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Abstract

The main purpose of this study is to test the hypothesis of the rebound effect for the South African case in the years between 1990 to 2014 by firstly, decomposing the driving forces of the changes in CO_2 emissions of the country and secondly, comparing with the behaviors of other emerging economies such as BRICS. From a policy perspective, it is important not only to comprehend the factors that intensify the CO_2 emissions of the country but since energy efficiency is globally promoted as a significant tool to control emissions from a demand-side, to examine whether energy efficiency improvements have indeed reduced CO_2 emissions. The overall results of the decomposition exercise for the BRICS countries for the whole studies period suggest that the changes in CO_2 intensity and energy intensity had a negative impact to the changes in CO_2 emissions: in other words, as the energy intensity (energy consumption per unit of economic output) decreased for all the countries (possible technological developments), the emissions kept rising. For South Africa specifically, the energy intensity was a negative contributor to CO_2 emissions only for the last period examined (2008-2014).

Keywords: decomposition; South Africa; BRICS; emissions; rebound effect

1 Introduction

Given its contribution to the warming of the earth atmosphere, the carbon dioxide (CO_2) matter captivates the attention of the world. The CO_2 emitted throughout human activities has been characterized as the most compelling contributor to greenhouse gas (GHG) emissions. From a supply point of view, substitution of traditionally "dirty" fossil fuels for energy generation with renewable cleaner ones is considered the way forward to eliminate the negative

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consequences of CO_2 emissions. Their main aim for a demand point of view is the reduction of the energy requirements of the countries and at the same time, make sure they consume energy less intensively (energy efficiency improvements).

In the past two decades, South Africa has taken significant steps towards the reductions of CO_2 emissions. In 2002 South Africa signed the Kyoto Protocol which is a legally binding agreement to lower emissions of GHG. South Africa adhered to the United Nations Framework Conventions on Climate Change (UNFCCC) with the aim to reduce GHG emissions by 34% by 2020. In 2005, the first National Energy Efficiency Strategy of South Africa was released demonstrating the political will to improve energy efficiency in the country by suggesting and promoting certain technologies, programs and policies. South Africa established a carbon capture and storage (CCS) Centre in 2009. The aim was to construct a CCS plant by 2020 for coal and liquid fuels, capturing 40 million tons per year. The South African energy development institute (SANEDI) was put in place in 2008 to uplift the climate mitigation options, energy efficiency and renewable energy and to facilitate the implementation of drafted climate policies. So if all these are in place why do CO_2 emissions keep rising? And of course not only in South Africa but in most emerging economies such as the BRICS.

The main purpose of this study is to test the hypothesis of the rebound effect for the South African case in the years between 1990 to 2014 by firstly, decomposing the driving forces of the changes in CO_2 emissions of the country and secondly, comparing with the behaviors of other emerging economies such as BRICS. From a policy perspective, it is important not only to comprehend the factors that intensify the CO_2 emissions of the country but since energy efficiency is globally promoted as a significant tool to control emissions from a demand-side, to examine whether energy efficiency improvements have indeed reduced CO_2 emissions. Also, appreciating that the relationships are quite dynamic and changing, the paper will also divide the total period in smaller ones (1990-2000, 2000-2008, 2008-2014) to compare and contrast the differences, making an effort to pinpoint the factors that influenced each period.

2 Literature review

2.1 Decomposition applications

In the energy and environmental literature, studies have shown particular interest in decoupling the determinants of energy use behavior and emissions in order to provide recommendations to policy makers on mitigating options. Various econometric and multivariate methodologies have been employed to examine the tendencies of the indicators (Kopidou et al., 2016): they aim at presenting the most influential factors by almost “adding” the smaller ones as a residual of the modelling exercise. Decomposition techniques have certainly a different approach to that one: they do not present the interactions between the variables but their relative contributions to the change of the dependent variable in question over time. Decomposition techniques have been extensively used to disaggregate the factors of a number of indicators such as energy consumption, energy efficiency (Markandya et al, 2006; Andrade-Silva and Guerra, 2009; Sun, 1998; Korppoo et al, 2008; Metcalf, 2008; Liddle, 2009; Mendiluce et al, 2010; Zhao et al, 2010a; Zhou et al., 2010; Inglesi-Lotz and Blignaut, 2011; Inglesi-Lotz and Pouris, 2012) and greenhouse gas emissions (Ang and Choi, 1997; Bhattacharyya et al. 2010; Hammond and Norman, 2011; Kumbaroglu, 2011; Sheinbaum et al., 2011; Wang et al, 2011; Zhao et al, 2010b; Cansino et al., 2015; Shao et al. 2016; Sumabat et al., 2016; Xu et al., 2016). Some recent examples of decomposition applications focusing on emissions are discussed below

Karmelos et al. (2016) investigated the factors influencing changes in emissions in all European Union countries. They decomposed changes in emissions in five determinants: level of economic activity, electricity intensity, electricity trade, efficiency of electricity generation and fuel mix. Their findings showed that economic growth is the main reasoning force for the increase of emissions while the improvements in electricity intensity are the main negative contributor (decreasing the emissions).

Kopidou et al. (2016) examined the effect of various determinants on two indicators of sustainable industrial development, emissions and employment for five European Union countries (Greece, Portugal, Austria, Denmark, Germany). Economic growth and resource intensity were found to be the main contributors to CO_2 emissions while structural changes appeared to have a rather marginal effect. Changes in the fuel mix showed to be beneficial towards reducing emissions in all countries, particularly during the period 2007- 2011.

Lima et al. (2016) followed the same decomposition approach as Kopidou et al. (2016) but their study differentiated with regards to the chosen contributors to various countries' (Portugal, United Kingdom, Brazil and China) emissions. They aimed at decoupling energy – related emission drivers looking at all fuel alternatives (both fossil fuels and renewables, including nuclear energy). Their results showed that energy intensity and affluence effects, as well as the share of renewable energies to total supply are the main contributors in all countries.

Rustemoglu and Rodriguez Andres (2016) focused on two very dissimilar countries: Brazil and Russia to decouple their CO_2 emissions. This study used both aggregate and sectoral data (agriculture, industry and services). Four main factors were chosen and analyzed: economic activity, employment, energy intensity and carbon intensity. Brazil is found to be "far from a decoupling between economic growth and carbon dioxide emissions" while Russia experienced a decline in carbon emissions attributed to improvements in energy intensity. Interestingly, the Brazilian economic sectors experienced the economic activity effect as the main contributor in the increase of emissions while for Russia, the exact same effect was the reason for the decreasing trends in emissions.

The national/aggregated decomposition of emissions of various countries has the advantage that the analysis can compare countries' efficiencies from the point of view of environmental and economic sustainability (Rustemoglu and Rodriguez Andres, 2016). Within the BRICS framework, most studies focus on China (Wu et al., 2005; Wang et al., 2005; Ma and Stern, 2008; Zhang et al.,

2009) and India (Paul and Bhattacharya, 2004). Xu et al. (2016) showed that economic growth and living standards were negative contributors to emissions for China while the energy intensity effect varies depending on the geographic region.

3 The rebound effect

In the energy literature, the rebound effect is the reason why energy saving and energy efficiency policies do not have necessarily and always the expected impact on the reduction of CO_2 emissions. In the literature, various technologies and other instruments that aim at increasing efficiency and cleanliness of energy use were evaluated for their rebound effects. A clear distinction in the existence and magnitude of rebound effects should be made between those that promote technological changes (aiming at substitution between fuel-based and clean energy technologies) and those associated with incentive mechanisms (for example environmental policy applications and economic instruments).

A new energy-saving intervention (which can be a program, an economic instrument such as a tax or an actual tangible technology) aims at lowering the energy bill of the consumers and hence, eventually, a reduction in energy consumption and eventually, emissions. However, such a "lowering of the bill" may be perceived as a reduction of the real price of energy services and hence, a tendency of the consumers to eventually increase their demand for energy which partially offsets the energy-saving potential of the initial intervention. Also, by this reduction in energy prices, the real incomes of consumers' increase, and the consumers spend the increases in consuming other goods and services, offsetting here once more the emission reduction prospects of the initial intervention.

4 Methods and Data

Decomposition techniques have been used extensively in the energy literature to decouple the effects of various factors on the evolution of emissions (for example some recent studies include Ang and Choi, 1997; Bhattacharyya et al. 2010; Hammond and Norman, 2011; Kumbaroglu, 2011; Sheinbaum et al., 2011; Wang et al, 2011; Zhao et al, 2010b; Cansino et al., 2015; Shao et al. 2016; Sumabat et al., 2016; Xu et al., 2016). The paper of Shao et al. (2016) for example employed the specific LMDI model to disaggregate China's emissions into factors such production of the economy and the intensity of energy use. They extended their model by including also investment behaviors. Among their results, they showed that the impact of energy intensity towards cutting emissions was less than expected due to the rebound effect.

The energy rebound effect, that is this study's main topic of interest and as discussed in the previous section, stresses the net impact of energy-saving interventions or energy efficiency improvements to the energy consumption and subsequently to the total level of pollutants emitted. For that reason, this study chose the decomposition techniques to decouple the precise effect of energy intensity changes to changes in the emissions levels.

This study adopts the theoretical foundations from the initial Kaya identity: I=PAT, impact=population x affluence x technology). The assumption in that identity is that the drivers of the emissions do not interact with each other; but their relative contributions both in sign and magnitude can be detected and compared over time. In the LMDI method used here, changes in CO_2 emissions are decomposed into five factors: the carbon intensity of energy use (CIt), energy intensity of real GDP (EIt), contribution of the economy to the rest of the world (OutputShare), GDP per capita (OutputCap) and population. The decomposition identity looks as follows:

$$C02_i = \sum \frac{C0_{2,i}}{Energy\ consumption_i} \frac{Energy\ consumption_i}{GDP_i} \frac{Output_i}{Output} \frac{Output}{population} population \quad (1)$$

Hence, changes in emissions are equal to the sum in changes of each of all the drivers. The logarithmic scheme (weight) used here is adopted from Zhao, Ma and Hong (2010) where $w_{it}= \ln (CO_{2it}/CO_{2i0})=(CO_{2it}-C0_{2i0})/\ln(CO_{2it}/CO_{2i0})$.

The energy and emissions data are retrieved from the BP Statistical Review 2016 dataset while the economic and population data from the World Development Indicators of the World Bank for the BRICS countries (Brazil, Russia, India, China, South Africa) for the period 1990 to 2014. The BRICS countries are an important country group not only for its future potential and the current mutual policies but also for its current share to important energy and socioeconomic indicators globally such as the total emissions, energy use, GDP and total population (Figure 2).

To answer the main research question of the study, the empirical results presentation will be primarily focused on the second driver as discussed above: the energy intensity effect. The paper will examine the specific case of South Africa (within the context of BRICS) and see if the findings indicate a significant rebound effect for the full sample or whether it appeared only for some of the years and whether South Africa's behavior has any differences to the rest of the BRICS.

5 Empirical results

The overall results of the decomposition exercise for the BRICS countries for the whole studies period suggest that the changes in CO_2 intensity and Energy intensity had a negative impact to the changes in CO_2 emissions: in other words, as the energy intensity (energy consumption per unit of economic output) decreased for all the countries (possible technological developments), the emissions kept rising. The factors that intensified the increasing trend are primarily the socioeconomic drivers considered in the model (output share to the rest of the world, output per capita and population). These preliminary results provide an indication that the BRICS experienced a rebound effect for this period (Figure 3).

Figure 4 presents the decomposition results for the overall period for each of the BRICS countries individually. The output per capita is observed to be a positive contributing factor to emissions changes in all countries except Russia. The result is in accordance with Rustemoglu and Rodriguez Andres (2016) findings about the Russian economic sectors. The CO_2 intensity effect although varying in sign among the countries, is the smallest of all the effects. The focus of this paper however is the effect of energy intensity improvements to the changes in CO_2 emissions. The energy intensity effect was a positive contributor to CO_2 emissions ("pushed" the emissions higher) for Brazil and Russia, while for India and China an indication of the rebound effect was observed (negative contributors: lower intensity lead to higher emissions).

In order to decouple South Africa's determinants even more, Figure 5 presents the decomposition analysis only for South Africa dividing the sample period in three (1990-2000; 2000-2008; and 2008-2014). It is observed the energy intensity was a negative contributor to CO_2 emissions only for the last period, after the financial crisis of 2008-09. That is exactly the period where the effect of the output share to the world, although always positive, grew in magnitude substantially.

So for the last period, although the energy intensity was decreasing, the emissions kept increasing. This is an indication of the rebound effect from an improvement in the energy savings from a new technology or a policy.

6 Conclusions and Policy implications

Energy efficiency improvements have the potential to reduce the effective prices of energy and hence, reduce the initial targeted energy savings and conservation. Understanding, thus, the existence and magnitude of the rebound effect in a country, stemming from efforts to improve the country's energy intensity, will assist in choosing the most appropriate design and timing of an energy conservation policy or energy reducing technology promotion and implementation. This paper adopts a macroeconomic point of view in the studying of the phenomenon for the South African case. To do so, an LMDI decomposition model is used to disaggregate the energy intensity effect and other factors affecting the evolution of CO_2 emissions in the BRICS countries.

The results show an indication of the rebound effect taking place in the country, particularly in the latest period examined, from 2008 to 2014. In South Africa, the period of 2008/09 was characterized by a mismatch between the electricity supply and demand in the country resulting in load shedding with serious consequences for the economy. As a result of this, various energy efficiency policies have been proposed and implemented since then but most importantly the price restructuring of 2008/09 with increases of up to 25% annually for the following years was a high incentive for consumers to save energy or adopt technologies with lower intensity of energy use. This might be a primary reason why the rebound effect as described in previous sections might have occurred.

Establishing the existence and size of the energy rebound effect will assist the policy makers of the country with their expectations of the desired outcomes from environmental and energy policies, technologies, economic instruments etc., as well as better evaluating their performance, with regards to more efficient and cleaner use of energy, that will lead to reductions in emissions.

The approach followed here has certain limitations with regards to identifying and estimating the precise rebound effect in South Africa, which are also considered as points for further research of the matter:

a) *Not precise estimation of the effect:* Establishing the **exact size** of this direct effect will assist the policy makers of the country with their expectations of the outcomes from environmental and energy policies and implementation of technologies with regards to emission reduction;

b) *Different energy mixes:* The different choices in the **energy mixes** between the BRICS countries (i.e. South Africa higher dependence on coal then Russia) both from the supply but also the consumption of energy might have driven the results. More research to be done taking the energy contribution of various fuels for each country;

c) *Sectoral and technology rebound effect:* Economic sectors vary differently in various implementations of energy efficiency technologies. Not captured in this study. A study at **sectoral level and possibly on various technologies** within South Africa and in comparison with BRICS will assist in further policy decisions.

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Figure 1: The channels of effect of energy savings

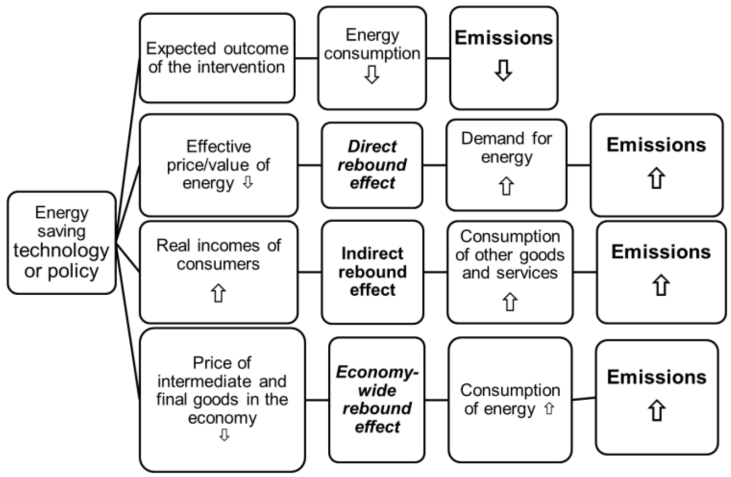

Figure 2: Contribution of BRICS countries to the world.

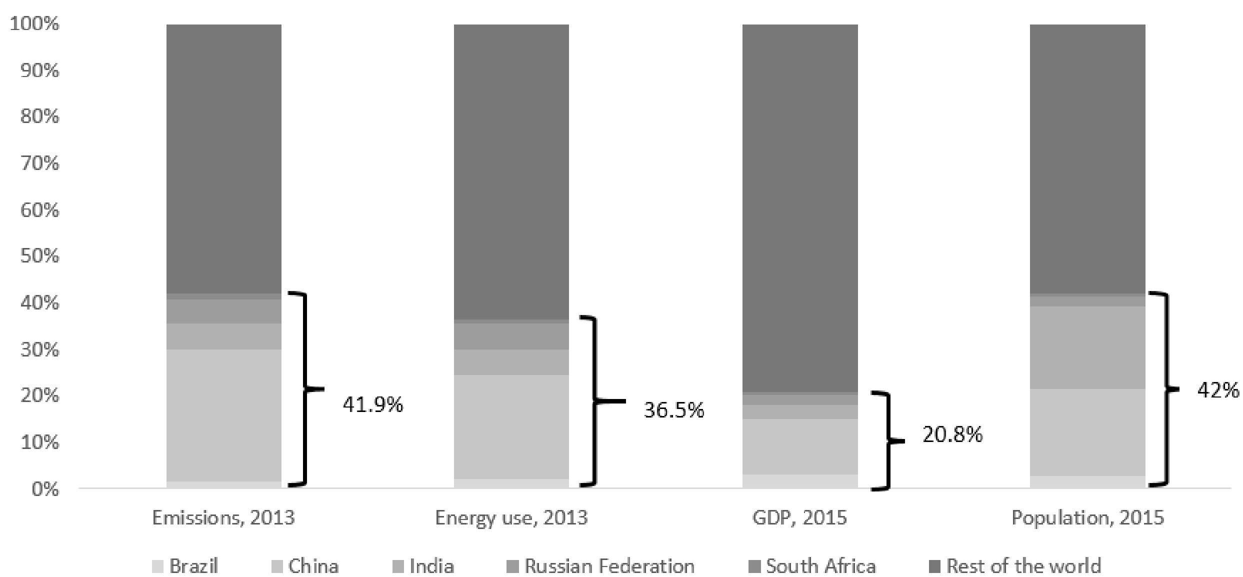

Figure 3: CO_2 decomposition of total group of BRICS countries for the period 1990-2014 (% contribution)

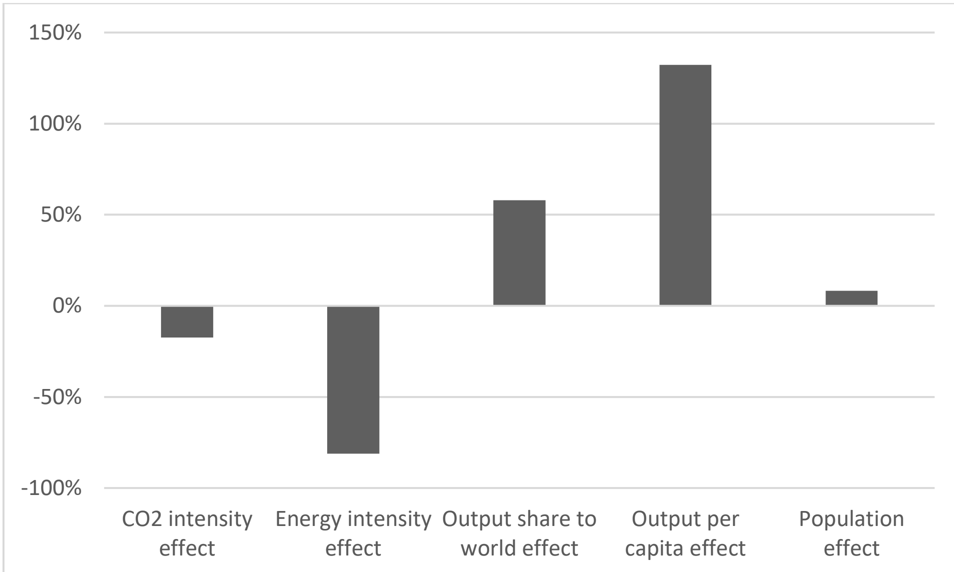

Figure 4: CO_2 decomposition of each of BRICS countries for the period 1990-2014 (% contribution)

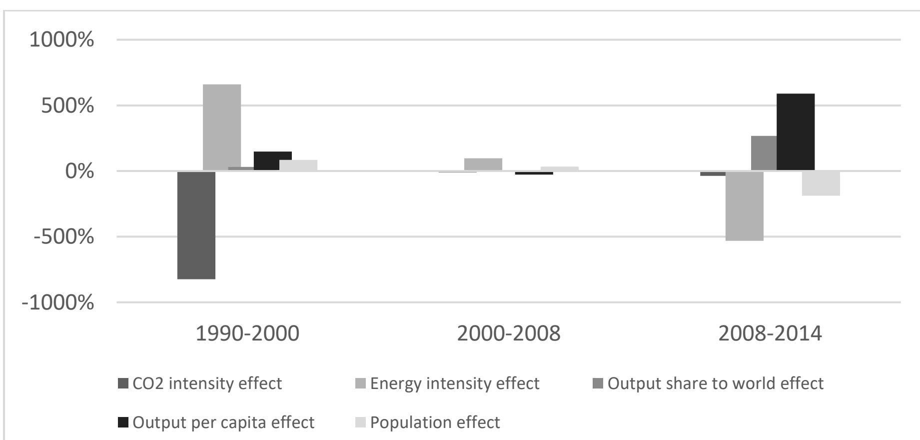

Figure 5: CO_2 decomposition of South Africa for three separate periods