The causal relationship between energy and economic growth through Research and Development (R&D): The case of BRICS and lessons for South Africa

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Highlights

- Causality between RE, NRE, GDP and R&D is examined for BRICS.
- R&D is potentially a crucial factor to promote the adoption of RE.
- Bidirectional causality for India, South Africa (RE.→ NRE) and Brazil (NRE→RE)
- One way causality from NRE .→ GDP in Brazil and South Africa; from Non-RE → R&D for Brazil, Russia and China
- One way causality from GDP to R&D in Russia, India and South Africa.

Abstract

The energy industry has a significant influence over the sustainability of the economies from job creation to resource efficiency and the environment. This study's purpose is to examine the causal dynamics between energy (renewable and non-renewable) on GDP taking into account the role R&D expenditure, representing technological progress, plays in each and how South Africa differs from other emerging economies, such as BRICS. To do so, we used the panel data method proposed by Emirmahmutoglu and Kose (2011) [1] for the period 1996 to 2015. The findings confirmed a bidirectional causality from RE to Non-RE for India and SA and the opposite for Brazil; a one way causality from Non-RE to GDP in Brazil and SA; from Non-RE to R&D for Brazil, Russia and China; and from GDP to R&D in Russia, India and SA. The results for SA are a reflection of the country's energy supply crisis. The fact that RE does not have an impact on GDP and R&D does not mean that the RE is not a promising option for the future. On the contrary, it might mean that the share of RE and the total R&D were both at low levels historically to make any significant impact.

Keywords: Renewable energy; Non-renewable energy; GDP; R&D; BRICS

1 Introduction

Developing and emerging economies are currently faced with a challenge in meeting the energy needs of billions of people while simultaneously participating in a global transition to clean, low-carbon energy systems. The energy industry has a significant influence over the robustness and sustainability of the entire economy, from job creation to resource efficiency. In most developing countries such as South Africa, the energy system is mainly reliant and dominated by fossil fuel, nuclear, and gas energy sources. These types of energy sources, particularly the fossil fuels, have posed many challenges such as unsustainability, poor security of supply and increased carbon emissions. These challenges have led to a need for a system transformation and a strengthening of cleaner and sustainable energy technologies.

In South Africa and the rest of the BRIC countries (Brazil, Russia, India, and China), renewable energy development has only started in recent years. The countries are also facing the challenge of lack of funding when juxtaposed to developed OECD countries. A green economy and the use of more renewable energy sources can assist to alleviate the difficulties that these developing countries are facing. However, the countries that are knowledgeable about these calculated alternatives are cautious as they are contemplating the repercussions of establishing a green economy over the overall developmental objectives. The gap between policy aspirations and implementation is substantial because of the instability of the civil services and the shortage of proper institutions and implementation agencies.

In bridging this gap, among the most apparent solutions is the promotion of technologies through focusing on the countries' Research and Experimental Development (R&D). This will encourage new developments and technological innovation progress in renewables and other energy supply side technologies and infrastructure. Persistent and appropriately allocated R&D expenditure eventually leads to technological progress improvements in efficiency and effectiveness and will lead to leveraged cost reductions in energy prices.

Traditionally, empirical and theoretical economic research has found that R&D is an essential contributor to economic growth. Romer (1986, 1990) found that technological progress is the main driver for economic growth, where R&D expenditure is considered a catalyst to innovation. R&D is a critical element that drives technological advancement as it contributes to new knowledge, which in turn contributes to the improvement in energy production and processes. R&D expenditure also plays a major role as the main driving force behind energy system transformation through knowledge accumulation of new and more advanced technology, alternative energy systems as well as in the long term strategies in curbing and reducing the carbon footprint and informing carbon emissions policies as well as energy prices.

With all economic activities requiring some form of energy to function, energy supply and consumption have become the most integral driving forces to economic growth. Alam(2006) shows that countries that export energy products have benefited from increased foreign earnings. Developing countries benefit the most from the transfer of technology and knowledge creation from energy exploration and production. The Growth Model by Romer (1986) accentuates that technical progress results from R&D investment, capital stock and human capital. This model further emphasizes that energy is a determinant of technology.

The significance of investment in R&D particularly in the energy sector is irrefutable. Yet, due to the inherent features and prospective of the numerous energy technologies, it has become a perplexing undertaking for policy makers and administrations to decide on the optimal allocation of R&D resources in the overall R&D budget, as well as within the energy category (Inglesi-Lotz, 2017). Renewable energy sources, until recently, were considered expensive and hence, could not compete with fossil fuel technologies. Investing in R&D activities that would develop renewable energy technologies might be a driver to a change in the energy generation picture. On the other side, developing countries face a dilemma on whether investing on R&D will yield more returns than importing and adapting technologies to reduce environmental degradation and improve energy efficiency.

Appreciating the importance of the potential linkages between energy, economic growth and technological progress, this study aims at empirically examining their causal dynamics for South Africa within the BRICS framework, to compare and contrast the trends in these emerging countries. To do so, a panel analysis will be used to estimate the causality using the Granger causality methodology as proposed by Emirmahmutoglu and Kose (2011) for the period 1996 to 2015. The variable representing energy in the trivariate system is to be further disaggregated to renewable and non-renewable energy, in an effort to capture how the different types of energy might impact on the BRICS countries' economic growth, taking into consideration of the changing supply mixes of this country group. Innovation will be proxied by the R&D expenditure of the countries, representing the input to technological progress by all these countries.

1.1 Literature Review

Economic development for the BRICS countries excluding Brazil has been expedited by principles that prefer economic expansion. In the last 20 years, China, India and the Russian Federation are still amongst the biggest greenhouse gas emitters globally. BRICS countries have ensured that energy is affordable in order to encourage competition in the industry. In China, the expansion of industries has been the main driving force behind energy demand as the industries are responsible for approximately half of the country's energy consumption. The strategies have, however, been associated with the impairment of environmental sustainability, which is linked to the energy systems (World Economic Forum, 2014).

BRICS countries have been dependent on fossil fuels for their energy production and exports. "The BRICS countries together contributed about 38 percent of global carbon emissions in 2014. By far the biggest share is China's as it is more than 24 percent of the global total, far ahead of the next biggest emitter in the group – India." (Green Peace, 2015) Many predict that coal will influence the attainment of meeting the countries' growing energy demands. However, the impact on the environment has forced these countries to search for alternative and more efficient fossil fuel technologies. Fiscal and financial disincentives for fossil fuel usage can lead to the creation of an environment for the configuration of low-carbon power generation. The BRICS countries intend to expand their portion of energy from renewable and low-carbon energy sources. Although installed renewable capacity has increased, cost effectiveness with fossil fuels, dependency on subsidies and incentives are still a major problem, this implies that a lot still needs to be done in order to tackle the renewables' expense and market structures. Renewable energy, however, might not fill the base-load gap if the coal supply and share is low. (World Economic Forum, 2014)

The current South African energy-mix is dominated by cheap domestic coal usage and as a result the majority of South Africa's GHG emissions arise from energy supply and use (~80%) with the electricity sector being responsible for 45%. Coal-To-Liquids (CTL) technology for liquid fuel production in the transportation sector is another major contributor to GHG emissions (National Planning Commision (NPC), 2018). According to the NPC Energy Paper 2018, "South Africa is a relatively energy-secure country with most domestic energy needs being met by domestic coal…" Domestic primary energy production is mainly coal-based (> 85%) and has historically been the driving force behind the South African economy". Biomass/waste, nuclear and hydro sources account for (≈15%) of South African energy. Oil and liquid fuels energy imports dominate (≈85%) and ≈ 15% comes from natural gas, electricity and coal. South Africa imports almost all its oil and liquid fuel (≈ 99%) (Pao, et al., 2014). South Africa has domestic solar and wind resources and these could be utilized to drive a future sustainable economy. Supportive technologies and services should be incentivized to enable future energy economy and to support economic growth (Pao & Tsai, 2010).

The relationship between energy use and economic growth has been the subject of extensive academic research. Most researchers have studied the connection between the use of renewable and non-renewable energy and economic growth using panel data. Multivariate co-integration techniques and VECM are the most used techniques to study this subject (Hsiao-Tien Pao, 2014). It is far more insightful to investigate disaggregated energy sources as it enables the examination of the short run and the long run relationships and causality as a direct result of renewable energy or non-renewable energy and if there is a difference between the two. In addition, as stated by Dogan (2016), this variety in the energy expansion sector's research is important as management can then create other blueprints for different energy bases in order for them to get maintainable growth rates. Pao et al. (2014),state that there are dual goals of checking the connection between the separation of the use of clean and dirty energy and economic expansion, one is confirming if clean energy can be replaced with the use of non-clean energy. The other goal is the use of the proposed disaggregated analysis in order to get a global green economy.

There are varied views and findings that either support or oppose the benefits of the use of either energy source. Apergis and Payne (2011a), note a two-way short-and long-run causality connecting renewable and non-renewable energy usage and economic growth. They found a negative one direction short-run causality from renewable energy usage to non-replaceable energy usage with positive results for dual panels of 25 developed countries and 55 developing countries. This shows the significance of replaceable and non-replaceable energy sources for maintainable economic growth.

Apergis and Payne (2011b), also highlight that there exists a one directional short-run causality from economic expansion to replaceable electricity usage with bidirectional long-run causality, and a bidirectional short-and long-run causality between non-renewable electricity usage and economic expansion for a panel of 16 growing markets. This shows that as the economy expands, there will be an increase in capital, which will stimulate the expansion of the replaceable energy industry thereby making the emerging markets to rely on non-replaceable energy.

Non-renewable energy sources such as coal and gas have a positive impact on economic growth. Lei et al. (2014), state that the consumption of coal has an impact on the economic growth in Germany, Russia, and Japan. They found that an increase of the consumption of coal indicates the increase of the production activity that leads to the increase of economic growth. Xu et al. (2016), also found that the increase of coal consumption promotes economic growth in China. Solarin and Shahbaz (2015) identified that the consumption of natural gas has a positive effect on the economic growth in Malaysia. On the other hand, Destek (2016), found that the consumption of natural gas has a positive impact on the GDP growth in OECD countries. More recently, Dogan (2016) analyzes Turkey's estimates and the causality connection between economic growth, renewable and non-renewable energy consumption in a multivariate model that includes capital and labor. The findings show that renewable energy usage has an insignificant impact on economic growth while non-renewable energy consumption has a significant positive effect. There is also evidence to support conservation hypothesis and feedback hypothesis both in the short and long runs.

Apergis and Payne (2010), analyze the connection between the use of renewable energy, GDP, capital and labor for 13 Eurasian countries through the application of the panel ADF unit root test, the Pedroni panel cointegration test, the Fully Modified Ordinary Least Squares estimation (FMOLS) and the panel causality test to the panel data from 1992 to 2007. Their conclusion is that, the use of renewable energy, capital, and labor has positive effects on economic growth, and there is feedback hypothesis between renewable energy and real GDP. The long run estimation results highlight statistically notable and constructive coefficients on the use of renewable energy, greenhouse gas releases and employment whereas the ultimate use of energy has a coefficient of zero. The neutrality hypothesis is valid between the use of renewable energy and economic growth.

In line with Menegaki (2011), who finds the same when, evaluating the case of 27 European countries by applying the ARDL approach to cointegration with structural break and the VECM causality test to the data from 1997 to 2007. She finds that the long run estimation results suggest statistically significant and positive coefficients on renewable energy consumption, greenhouse gas emissions and employment whereas the final energy consumption has a statistically significant coefficient of zero. Salim et al. (2014), analyze the link between real GDP, the use of renewable energy, non-renewable energy use, capital and labor for 29 OECD countries as from 1980-2011 through the employment of a number of panel unit root tests. They conclude that all the explanatory variables have positive and numerically notable coefficients on the economy's growth. The panel Granger causality test results highlight that the feedback hypothesis is reinforced between the growth of the economy and the use of non-renewable energy while growth hypothesis is valid between the use of renewable energy and the growth of the economy in the short run and bidirectional causality is found between the use of renewable energy, non-renewable energy usage and the actual output in the long run.

Tugcu et al. (2012), acknowledge that energy source is more supreme for the growth of the economy in G7 countries. The authors utilize the ARDL approach to cointegration and the Hatemi-J causality test (Hatemi, 2012) in a production function framework for the countries from 1980 to 2009. Additionally, physical capital, labor, Research and Development (R&D), and human capital are utilized as control variables. The results highlight that, bi-directional causality between renewable energy and the growth of the economy is prevalent in all the countries. The authors' conclusion is that both the use of renewable and non-renewable energy has a notable responsibility in augmenting economic growth. More recent efforts, such as Khan et al. (2019a) and Khan et al. (2019b) also employed the ARDL modelling approach to examine the energy – environment – economic growth nexus and its interlinkages with other factors such as globalization, financial development, foreign direct investment, urbanization and innovation for the case of Pakistan. Khan et al. (2019a) proxied innovation and technological progress as the number of trademark applications, a measurement of an output innovation indicator, and conclude that innovations have a negative effects on carbon dioxide emissions.

Other studies have chosen R&D expenditure as a proxy for technological progress. It is assumed that, increased R&D expenditure towards the exploration of renewable or non-renewable energy source innovation and production process can be regarded as a means to enhance and increase economic activity. This includes, enabling the substitution and transitioning between the energy sources to ensure sustained and consistent energy generation and supply. The overall assumption is that R&D expenditure has a positive impact on economic growth. With this impact being stronger either in expenditure on renewable energy or non- renewable energy sources.

In past studies such as Apergis and Sorros (2014), it has been found that there is a strong relationship between R&D expenses and profitability for energy sector firms that sell renewable energy rather than in firms that sell fossil energy. This can be an indication of the importance of renewable energy and the money spent on R&D. They also state that “this is also due to fossil energy firms’ technological innovations being slow to play a substantial role in the profitability, given the pressure on maintaining a clean environment.” (Apergis & Sorros, 2014) In agreement with this view, this study also expects to find a strong impact on economic growth through R&D expenditure towards renewable energy rather than non-renewable energy sources. This is due to the global drive for ardent policies that promote the transition to cleaner and sustainable energy sources through technology innovation.

As can been seen in the literature review above, extensive work on the nexus of energy usage and the growth of the economy has been done. However, very few studies have been conducted specifically on the BRICS countries as a bloc since the inclusion of South Africa in 2010. Many have argued the similarities of the BRICS if any especially the inclusion of South Africa with its much smaller population and economic growth standing when compared to the other countries in the group. Even though South Africa is also Africa's largest economy, but as number 31 in global GDP it is far behind its counterparts (Graceffo, 2011). According to Amorim (2010) and Camioto (2016), the BRICS, in addition to rapid economic growth, hold significant land mass, natural resources and considerable amounts and diversity of energy and technological advances. The BRICS countries are an alliance covering four continents and all members are emerging economies, with actions that go beyond pure diplomacy. The five countries that form the bloc are generally grouped by their similarities. However, individually, they have different economic, social, political and cultural characteristics, as well as differences in history, religion, geographies and climates. Energy is one of the essential components for social and economic development of a nation and must be closely linked to sustainable, efficient and safe use of energy from ecological and more economically viable approaches for future short and long-term partnerships (Tugcu, et al., 2012).

With their fast paced economic growth and industrialization, the BRICS are also fast becoming the world's biggest emitters due to their reliance and utilization of mostly fossil fuels in their energy mixes. According to the 2015 UNEP Emission Gap Report, it is highlighted that China; Russia; and India are constituent of the six largest emitters of Carbon dioxide (CO2) in the world with the largest being China (UNEP, 2015). This imposes a threat for these countries in attaining sustainable development. With the global and national increased pressure to decarbonize and also the need for the transition of energy sources has led to the increased interest in this topic and there have been various studies that have been conducted to find solutions and inform policies.

Pao and Tsai (2010), investigate the dynamic causal relationships between pollutant emissions, energy consumption and output for a panel of BRIC countries over the period 1971–2005, except for Russia (1990–2005). They find that in the long-run equilibrium energy consumption has a positive and statistically significant impact on emissions, while real output displays the inverted U-shape pattern associated with the Environmental Kuznets Curve (EKC) hypothesis with the threshold income of 5.393 (in logarithms). They suggest that in the short term, changes in emissions are driven mostly by the error correction term and short-term energy consumption shocks. In addition, the panel causality results indicate that there are energy consumption emissions, bidirectional strong causality and energy consumption output, bidirectional long-run causality, along with unidirectional both strong and short-run causalities from emissions and energy consumption, respectively, to output. Increasing energy supply investment and energy efficiency, and stepping up energy conservation policies to reduce unnecessary wastage of energy can be done for energy-dependent BRIC countries in order to reduce emissions.

Subsequent to this Pao and Tsai (2011), examined the extent to which the impact of the growth of the economy and financial growth on environmental degradation for BRIC countries utilizing a panel cointegration technique from 1980 and 2007, except for Russia where the period was from 1992 to 2007. Their results highlight that there is bidirectional causality between emissions and FDI as well as unidirectional causality from output to FDI. Therefore, in attracting FDI, developing countries should check the foreign investment qualifications or encourage environmental protection. There exists strong output-releases and output-energy usage bidirectional causality, while there is unidirectional strong causality between energy usages to emissions. In conclusion, managing both energy demand and FDI as well as increasing investment in the energy supply and energy efficiency to reduce CO2 emissions can be adopted by energy-dependent BRIC countries.

When Cowan et al. (2014), re-examined the causal link between the use of electricity, the growth of the economy and CO2 releases in the BRICS countries from 1990 to 2010, using a panel causality analysis. They found that with the electricity–GDP nexus, their empirical results are in line with Russia's feedback hypothesis as well as South Africa's conservation hypothesis. However, they found that Brazil, India and China have a neutrality hypothesis. With regard to the GDP– CO2 emissions nexus, the authors highlight that there exists a feedback hypothesis for Russia, a one-way Granger causality running from GDP to CO2 emissions in South Africa and a reverse relationship from CO2 emissions to GDP in Brazil. There is no evidence of Granger causality between GDP and CO2 releases in India and China. Additionally, electricity usage is found to Granger cause CO2 emissions in India, while there is no Granger causality between electricity usage and CO2 releases in Brazil, Russia, China and South Africa.

Zhang et al. (2011), investigate the renewable energy policy evolution of the BRICs countries based on the Bai and Perron's structure breaks test. Their results highlight that there are no time series breaks for renewable energy production in Russia, while the series of renewable production and usage are characterized as segmented trend stationary processes around one or two structural breaks in Brazil, India and China. The results indicate that Brazil and China's renewable policies have long-term positive effects on renewable energy production and usage. In addition, they found that the Russian renewable policies are not working, as they are decreasing renewable energy usage growth in the long-run. This shows that policy implications in China should command the promotion of renewable energy, develop biomass energy on the base of comparative advantage and improve the renewable energy industry chain integration.

Similarly Sebri and Ben-Salha (2014), analyzed the causal relationship between economic growth and renewable energy consumption in the BRICS countries over the period 1971–2010 within a multivariate framework. They examined the long-run and causal relationships between economic growth, renewable energy consumption, trade openness and carbon dioxide emissions. They found that, there exists a long-run equilibrium relationship among the competing variables. Based on the VECM results it was noted that there was a bi-directional Granger causality between the growth of the economy and renewable energy usage. Recently in studies pertaining to the investigation of the nexus between energy and the growth of the economy, there has been interest in the development of new and renewable energy technology. Funding is being invested in creating new and renewable energy technologies in order to decrease the dependence on fossil fuels. (Lee & Lee, 2013).

Encouragingly, according to the 2014/15 National Survey of Research and Experimental Development (R&D survey), South African investment in R&D has shown an improved positive outlook. In addition, certain industries such as the electricity, gas, water supply, transport, storage and communication that have for the past three surveys reported declines are now showing an improved increase in R&D expenditure (Mail and Guardian, 2017). South Africa follows global trends for recovering R&D spending, R&D trends around the globe indicate that there is renewed interest in investing in R&D after the 2008-2010 economic crisis. Within BRICS, China has shown the highest growth in such investments. To insure enhanced global competitiveness, it is essential for countries to promote and support high level expenditure on R&D. Investment towards R&D is an essential contribution towards achieving key developmental objectives of the country. R&D undertakings are an eminent mechanism for knowledge production and the creation of new ideas. As R&D plays a critical role in innovation and economic development.

These economic outputs, direct and indirect, contribute to and can be accounted for as part of the economic output of a country through the national accounting system, which uses GDP as an indicator of economic size. The significance of R&D expenditure and the prospects for these investments to enhance development projections have concurred with or directed the growth in the number and range of countries that are dedicated to science and technology policy and technology-led growth strategies. Formerly, high levels of investment towards R&D were mainly associated with developed countries as has been found in the study by Bointner

(2014) where he states that, "nearly all energy R&D is performed in the world's richest nations, he is also supported by Breyer et al (2010) who find that 85-90% of global energy R&D is performed in OECD countries" (Bointner, 2014).Conversely, it has been seen in the last two decades developing countries such as Brazil, India and China have also increased their national investment in R&D significantly (Mail and Guardian, 2017).

Inglesi-Lotz (2017) estimated the social rate of return of R&D on a number of energy applications and technologies for the G7 countries. The results highlight that R&D investment on energy efficiency technologies as well as nuclear get high social benefits and the opposite is true for fossil fuels. Johnstone et al. (2010) investigates the effect of environmental policies on technological revolution in renewable energy. The findings indicate that tradable energy certificates can influence transformation in technologies that are in competition with fossil fuels. Similarly, Garrone and Grilli (2010), examine the causality connections that relate R&D to carbon intensity, carbon factor and energy intensity in OECD economies from 1980 to 2004 through the use of a dynamic panel. The findings show that there is a positive link between public expenditures in energy R&D and energy efficiency.

Pfeiffer and Mulder (2013), inspect the diffusion of Non-Hydro Renewable Energy (NHRE) technologies for electricity generation across 108 developing countries from 1980 to 2010. They use two-stage estimation methods to identify the determinants of whether or not to adopt NHRE and on the amount of electricity to generate from renewable energy sources. The results indicate that various energy mixes increase the chances of NHRE adoption. (Wong, et al., 2013), investigate the causal connection between fossil fuel R&D, renewable energy R&D and real output for 20 OECD countries between 1980 and 2010. Fully-Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) were used for this investigation. The results indicate that there is some R&D energy that is imputed to the growth of the economy thereby indicating that output is also reliant on energy R&D.

For the case of China Li and Lin (2016), investigate the effects of R&D investment activities, economic growth, and energy price on energy technology patents in 30 provinces of China over the period 1999 to 2013. Their results highlight that R&D investment activities and economic growth have a good impact on energy technology patents. However, the panel error correction models show that the cointegration relationship promotes the growth of the economy but it reduces R&D investment and energy price in the short term. Similarly Guo et al. (2016) examined the elements that may prompt the transition of a coal resource-based economy by categorizing them into four types; Innovation policy, innovation input, innovation ability, and innovation organization. They collected data from 314 Chinese energy firms. The results indicate that the four proposed factors are crucial in transforming the coal resource-based economy.

Noaillya and Shestalova (2016), investigate the relevance of knowledge flows within the same specific technological field (intra-technology spill overs), to other technologies in the field of power generation (inter-technology spill overs), and to technologies that are not connected to power-generation (external-technology spill overs). Using citation data of patents in renewable technologies filed at 18 European patent offices from 1978 to 2006. The results indicate that there are notable differences in numerous technologies. Nicolli and Vona (2016), investigate the impact of market regulation and renewable energy policies on change activity in different renewable energy technologies. Their results show that reducing entry barriers is a more notable driver of renewable energy innovation. However, its effect is different across technologies.

In contribution, this study will close the gap pertaining to the investigation fixated explicitly on R&D for BRICS countries. Secondly, this study identifies whether a trivariate causality exists between RE; NRE; and economic growth taking into consideration R&D expenditure for the developing BRICS countries. The outcome of this study will enable and direct policy intervention and also inform policy decision in the investment towards R&D expenditure for RE and NRE which will be beneficial to promoting economic growth.

2 Methodology and Data

2.1. Data

The study covers the period from 1996 to 2015 using a panel of five developing countries. The main reason for selecting the BRICS countries is that, except of their similar socioeconomic challenges, they have also all made commitments to transition to low carbon energy supply mixes in the future and are also faced with similar socioeconomic challenges. As Sahu (2016) explains the BRICS is the first attempt to cluster together countries based on their future potential and not necessarily their existing wealth or cultural identity. Russia and Brazil are mainly energy exporters, while the other three share challenges related to energy security and demand management. The BRICS countries also have accounted for 38% of the global carbon emissions in 2014 – with significantly and rapidly growing populations (almost half the global population) and hence consumers of energy. Ndlovu and Inglesi-Lotz (2019) also find that BRICS have remained historically dependent on fossil fuels for energy generation for domestic purposes and exports.

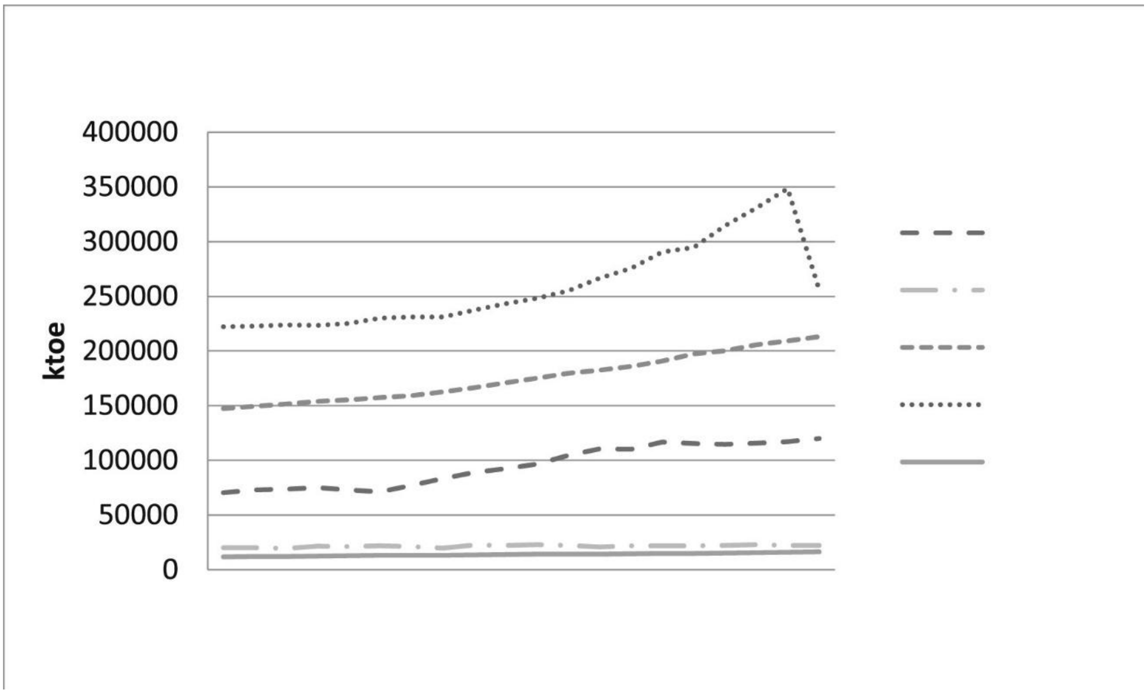
The data used for the empirical analysis exercise for this study consist of economic growth measured by Gross Domestic Product (GDP) in constant US $; Total Primary Energy Supply (TPES) of geothermal, solar, biofuels, and waste (kiloton of oil equivalent) are used for renewable energy (RE); Total Primary Energy Supply of coal, crude oil, oil products, natural gas, and nuclear (kiloton of oil equivalent) are used for non-renewable energy (NRE); GERD is research and development expenditure. Annual time-series data for GDP, and research and development expenditure are collected from the World Bank's World Development Indicators and the data on renewable energy supply, non-renewable energy supply, are collected from the IEA database from the period 1996-2015, due to data availability. Table 1 shows the descriptive statistics of the variables contained within the dataset.

Table 1. Variables descriptive statistics.

Variables	Obs	Mean	SD	Min	Max
lnGDP	100	27.87367	0.88003	26.21505	29.818
lnRE	100	11.09457	1.162229	9.371268	12.7613
lnNRE	100	12.78399	1.007514	11.47311	14.81568
lnGERD	100	18.28279	1.645443	15.12156	21.0718

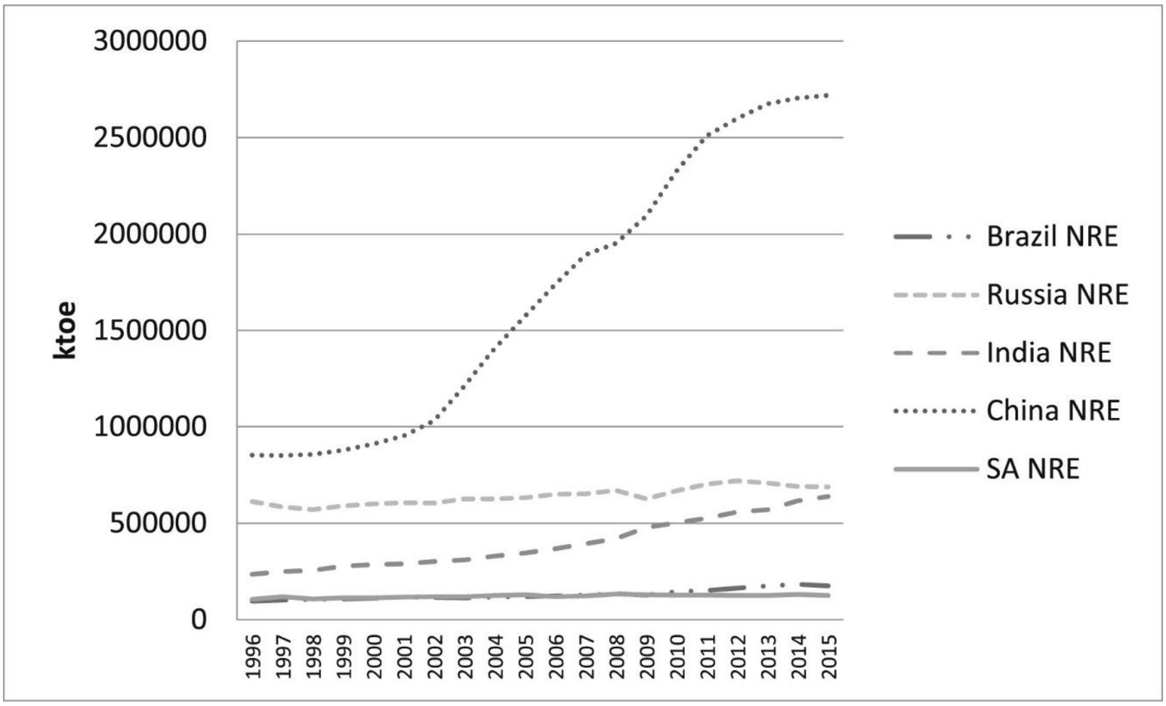
Figures 1-4 illustrate how the renewable and non-renewable energy share of the total primary energy supply, as well as the GDP and R&D expenditure respectively for the panel of the 5 BRICS countries have performed over the examined period 1996-2015. There appears to be an upward trend for majority of the countries with an exception of Brazil and South Africa with flat trends over the years. China seems to be the dominant country in all four areas of study. Showing a heavy reliance on non-renewable energy supply, high GDP, as well as high R&D expenditure. South Africa on the other hand, appears to be the least established of the BRICS panel with the lowest contribution to the TPES (renewable and non-renewable), GDP, and R&D expenditure.

Fig. 1. Total Primary Energy Supply (TPES) of geothermal, solar, biofuels, and waste (kiloton of oil equivalent) (RE in paper).



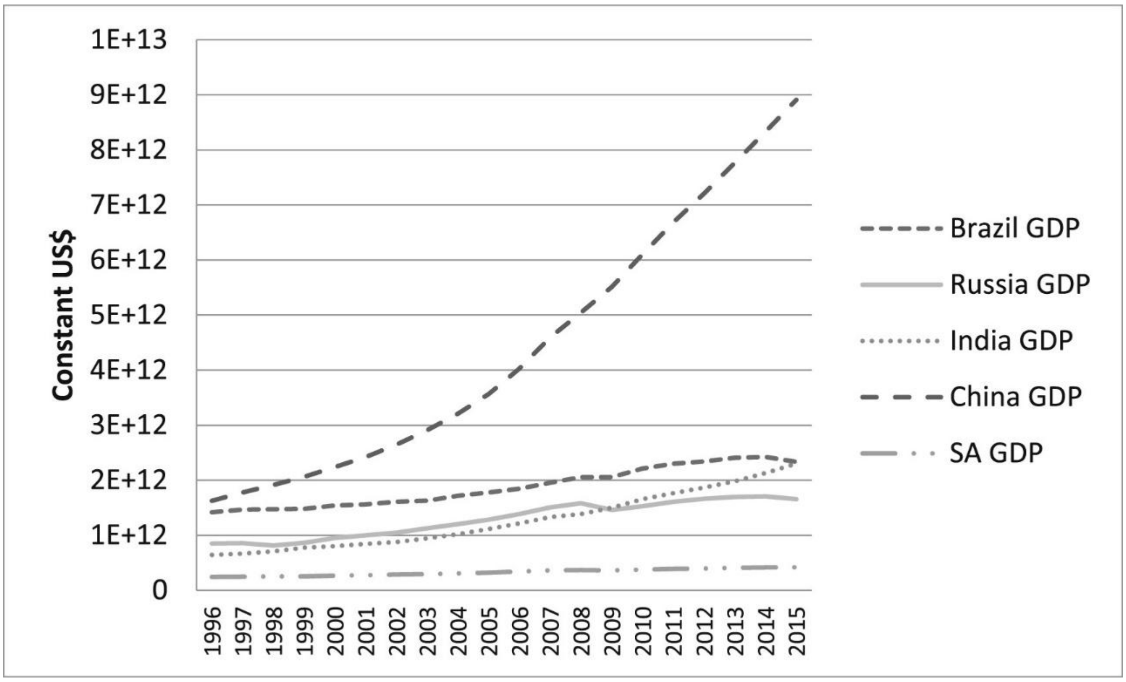
Source: Authors calculation from IEA.

Fig. 2. Total Primary Energy Supply of coal, crude oil, oil products, natural gas, and nuclear (kiloton of oil equivalent) (NRE).



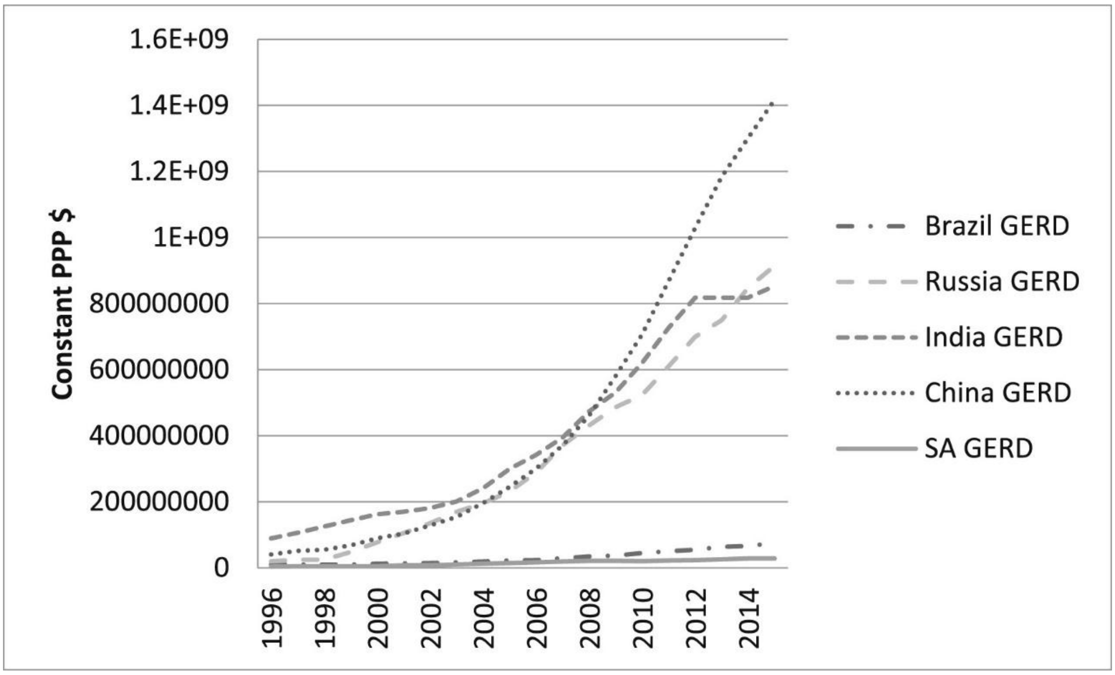
Source: Authors calculation from IEA.

Fig. 3. GDP 1996-2015.



Source: Authors calculation from World Bank.

Fig.4. Gross Expenditure in Research and Development (R&D).



Source: Authors calculation from World Bank.

2.2 Empirical Methodology

The theoretical framework that will be followed for this study is adopted from the combined experience of others, primarily by Emirmahmutoglu and Kose (2011). In this study, the researchers postulate a bivariate or pairwise Granger-causality model to identify the causal relationship between each of the variables. Preceding the panel Granger causality analysis, a prerequisite of the Granger causality test is to conduct stationarity and cointegration tests. Should the variables be found to be stationary once differenced, or I (1) and not cointegrated, then the traditional pairwise Granger causality tests are valid. Should the variables be a mix of I (1) and I (0), then the methodology set out by Emirmahmutoglu and Kose (2011) for mixed panels will be used.

To test for the existence of unit roots and determining the order of integration of a panel requires several tests. The formal tests consist of hypothesis testing where the null hypothesis postulates that all series in the panel contain unit roots. There are two approaches which are available for determining whether unit roots exist within the different series in the panel. The first option tests each cross-section separately and makes inference about the presence of unit roots in each individual series. The second option pools all the cross sections together and determines if a common unit root is present in all the cross-sections.

In order to determine whether the GDP, RE, NRE, and RD variables are stationary, three unit root tests will be carried out namely, the (Levin, et al., 2002)(LLC); Im, Pesaran and Shin (2003)(IPS) and the Phillips-Perron (1988)(PP) tests.

Similar, to the unit root tests discussed above, a hypothesis test is used in this method to determine cointegration of the panel. Once the stationarity of the variables, InGDP, InRE, InNRE, and InRD is determined, the following step is to test for cointegration between the variables. Cointegration implies the existence of a long-run relationship among the variables within the group of countries. To test for cointegration, the method by Johansen (1988) will be used, which estimates two combined likelihood ratios that capture the individual tests.

The two likelihood ratios are based on the two tests as suggested by Johansen (1988). The first test statistic is the trace statistic and the second is the maximum or maximum eigenvalue, statistic. Even though these two statistics utilize an almost exact methodology to derive their respective alternative hypotheses they are slightly different. The trace statistics are used to test the null hypothesis of r cointegrating relationships against the alternative hypothesis of n cointegrating relationships. On the contrarily, the maximum eigenvalue statistic is used to test the null hypothesis of r cointegrating relationships versus the alternative hypothesis of $r + 1$ cointegrating relationships.

The Kao (1999) test of cointegration ensues a similar process to that of the Pedroni test for cointegration. However, the Kao's test differentiates between cross sections by specifying that the intercepts are heterogeneous while the coefficients are homogeneous as can be seen in equation 2 below.

$$y_{it} = \alpha_i + \delta_i t + \sum_{m=1}^{M} \beta_{mi} x_{mit} + e_{it} \quad (2)$$

Where:

$t = 1, \dots, T$ and T is the number of time periods

$i = 1, \dots, N$ and N is the number of cross sections

$m = 1, \dots, M$ and M is the number of regressors.

Applying the results from the panel multivariate regression in equation 2 the 7 tests referred to in Pedroni (1999) can be calculated. These 7 Pedroni tests are divided into 4 tests which relate to pooling along the within dimension and 3 tests relate to pooling along the between dimension. The within dimension statistics test the null hypothesis of $H_0: \gamma_i = 1\ \forall i$ versus the alternative hypothesis of $H_A: \gamma_i = \gamma < 1\ \forall i$ while the between dimension statistics test the null hypothesis $H_0: \gamma_i = 1\ \forall i$ versus the alternative hypothesis of $H_A: \gamma_i < 1$. Therefore, the within dimension statistics forces homogeneity across cross sections while the between dimension statistics allow for heterogeneity across the cross sections.

Proceeding with the Emirmahmutoglu and Kose (2011) technique to test for pairwise Granger non-causality, the next step involves a Granger causality test procedure combined with the LA-VAR approach of Toda and Yamamoto (1995) for heterogeneous mixed panels. The LA-VAR approach seems to have a good empirical size for large T in mixed panels under the cross-section independence.The Fisher test statistic proposed by Fisher (1932) to test the Granger non-causality hypothesis in heterogeneous panels is used. The Fisher test statistic (λ) is defined as follows:

$$\lambda = -2 \sum_{i=1}^{N} ln(p_i) \quad (3)$$

Where i= *1,..., N.* in this case p_i is the *p*-value corresponding to the Wald statistic of the *i*-th individual cross-section. This test statistic has a chi-square distribution with 2N degrees of freedom. However, the limit distribution of the Fisher test statistic is no longer valid in the presence of cross correlations among the cross-sectional units. In order to deal with such inferential difficulty within panels with cross correlations, the technique utilizes the bootstrap methodology to test the Granger causality test for cross-sectional dependent panels. This method recommends running the following linear panel regression for each of the cross sections:

$$y_{i,t} = \alpha_i + \sum_{j=1}^{k_i+d\ max_i} \theta_i^j x_{i,t-j} + \sum_{j=1}^{k_i+d\ max_i} \beta_i^j y_{i,t-j} + \varepsilon_{i,t} \qquad (4)$$

Equation 4 is estimated without imposing any parameter restrictions on it and then the individual Wald statistics are calculated to test non-causality null hypothesis separately for each individual cross section. Using these individual Wald statistics has an asymptotic chi-square distribution with k_i degrees of freedom; we compute individual p-values. The optimal lag orders are identified for each cross section. Thereafter, the Fisher test statistic is given by equation 3.The null and alternative hypotheses can be defined as follows:

$$H_0: \beta_i = 0\ for\ i = 1, \ldots, N$$

$$H_A: \beta_i = 0\ for\ i = 1, \ldots, N_1, \beta_i \neq 0\ for\ i = N_1 + 1, \ldots, N$$

Rejection of the null with $N_1 = 0$ implies that all x Granger causes y for all i whereas the rejection of the null with $N_1 > 0$ implies that there are variations of the regression model and causality across individuals. This method is used to control for mixed panels involving I (0), I (1), cointegrated and non-cointegrated in the series of variables.

2.3 Empirical Results

Informed by the Schwarz information criterion, the unit roots resulting from the LLC (2002), Breitung (2000), IPS (2003), ADF (1984), and PP (1988) tests have confirmed that LnGDP, LnRE, LnNRE and LnRD are I(1) in all panel groups (see Table 2).

Table 2. Panel unit root tests.

Variable	LLC	Breitung	IPS	Fisher ADF	Fisher PP	Inference
LnGDP	1.150	1.343	1.092	4.237	2.891	Unit root
LnRE	−0.244	−0.672	−0.381	9.566	10.598	Unit root
LnNRE	0.381	0.376	−0.068	10.368	17.938[a]	Unit root
LnGERD	0.264	1.883	1.047	9.469	6.145	Unit root
ΔLnGDP	−3.294[c]	−0.307	−0.793	15.222	14.726	No unit root
ΔLnRE	0.186	1.967	−0.159	12.482	36.155[c]	No unit root
ΔLnNRE	−2.296[b]	−0.821	−2.375[c]	23.185[b]	52.327[c]	No unit root
ΔLnGERD	−4.339[c]	−1.435[a]	−2.471[c]	23.769[c]	30.839[c]	No unit root

[a]Indicates 10% level of significance.
[b]Indicates 5% level of significance.
[c]ndicates 1% level of significance.

Source: Authors calculation.

Cointegration testing was conducted using the Johansen test of cointegration to determine whether one or more cointegrating relationships exist amongst the four variables. Table 3 presents the results of the test that confirms the existence of a long-run relationship among the variables tested.

Table 3. Overall Johansen test of cointegration.

Hypothesized number of cointegrating equations	Trace Critical value	Max-eigen critical value
None	58.21[a]	52.66[a]
At most 1	17.12	16.14
At most 2	8.459	8.574
At most 3	7.514	7.514

[a]Indicates 1% level of significance.

Source: Authors calculation from IEA.

Table 4. Cointegration tests with RE.

Panel	*Johansen test for cointegration*			*Kao*
	Hypothesized number of cointegrating equations	Fisher Trace Test statistic	Fisher Max-Eigenvalue trace statistic	
Brazil	None At most 1 At most 2	22.4434 7.7246 0.5516	14.7188 7.1730 0.5516	0.3541
Russia	None At most 1 At most 2	29.6871 15.6501[b] 6.6714[c]	14.0370 8.9787 6.6714[c]	
India	None At most 1 At most 2	29.9351[b] 10.2307 0.3985	19.7044[a] 9.8322 0.3985	
China	None At most 1 At most 2	39.0701[c] 10.0759 0.0105	28.9942[c] 10.0654 0.0105	
SA	None At most 1 At most 2	22.9052 8.4979 0.2646	14.4073 8.2332 0.2646	

[a]Indicates 10% level of significance.
[b]Indicates 5% level of significance.
[c]Indicates 1% level of significance.

Source: Authors calculation. Note:

Table 4 presents separate cointegration tests run including renewable energy (lnRE) and non-renewable energy (lnNRE) respectively to determine the existence of a long-run relationship (cointegration) of each with lnGDP and lnRD. The Johansen cointegration test confirmed cointegration for both energy types for the entire BRICS countries panel. Using the Johansen test for robustness, it is concluded that there exists at most two cointegrating vectors between lnGDP, lnRE, lnNRE and lnRD for all panels.

Consequently, the results of the Johansen and Kao cointegration tests are inconsistent for both the RE and NRE, where cointegration is found for both when testing with the Johansen test but no cointegration is found for both when testing with the Kao test. A possible reason for this is that the results treat all cross sections (countries) homogenously. This further stipulates that the cross sections in the panels are heterogeneous and mixed. This indicates that the countries in the panel differ in their characteristics. These results also validate the decision of choosing to utilize the Granger causality methodology as used by Emirmahmutoglu and Kose (2011).

Table 5 displays the results of the bivariate pairwise Granger causality test between lnGDP, lnRE, lnNRE, and lnGERD as defined above for the entire BRICS countries panel. The test assesses the existence of a causal relationship running from one variable to the other in this model in a pairwise manner for the panel of countries; the LA-VAR Granger causality simulation determines the optimum lag for each cross-sectional unit. The results show that there is causality only from lnRE to lnRD and from lnGDP to lnRD; while all the other hypotheses could not be rejected for the entire BRICS panel.

Table 5: Fisher test statistics for panel non-causality test (levels) –BRICS

Hypothesis	Fisher Statistic	Conclusion
lnRE ≠ →lnNRE	*15.528*	No Causality
lnNRE ≠ → lnRE	14.667	
lnRE ≠ → lnGDP	10.813	No Causality
lnGDP ≠ → lnRE	11.886	
lnRE ≠ → lnRD	10.090	No Causality
lnRD ≠ → lnRE	8.130	
lnNRE ≠ → lnGDP	20.021	No Causality
lnGDP ≠ → lnNRE	3.214	
lnNRE ≠ → lnRD	25.890 ***	One way Causality from Non-RE to R&D
lnRD ≠ → lnNRE	9.404	
lnGDP ≠ → lnRD	26.403 **	One way Causality from GDP to R&D
lnRD ≠ → lnGDP	10.948	

Granger causality carried out using a maximum of 2 lags. * (**) (***) denote statistical significance at the 10% (5%) (1%) level of significance. Lag orders k_i are selected by minimizing the Schwarz Bayesian criteria.

To account for potential limitations of the test results due to the fact that the panel Fisher test statistics are created for large numbers of cross sections N and the possibility that some countries, due to their size, drive the group's results, Table 6 reports the individual Wald test statistics for the LA-VAR Granger causality approach.

Table 6: Individual cross-section p-values

Hypothesis	Brazil P value	Wald stat	Russia P value	Wald stat	India P value	Wald stat	China P value	Wald stat	SA P value	Wald stat	Conclusion
lnRE ≠ → lnNRE	0.409	1.786	0.560	0.339	0.096*	2.774	0.263	2.670	0.073*	3.204	Two way causality from RE to Non-RE in India and SA and Non-RE to RE in Brazil.
lnNR ≠ → lnRE	0.048**	6.079	0.148	2.089	0.329	0.952	0.283	2.522	0.986	0.000	
lnRE ≠ → lnGDP	0.132	2.266	0.151	2.063	0.504	0.447	0.804	0.061	0.555	0.349	No causality
lnGDP ≠ → lnRE	0.722	0.127	0.167	1.910	0.131	2.278	0.340	0.910	0.488	0.481	
lnRE ≠ → lnRD	0.175	1.843	0.453	0.562	0.133	4.038	0.699	0.149	0.876	0.024	No causality
lnRD ≠ → lnRE	0.646	0.211	0.915	0.011	0.375	1.960	0.374	0.789	0.207	1.595	
lnNRE≠→ lnGDP	0.007***	7.303	0.352	0.865	0.931	0.008	0.537	1.245	0.037**	6.590	One way causality from Non-RE to GDP in Brazil and SA.
lnGDP≠→ lnNRE	0.629	0.233	0.907	0.014	0.984	0.000	0.363	2.025	0.983	0.034	
lnNRE≠→ lnRD	0.072*	3.245	0.096*	2.775	0.376	0.785	0.001***	13.390	0.749	0.103	One way causality from Non-RE to R&D in Brazil; Russia and China.
lnRD →lnNRE	0.872	0.026	0.881	0.022	0.306	1.048	0.128	4.106	0.301	1.070	
lnGDP ≠ → lnRD	0.865	0.029	0.044**	4.045	0.010**	9.183	0.372	1.976	0.013**	6.201	One way causality from GDP to R&D in Russia; India; and SA.
lnRD ≠ → lnGDP	0.344	0.894	0.863	0.030	0.925	0.156	0.107	4.463	0.142	2.156	

Source: Authors calculation. Note: * indicates 10% level of significance ** indicates 5% level of significance *** indicates 1% level of significance

Analysing the individual cross-section results above in Table 6, there is bidirectional causality found for India, South Africa and Brazil, with the direction running from RE to Non-RE for India and South Africa and the opposite for Brazil with the direction running from Non-RE to RE. The null hypothesis of no granger causality was rejected at a 10% and 5% level of significance respectively; implying that RE and Non-RE have a significant impact on each other.

This makes sense intuitively in the case of South Africa, where RE would have an impact on Non-RE if there is an increase in energy supply through RE it would imply a decrease in the coal (Non-RE) energy supply production, especially in the case of Eskom (the national utility supplier) sales and revenue where they will be requiring less coal fired electricity. The results also showed that the null hypothesis of RE does not Granger cause GDP and R&D was not rejected for neither of the countries in the panel. Implying that there is no causality running from RE to GDP nor R&D. This makes intuitive sense due to the fact that the proportion of RE compared to other forms of energy such as Non-RE has been historically low and has less contribution towards the GDP and R&D of those countries.

Furthermore, the results showed that in Brazil and South Africa the null hypothesis Non-RE does not Granger cause GDP was rejected implying that there is a unidirectional causality running from Non-RE to GDP in Brazil and South Africa. Particularly in South Africa that experienced a crisis in 2008 during the coal shortages, which resulted in load shedding as well as a negative impact on the South African GDP, as was expected. The results also showed that for most of the BRICS countries apart from India and South Africa the null hypothesis of Non-RE does not Granger cause R&D was rejected implying a unidirectional causality running from Non-RE to R&D in Brazil, Russia and China. This could be an indication that R&D funds are mostly directed at non-renewable R&D in those countries due to their dependence on fossil fuels.

Lastly, it was found that for most of the BRICS countries apart from Brazil and China, the null hypothesis GDP does not granger cause R&D was rejected indicating that GDP drives R&D expenditure in Russia, India, and South Africa all at a 5% level of significance. This implies a unidirectional causality from GDP to R&D in Russia, India, and South Africa, in other words the more these economies grow, the higher their investment to technological developments.

3 Discussion and conclusion

The main purpose of this study is to examine the existence and direction of the causal dynamics between energy (renewable and non-renewable) on GDP taking into account the role R&D expenditure plays in each and how South Africa differs from other emerging economies. Using the Johansen (1988) and Kao (1999) test of cointegration approach the researchers established whether there exists a long-run relationship between the variables after determining their stationarity at first difference. To estimate the causality, the Granger causality methodology as used by Emirmahmutoglu and Kose (2011) within a panel data framework comprising of BRICS countries was used for the period 1996 to 2015.

The selection of BRICS as a cluster of countries with its heterogeneity has its own challenges that are portrayed here as points to examine further and include in future country specific studies. The disaggregation of energy supply into renewable and non-renewable energy is the first step into decomposing the energy impact on economic growth and depicting their differences, since the BRICS counties' energy supply mix is still highly dependent on coal and other fossil fuels (Ndlovu and Inglesi-Lotz, 2019). However, most of the BRICS are oil importers and hence, further investigation on the dynamics of oil will give another perspective too. Furthermore, trade as well as energy market structures and regulation are also important factor that can alter the energy-growth nexus that are not considered in this study that focuses more on the dynamics the technological progress bring into the nexus discussion.

Specifically for South Africa, that was the initial focus country, the causality runs from NRE (←→RE) → GDP → R&D. From that it is obvious that although the use of fossil fuels, as the dominant fuel in the country's energy supply mix, is detrimental to the environment; it promotes economic growth that in its turn affects R&D improving the country's technological progress. The results found in this study are a reflection of the energy supply crisis that South Africa experienced in 2008 during the coal shortages, which resulted in load shedding as well as a negative impact on the South African GDP, as expected. The fact that RE does not have an impact on GDP and R&D in the country does not mean that the RE is not a promising option for the future. On the contrary, it might mean that the share of RE has stagnated at low levels in the studied time period so much so that it did not have any effect. Another possible reason for total R&D not having an impact on RE nor Non-RE might be due to its share in the energy R&D expenditure being too small and hence, R&D is not directed to any specific energy technologies.

Due to the lack of an updated energy policy framework in alignment with RE, Non-RE, GDP, and R&D expenditure, the following recommendations are made specifically for South Africa based on the study results in comparison to its BRICS counterparts:

- As a primary policy change, a benchmark needs to be set on R&D expenditure that is commensurate to the compared bloc of countries. The reason being as indicated by the results of the study, that the progress towards a growing economy requires investment.

- Implementation of a well-coordinated R&D programme to insure that the investment is channelled into RE and future technologies. The projects in this programme would have to demonstrate innovation and future value add.
- Given that the economy of a country is measured by its GDP, the influence of RE and Non-RE technologies need to be addressed, as seen from the results of the study that their mutual interrelationships cannot be avoided.

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Table A1. Fisher test statistics for panel non-causality test (levels) –BRICS.

Hypothesis	Fisher Statistic	Conclusion
ln%RE ≠ → ln%Non-RE	*25.234*	No Causality
ln%Non-RE≠ →ln %RE	*23.854*	
ln%RE ≠ → lnGDPPC	*14.232*	One way Causality from GDPPC to %RE
lnGDPPC ≠ → ln%RE	*28.852* *	
ln%RE ≠ → lnTRE	*8.802*	No Causality
lnTRE ≠ → ln%RE	*14.740*	
ln%Non-RE≠ → lnGDPPC	*22.312* **	Two way Causality from %Non-RE to GDPPC and from GDPPC to %Non-RE
lnGDPPC ≠ → ln%Non-RE	*21.389* **	
ln%Non-RE≠ → lnTRE	*11.144*	No Causality
lnTRE ≠ → ln%Non-RE	*16.196*	
lnGDPPC ≠ → lnTRE	*17.175*	No Causality
lnTRE ≠ → lnGDPPC	*10.424*	

Granger causality carried out using a maximum of 2 lags. * (**) (***) denote statistical significance at the 10% (5%) (1%) level of significance. Lag orders k_i are selected by minimizing the Schwarz Bayesian criteria.

Table A2. Individual cross-section p-values.

Hypothesis	Brazil P value	Wald stat	Russia P value	Wald stat	India P value	Wald stat	China P value	Wald stat	SA P value	Wald stat	Conclusion
Ln%RE ≠ → In%NRE	0.078*	5.108	0.800	0.064	0.355	2.073	0.001***	14.376	0.199	3.231	Two way causality from %RE to %Non-%RE in China and from %RE to %NRE in Brazil
Ln%NRE ≠ → In%RE	0.119	4.255	0.866	0.028	0.398	1.841	0.000***	17.241	0.891	0.230	
Ln%RE ≠→ InGDPPC	0.116	2.474	0.548	0.360	0.045**	6.209	0.756	0.096	0.377	1.950	Two way causality from %RE to GDPPC in India and GDPPC to %RE in Brazil and China.
InGDPPC≠ → In%RE	0.076*	3.144	0.135	2.236	0.769	0.527	0.000***	12.979	0.218	3.044	
Ln%RE ≠ → InTRE	0.182	3.406	0.763	0.091	0.577	0.311	0.286	1.137	0.534	1.255	One way causality from TRE to %RE in Brazil
LnTRE ≠ → In%RE	0.023**	7.531	0.852	0.035	0.384	0.757	0.135	2.232	0.615	0.973	
Ln%NRE≠→ InGDPPC	0.264	1.246	0.602	0.272	0.503	0.449	0.547	0.363	0.000***	16.055	Two way causality from %Non-RE to GDPPC in SA and GDPPC to %Non-RE in Brazil and China.
LnGDPPC≠→ In%NRE	0.085*	2.975	0.225	1.471	0.380	0.771	0.003***	8.591	0.928	0.149	
Ln%NRE ≠ → InTRE	0.390	0.739	0.760	0.094	0.668	0.184	0.354	2.076	0.054**	5.828	Two way causality from %Non-RE to TRE in SA and TRE to %Non-RE in Brazil and China.
LnTRE ≠ → In%NRE	0.078*	3.101	0.837	0.043	0.788	0.072	0.006***	10.160	0.948	0.108	
InGDPPC ≠ → InTRE	0.527	0.400	0.001***	14.890	0.892	0.019	0.712	0.679	0.953	0.096	Two way causality from GDPPC to TRE in Russia and TRE to GDPPC in SA.
LnTRE ≠ → InGDPPC	0.944	0.005	0.114	4.352	0.789	0.071	0.807	0.428	0.080*	5.056	

Source: Authors calculation. Note: * indicates 10% level of significance ** indicates 5% level of significance *** indicates 1% level of significance.