The Energy Rebound Effect in South Africa:

Evidence from a decomposition exercise and system dynamics

Roula Inglesi-Lotz

Department of Economics, University of Pretoria

Paper submission to

Biennial Conference of the Economic Society of South Africa (ESSA) 2017

Abstract

The energy literature attributes to the rebound effect the reason why energy saving interventions do not produce the expected impact on the reduction of energy consumption and subsequently of CO2 emissions. Various technologies and other instruments that aim at increasing efficiency and cleanliness of energy use were evaluated for their rebound effects, including 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). This paper aims at answering questions related to the rebound effect from a macroeconomic point of view for South Africa, trying to draw the overall picture of the energy sector within a causal-loop framework adopted from system dynamics thinking and as well as decomposing the effects of various factors to the level of emissions in the country, in order to decouple the role of energy intensity and others to the emissions produced. The last is done by putting South Africa in a comparison with the rest of the BRICS countries for the period from 1990 to 2014.

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 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, programmes and policies (updated in 2015). 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. For example, Qiu and He (2017) have observed that although various green policies have been implemented in China to reduce the emission levels at the road transport sector, they have not been fully effective in the short and long – run; fact that they attribute to possible rebound or feedback effects.

This paper aims at answering questions related to the rebound effect from a macroeconomic point of view for South Africa, trying to draw the overall picture of the energy sector within a causal-loop framework adopted from system dynamics thinking and as well as decomposing the effects of various factors to the level of emissions in the country, in order to decouple the role of energy intensity and others to the emissions produced. The last is done by putting South Africa in a comparison with the rest of the BRICS countries for the period from 1990 to 2014.

Overview: the rebound effect

In the 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 CO2 emissions.

Sorrell and Dimitropoulos (2008: 636) define provide a general definition of the rebound effect, before they proceed with further analysis of the phenomenon: "The rebound effect results in part from an increased consumption of energy services following an improvement in the technical efficiency of delivering those services. This increased consumption offsets the energy savings that may otherwise be achieved. If the rebound effect is sufficiently large it may undermine the rationale for policy measures to encourage energy efficiency". In short, Small and van Dender (2007: 25) state that "improving energy efficiency releases an economic reaction that partially offsets the original energy saving".

A new energy-saving intervention in the form of a technology, policy, programme, or a tax imposition aims at lowering the energy bill of the consumers and hence, eventually, a reduction in 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 technology. Also, by this reduction in energy prices, the consumers' real incomes increase, and the consumers spend the increases in consuming other goods and services, offsetting here once more the emission reduction prospects of the initial technology. In the literature, interventions that were evaluated for their rebound effects were the carbon tax and technologies that directly increase the energy efficiency of consumers.

Figure 1 presents the channels of the effects of an energy saving technology or policy.

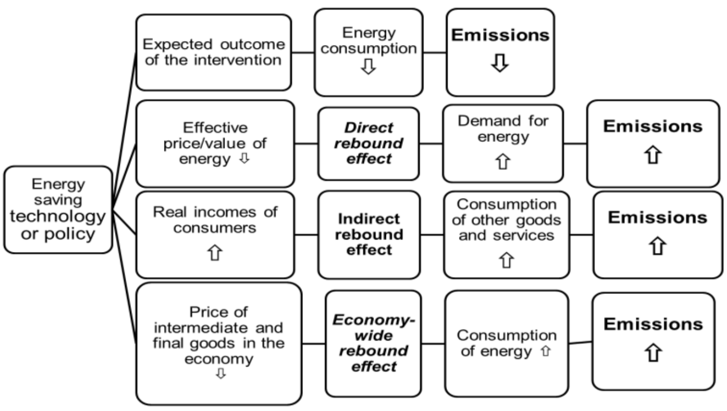

Figure 1: The channels of effect of energy savings.

Source: Greening et al. (2000)

Methods and data

In order to look at an overall picture of the impact of various energy saving interventions for consumers of energy, a system dynamics approach will be used to finally incorporate our understanding the energy linkages in the South African case. A system dynamics model will be conceptualized, constructed, simulated and analyzed using the Vensim® software. Causal-loop and stock and- flow diagrams as well as simulation modelling are done with simplicity and flexibility. Causal-loop diagram displays, in a qualitative manner, the interactions between the key elements and the feedback loops of the modelled system (see Figure 2). Each arrow in the diagram shows the influence of one variable on another. To estimate the interlinkages and impacts of such an exercise, econometrics techniques will be used to provide with elasticities/coefficients to quantify the relationships and the "size" and "sign" of the arrows.

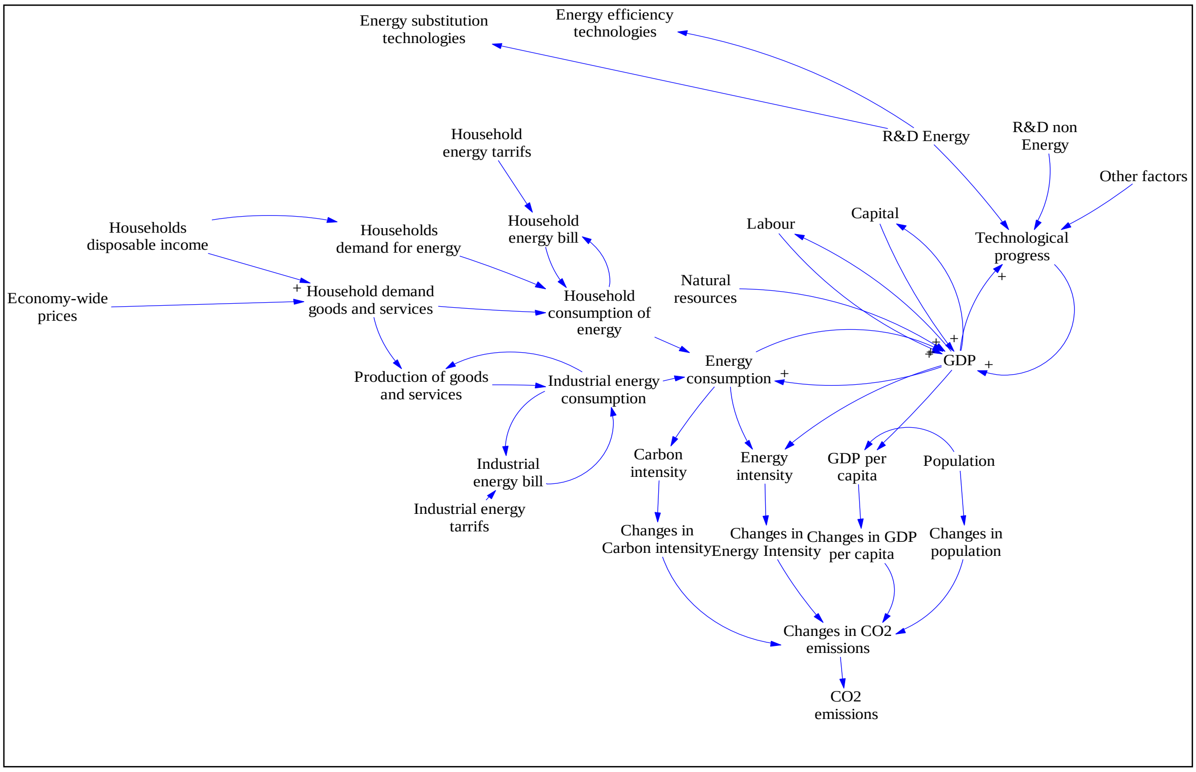

Figure 2: Causal-loop diagram of aspects and interactions in the energy sector.

For example, in the figure above on the middle-east side, the "flower" around GDP represents the effect of factors of production to GDP (including energy consumption): the precise coefficients will need to be estimated to understand better the effect of a certain change in one of the factors to the country's economic growth. Another example can be seen on the middle-west side of the figure: the households' energy bill gets impacted by fluctuations in energy tariffs and energy consumption; we need hence to quantify precisely the behavior of households with regards to their energy consumption when the tariffs change.

A final example is seen on the southern east side of the figure where selected energy and socioeconomic determinants (carbon intensity, energy intensity, GDP per capita, and population) affect the total emissions. The precise quantitative figures on the exact impact were estimated by using a decomposition exercise. Theoretical foundations are adopted 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 CO2 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 (examples in the literature that aimed at decomposing emissions can be found at 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 decomposition identity looks as follows:

$$CO2_i = \sum \frac{CO_{2,i}}{Energy\ consumption_i} \frac{Energy\ Consumption_i}{GDP_i} \frac{Output_i}{Output} \frac{Output}{population} population$$

The energy and emissions data are retrieved from the BP Statistical Review 2016 dataset while the economic (BP, 2016) and population data from the World Development Indicators of the World Bank (World Bank, 2016) for the BRICS countries (Brazil, Russia, India, China, South Africa) for the period 1990 to 2014. 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. I 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.

Results

System Dynamic model's results will be finalized as soon as all the individual quantitative estimations will be completed. In this summary of the work thus far, I present only the results of the decomposition exercise (southern east part of the figure). The overall results of the decomposition exercise for the BRICS countries for the whole studies period suggest that the changes in CO2 intensity and Energy intensity had a negative impact to the changes in CO2 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 (see Figure 3). 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.

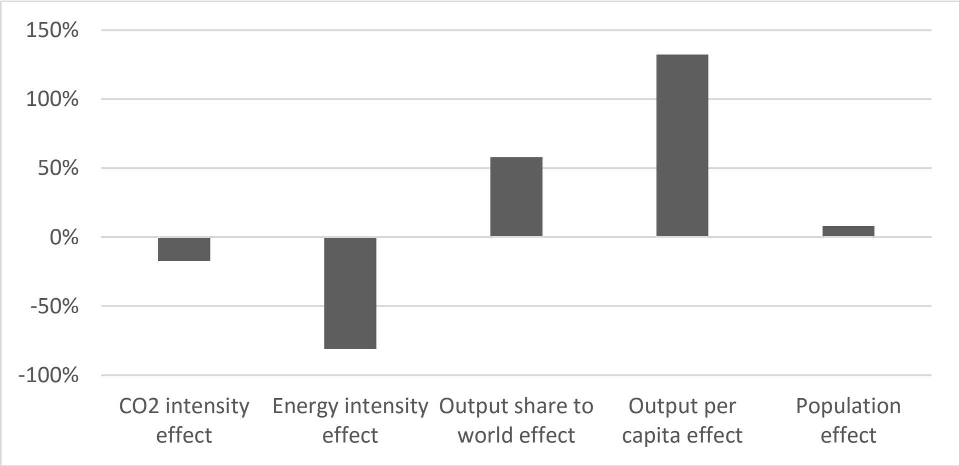

Figure 3: CO_2 decomposition of total group of BRICS countries for the period 1990-2014 (% contribution)

Dividing the sample period in three (1990-2000; 2000-2008; and 2008-2014), it is observed the energy intensity was a negative contributor to CO2 emissions only for the last period, after the financial crisis of 2008-09 (see Figure 4). 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.

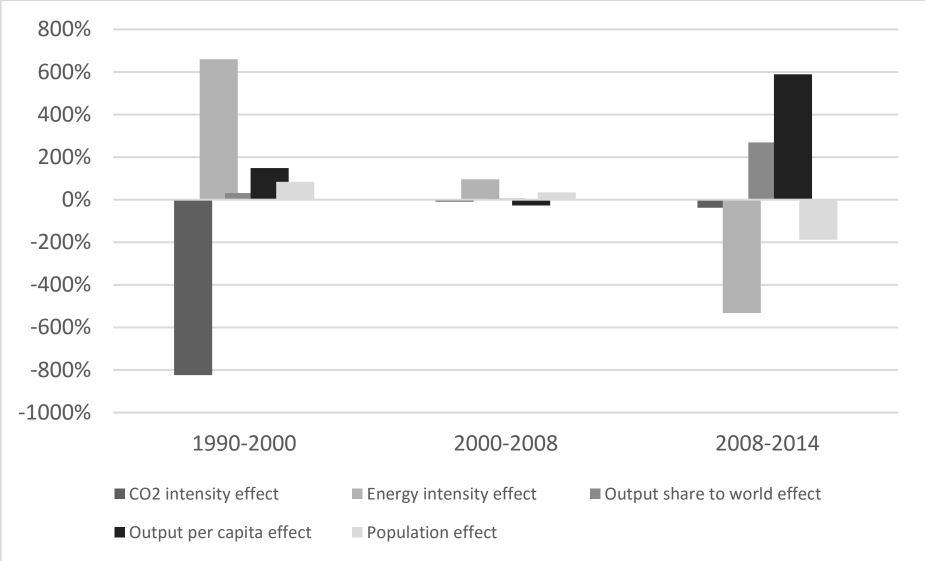

Figure 4: CO_2 decomposition of South Africa for three separate periods

Conclusions

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.

Establishing the size of this direct effect will assist the policy makers of the country with their expectations of the expected outcomes from environmental and energy policies and implementation of technologies with regards to emission reduction. Future research will include an econometric analysis taking into account microeconomic principles and household characteristics of the rebound effect and the relationship between energy efficiency and CO2 emissions. A synchronous modelling approach will be employed to be able to "import" in the system dynamics model all the information and knowledge from the decomposition exercise as well as future econometric estimations.

References

Ang BW, Choi KH. (1997). Decomposition of aggregate energy and gas emission intensities for industry: a refined Divisia index method. The Energy Journal, 18, 59-73.

Bhattacharyya SC, Matsumura W. (2010). Changes in GHG emission intensity in EU- 15: lessons from a decomposition analysis. Energy, 35, 3315-22.

BP (2016). Statistical Review of World Energy. London, UK.

Cansino, J.M., Sanchez-Braza, A., Rodriguez-Arevalo, M. (2015). Driving forces of Spain's CO2 emissions: A LMDI decomposition approach. Renewable and Sustainable Energy Reviews, 48, 749-759.

Greening, L.A., Greene, D.L., Difiglio, C. (2000). Energy efficiency and consumption – the rebound effect – a survey. Energy Policy, 28 (6-7), 389-401.

Hammond GP, Norman JB. (2011). Decomposition analysis of energy-related carbon emissions from UK manufacturing. Energy, 41, 220-7.

Kumbaroglu G. (2011). A sectoral decomposition analysis of Turkish CO2 emissions over 1990e2007. Energy, 36, 2419-33.

Qiu, L.-Y., He, L.- Y., (2017). Are Chinese green transport policies effective? A new perspective from direct pollution rebound effect, and empirical evidence from the road transport sector. Sustainability, 429(9), 1-11.

Shao, S., Yang, L., Gan, C., Cao, J., Geng, Y., Guan, D., (2016). Using and extended LMDI model to explore techno-economic drivers of energy-related industrial CO2 emissions changes: A case study for Shangai (China). Renewable and Sustainable Energy Reviews, 55, 516-536.

Sheinbaum C, Ruiz BJ, Ozawa L. (2011). Energy consumption and related CO2 emissions in five Latin American countries: changes from 1990 to 2006 and perspectives. Energy, 36, 3629-38.

Small, K.A., Van Dender, K. (2007). Fuel efficiency and motor vehicle travel: the declining rebound effect. The Energy Journal, 28 (1), 25-51.

Sorrell, S., Dimitropoulos, J. (2008). The rebound effect: microeconomic definitions, limitations and extensions. Ecological Economics, 65, 636-649.

Sumabat, A.K., Lopez, N.S., Yu, K.D., Hao, H., Li, R., Geng, Y., Chiu, A.S.F. (2016). Decomposition analysis of Philippine CO2 emissions from fuel combustion and electricity generation. Applied Energy, 164, 795-804.

Wang, W.W., Zhang, M., Zhou, M. (2011). Using LMDI method to analyze transport sector GHG emissions in China. Energy, 36, 5909-15.

World Bank (2016). World Development Indicators 2016. Paris, France.

Xu, S.-C., He, Z.-X., Long, R.-Y., Chen, H., Han, H.-M., Zhang, W.-W. (2016). Comparative analysis of the regional contributions to carbon emissions in China. Journal of Cleaner Production, 127, 406-417.

Zhao M, Tan L, Zhang W, Ji M, Liu Y, Yu L. (2010b) Decomposing the influencing factors of industrial carbon emissions in Shangai using the LMDI method. Energy, 35, 2505-10.