environment as a factor of production: the effects of economic growth and trade liberalization. *Journal of Environmental Economics and Management*, 27(2):163-184.

Managi, S., Hibiki, A., & Tsurumi, T. (2009). Does trade openness improve environmental quality? *Journal of Environmental Economics and Management*, 58(3):346-363.

Mapapu, B., & Phiri, A. (2018). Carbon Emissions and Economic Growth in South Africa: A Quantile Regression Analysis. *International Journal of Energy Economics and Policy*, 8(1):195-202.

Ming Qing, J., & Jia, Y. (2011). Empirical research on the environmental effect of foreign direct investment: The case of Jiangsu Province. *Advanced Materials Research*, 204:1–4.

Moulton, B.R., (1986). Random group effects and the precision of regression estimates. *Journal of Econometrics,* 32, 385–397.

Moulton, B.R. (1987. Diagnostics for group effects in regression analysis, *Journal of Business and Economic Statistics* 5, 275–282.

Nasir, M., & Rehman, F. U. (2011). Environmental Kuznets curve for carbon emissions in Pakistan: an empirical investigation. *Energy Policy*, 39(3):1857-1864.

Ngepah, N., & Udeagha, M. C. (2018). African regional trade agreements and intra-African trade. *Journal of Economic Integration*, 33(1), 1176–1199.

Ngepah, N., & Udeagha, M. C. (2019). Supplementary trade benefits of multi-memberships in African regional trade agreements. *Journal of African Business*, 20(4), 505–524.

Nriagu, J. O. (1992). Toxic metal pollution in Africa. *Science of the Total Environment*, 121, 1–37.

Oh, K. Y., & Bhuyan, M. I. (2018). Trade Openness and CO_2 Emissions: Evidence of Bangladesh. *Asian Journal of Atmospheric Environment* (AJAE), 12(1).

Omri, A., Nguyen, D. K., & Rault, C. (2014). Causal interactions between CO_2 emissions, FDI, and economic growth: Evidence from dynamic simultaneous-equation models. *Economic Modelling*, 42:382-389.

Panayotou, T. (1993). Empirical tests and policy analysis of environmental degradation at different stages of economic development. ILO Working Paper 292778, International Labour Organization.

Pedroni, P. (2000). Fully modified OLS for heterogeneous cointegrated panels, in: Nonstationary Panels, Panel Cointegration, and Dynamic Panels, Emerald Group Publishing Limited, pp. 93-130.

Pedroni, P. (2001a). Fully modified OLS for heterogeneous cointegrated panels, *Adv. Econom*. 15 (2001) 93-130.

Pedroni, P. (2001b). Purchasing power parity tests in cointegrated panels. *Rev. Econ. Stat*. 83 (4) (2001) 727-731.

Pedroni, P.(1997). Panel Cointegration: Asymptotic and Finite Sample Properties of Pooled Time Series Tests with an Application to the PPP Hypothesis: New results, «mimeo», Indiana University.

Perron, P. (1989). The great crash, the oil price shock and the unit root hypothesis. *Econometrica*, 57, pp. 1361–401.

Pesaran, M.H. (2004). General Diagnostic Tests for Cross Section Dependence in Panels, Cambridge University, Cambridge, Cambridge Working Papers in Economics No. 0435.

Pesaran, M.H. (2007). A simple panel unit root test in the presence of cross section dependence. *J. Appl. Econom*. 22 (2) 265-312.

Raza, S. A., & Shah, N. (2018). Impact of Financial Development, Economic Growth and Energy Consumption on Environmental Degradation: Evidence from Pakistan. MPRA Paper No. 87095.

Ridley, D. A., Heald, C. L., & North, F. B. (2012). African dust export and deposition: A satellite and model perspective. *Journal of Geophysical Research: Atmospheres*, 117, D02202. doi:10.1029/2011JD016794.

Rooney, M. S., Arku, R. E., Dionisio, K. L., Paciorek, C., Friedman, A. B., Carmichael, H. (2012). Spatial and temporal patterns of particulate matter sources and pollution in four communities in Accra, Ghana. *Science of the Total Environment*, 435–436, 107–114.

Roy, J. (2017). On the environmental consequences of intra-industry trade. *Journal of Environmental Economics and Management*, 83:50-67.

Saboori, B., Sulaiman, J., & Mohd, S. (2012). Economic growth and CO2 emissions in Malaysia: a cointegration analysis of the environmental Kuznets curve. *Energy Policy*, 51:184-191.

Sadat, S. D., & Alom, F. (2016). Environmental quality, international trade and economic growth: the case of Malaysia. *International Journal of Green Economics*, 10(3-4):302-326.

Sam, R. A., Ofosu, F. G., Atiemo, S. M., Aboh, I., Gyampo, O., Ahiamadjie, H. (2015). Heavy Metal Contamination Levels in Topsoil at Selected Auto Workshops in Accra. *International Journal of Science & Technology*, 4(5), 222–229.

Samargandi, N. (2017) Sector value addition, technology and CO_2 emissions in Saudi Arabia. *Renewable and Sustainable Energy Reviews* 78:868–877.

Santos Silva, J. M.C., and S. Tenreyro (2006). The Log of Gravity. T*he Review of Economics and Statistics*, 88(4): 641-658.

Selden, T.M., Song, D. (1994). Environmental quality and development: is there a Kuznets curve for air pollution emissions? *J. Environ. Econ. Manag.* 27 (2), 147–162.

Shafik, N. (1994). Economic development and environmental quality: an econometric analysis. Oxford Economic Papers, pp. 757–773.

Shafik, N., Bandyopadhyay, S. (1992). Economic Growth and Environmental Quality: Time-series and Cross-country Evidence. World Bank Publications, Washington D.C.

Shahbaz, M., Khan, S. and Tahir, M.I. (2013a). The dynamic links between energy consumption, economic growth, financial development and trade in China: fresh evidence from multivariate framework analysis. *Energy Econ* 40:8–21.

Shahbaz, M., Dube, S., Ozturk, I., & Jalil, A. (2015). Testing the environmental Kuznets curve hypothesis in Portugal. *International Journal of Energy Economics and Policy*, 5(2):475-481.

Shahbaz, M., Khraief, N., Uddin, G. S., & Ozturk, I. (2014a). Environmental Kuznets curve in an open economy: a bounds testing and causality analysis for Tunisia. *Renewable and Sustainable Energy Reviews*, 34:325-336.

Shahbaz, M., Lean, H. H., & Shabbir, M. S. (2012). Environmental Kuznets curve hypothesis in Pakistan: cointegration and Granger causality. *Renewable and Sustainable Energy Reviews*, 16(5):2947-2953.

Shahbaz, M., Nasreen, S., Ahmed, K., & Hammoudeh, S. (2017). Trade openness–carbon emissions nexus: The importance of turning points of trade openness for country panels. *Energy Economics*, 61:221-232.

Shahbaz, M., Sbia, R., Hamdi, H., & Ozturk, I. (2014b). Economic growth, electricity consumption, urbanization and environmental degradation relationship in United Arab Emirates. *Ecological Indicators*, 45:622-631.

Shahbaz, M., Solarin, S. A., Mahmood, H., & Arouri, M. (2013b). Does financial development reduce CO_2 emissions in Malaysian economy? A time series analysis. *Economic Modelling*, 35:145-152.

Shahbaz, M., Tiwari, A. K., & Nasir, M. (2013c). The effects of financial development, economic growth, coal consumption and trade openness on CO_2 emissions in South Africa. *Energy Policy*, 61:1452-1459.

Shiller, R. J. and Perron, P. (1985). Testing the random walk hypothesis: power versus frequency of observation. *Economics Letters*, 18, 4, pp. 381–6.

Sjöstedt, M., & Jagers, S. C. (2014). Democracy and the environment revisited: The case of African fisheries. Marine Policy, 43:143-148.

Sohag, K., Al Mamun, M., Uddin, G. S., & Ahmed, A. M. (2017). Sectoral output, energy use, and CO_2 emission in middle-income countries. *Environmental Science and Pollution Research*, 24(10), 9754-9764.

Sohag, K., Begum, R. A., Abdullah, S. M. S., & Jaafar, M. (2015). Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia. *Energy*, 90, 1497-1507.

Solarin, S. A., Al-Mulali, U., Musah, I., & Ozturk, I. (2017). Investigating the pollution haven hypothesis in Ghana: an empirical investigation. *Energy*, 124:706-719.

Soytas, U., Sari, R., Ewing, B.T. (2007). Energy consumption, income, and carbon emissions in the United States. *Ecol. Econ*. 62 (3), 482–489.

Squalli, J., and Wilson, K. (2011). A new measure of trade openness. *The World Economy*, 2011, 34 (10):1745–1770.

Stock, J., Watson, M.W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. *Econometrica*, 61 (4), 783–820.

Sunde, T. (2020). Energy consumption and economic growth modelling in SADC countries: an application of the VAR Granger causality analysis. *Int. J. Energy Technology and Policy*, 16 (1): 41-56.

Tamazian, A., & Rao, B. B. (2010). Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies. *Energy Economics*, 32(1):137-145.

Taylor, M. (2004). Unbundling the pollution haven hypothesis. *Adv. Econ. Anal. Pol*.4(2) article 8.

The Economist (2018). A burning issue in Africa: Africa's big carbon emitters admit they have a problem. https://www.economist.com/middle-east-and-africa/2018/04/21/africas-big-carbon-emittersadmit-they-have-a-problem

Tsurumi, T., & Managi, S. (2010). Decomposition of the environmental Kuznets curve: scale, technique, and composition effects. *Environmental Economics and Policy Studies*, 11(1-4):19-36.

Twerefou, D. K., Appiah-Konadu, P., & Anaman, K. A. (2015). Impact of international trade on the quality of the natural environment: A case study of Ghana from 1970 to 2010. *Ghana Social Science Journal,* 12(1):1-21.

Udeagha, M.C & Ngepah, N .(2019b). Trade liberalization and the geography of industries in South Africa: fresh evidence from a new measure. *International Journal of Urban Sciences*: https://doi.org/10.1080/12265934.2019.1695652.

Udeagha, M.C & Ngepah, N. (2019a). Revisiting trade and environment nexus in South Africa: Fresh evidence from new measure. *Environmental Science and Pollution Research*, 26:29283–29306.

Wan, R., Nakada, M., & Takarada, Y. (2018). Trade liberalization in environmental goods. *Resource and Energy Economics*, 51:44-66.

Westerlund, J. (2007). Testing for error correction in panel data. *Oxf. Bull. Econ. Stat*. 69 (6) 709-748.

White, H. (1980). A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. *Econometrica*, 48: 817–838.

World Bank (2007). Warming up to Trade : Harnessing International Trade to Support Climate Change Objectives. World Bank, Washington, D.C. World Bank Report no. 40217.

World Development Report (1992). Development and the Environment. World Development Report; World Development Indicators. World Bank Group, Washington, DC.

Yii, K.J., Geetha, C. (2017). The nexus between technology innovation and CO_2 emissions in Malaysia: evidence from granger causality test. *Energy Procedia,* 105:3118–3124

Zerbo, E. (2015). CO_2 emissions, growth, energy consumption and foreign trade in Sub-Sahara African countries.

Zerbo, E. (2017). Income-environment relationship in Sub-Saharan African countries: Further evidence with trade openness. *Environmental Science and Pollution Research*, 24(19):16488-16502.

Ziramba, E. (2015). Determinants of CO_2 Emissions: Evidence from Southern Africa. CEEPA Discussion Paper No.59.