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# How far is Colombia from decoupling? Two-level decomposition analysis of energy consumption changes

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A B S T R A C T

A decoupling elasticity analysis and a two-level decomposition analysis of energy consumption in Colombia from 2000 to 2015 are developed. Firstly, the decoupling elasticity approach is used to analyse the importance of energy consumption changes in relation to the GDP changes. Then, a Logarithmic Mean Divisia Index analysis is carried out, decomposing the changes in energy consumption into four effects: Population, Activity, Structural and Intensity. Secondly, a decoupling index determines the main drivers of the inhibiting effect on energy consumption. The results show that the Population and Activity effects contribute to the country's increase of energy consumption, while the Intensity effect and, to a lesser extent, the Structure effect help to decrease it. From a sectoral perspective, variations in the energy consumption are mainly caused by the Transport and Industrial sectors. In the light of the results obtained, current decoupling-oriented measures are steps in the right direction, but more efforts should be made because until now they have not been effective. New policy recommendations are provided.


## 1. Introduction

Colombia has the second largest hydropower potential in Latin America, after Brazil [1]. Brazil, Russia, Canada, the United States, Indonesia, China and Colombia are the top seven countries with water availability exceeding 2000 km$^3$ [2]. In 2015, Colombia had a total installed electricity generation capacity of 16.4 GW, with a share of 70% of hydropower (high, mid and small plants together). As a consequence, Colombia's electricity sector is highly vulnerable to sufficient water availability [3]. During 2015 and 2016, the droughts suffered in Colombia as a result of “El Niño" were close to causing a blackout due to the drop in the electricity generation of the hydroelectric plants. Gutiérrez and Dracup [4] provided evidence of the relationship between “El Niño” and hydrology. Arias-Gaviria et al. [3] analyse the impact of “El Niño” on Colombian's power generation. Low levels of rain caused by “El Niño” provokes more extreme and longer dry seasons than usual, reduces the country's total water reservoirs and has led to an energy crisis in Colombia. A recent state of the art of “El Niño” is available in Trenberth [5]. Even more recently, Smith and Ubilava [6] analyse a causal relationship between “El Niño” and economic growth in Colombia.

The phenomenon “El Niño" occurs with some regularity. Evidence for the period 1979–2009 with data collected from 341 data stations is provided by Córdoba-Machado et al. [7] and by Smith and Ubilava [6] for the period 1961–2015. The possibility of building predictive indicators was analysed by Gutiérrez and Dracup [3]. Colombia needs to take measures to guarantee electricity supply in particular and energy in general. These measures can come from the Generation System [8], or measures oriented to the management of demand, particularly those aimed at acting on the drivers of energy consumption. This paper focuses on the latter. A pool of policy measures is required. In this sense, the possibility of Colombia moving properly towards decoupling between energy consumption and economic growth is a desirable outcome. If limiting the global average temperature growth below 2° C is our aim, delinking between economic growth and energy consumption is a necessary part of the right roadmap regarding current fossil fuels dependence.

Colombia's economic fundamentals, including macroeconomic stability and openness to global trade and finance, have remained relatively strong in recent years. The economy has expanded by an average of around 5% annually over the past five years. Its

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population has risen to 47.7 million people with US $ 6056.1 per capita. In absolute terms, the Colombian economy is the 4th largest in the Latin American Area and the 5th in terms of per capita GDP (Purchasing Power Parity - PPP). Between 2000 and 2014, the ratio of total primary energy sources to population measured in toe/capita increased by 10.9% (2.6% for non-OECD American countries). For the same period, total energy production measured in Mtoe increased by 75.29%. Focusing only on electricity consumption measured in TWh, this increased by 83.9% and, expressed in per capita terms, electricity consumption also increased significantly, around 55.6% [9]. It should be considered that Colombia is among the countries with the greatest production of electricity [10].

The paper addresses the following questions. How far is the Colombian economy along the road to decoupling energy consumption from economic growth? Which factors have determined the changes in Colombia's energy consumption in the period examined? Was the success of past energy policies in Colombia decoupling oriented? Together with answering these questions, policy recommendations at the sectoral level are provided.

To answer all these questions three methodologies are combined in a novel way of providing information items that supplement each other. In a first step, the decoupling status between energy consumption and GDP growth is analysed with a decoupling elasticity index following Tapio [11] approach. In a second step, an additive decomposition analysis index (LMDI) is applied in order to identify the driving factors of the energy consumption changes in Colombia at the sectorial level. Four effects in the decomposition were considered: Population, Activity, Structure and Intensity for the period 2000–2015. The Agriculture, Mining, Industrial, Electricity, Gas and Water, Construction, Transport and Commercial and Public sectors were analysed. Finally, in a third step, considering the four effects from the LMDI analysis, a second level of decomposition was conducted to explore the efforts made to meet decoupling between energy consumption and economic growth.

The decomposition analysis is one of the most widely applied tools for analysing the mechanisms influencing energy consumption and its environmental side-effects. The literature offers two methodologic approaches for this analysis, developed exhaustively in environmental topics: Structural Decomposition Analysis (SDA), and Index Decomposition Analysis (IDA). Both methods decompose the variation experienced by a variable between their determining factors. These techniques have usually been applied in isolation to analyse the energy consumption and $CO_2$ emissions changes. Some of these papers are: Achão and Schaeffer [12]; Zhang et al. [13]; Ang and Su [10] and Cansino et al. [14] for the SDA method and Hoekstra and van den Bergh [15]; Hatzigeorgiou et al. [16]; Ma and Stern [17]; Andreoni and Galmarini [18] and Colinet and Román [19] for the IDA method. The latest comparisons between IDA and SDA have been shown in Su and Ang [20]. Comparatively, IDA has certain advantages over SDA. IDA enables decompositions for any aggregate (value, ratio or elasticity). Also, IDA requires less data than decomposition methods based on input-output (IO) analysis, and it is useful when decomposing changes in environmental variables between their various components [21]. It could be said that one of the main advantages of IDA methods over their competitors based on IO matrices is the abundant availability of data.

Within the IDA methods, there are two important types: the Laspeyres method and the Divisia method. Ang et al. [22]; Ang and Zhang [24]; Ang [25]; Fernández and Fernández [82]; among others, have compared these two types of analysis. Specifically the Laspeyres IDA method is proportionally less used than the Divisia IDA, as considerable residuals arise in its decomposition, although the calculation of the results can be simple and understandable as shown in Zhang et al. [27].

The LMDI method seems to offer the most advantages within these various IDA methods [22,23,27–31,33–37]. Ang et al. [38] conclude that the LMDI-I and LMDI-II methods satisfy most of the index number tests that are considered relevant for the IDA family, except that the LMDI-I fails the proportionality test, whereas the LMDI-II fails the aggregation test. Ang [28] assessed the various decomposition methods and concluded that LMDI-I is a more recommendable method due to both its theoretical base and its set of properties, which are satisfactory in the case of index decomposition. Additionally, LMDI-I provides a simple and direct association between the additive and the multiplicative decomposition form [39].

The literature offers evidence of a relationship between Colombian's energy consumption and economic growth using different approaches. Destek and Aslan [40] analysed this relationship for Colombia during the period 1980 to 2012 applying a bootstrap panel Granger causality test. A similar approach was used by Narayan and Doytch [41]; who also studied the link between economic growth and energy consumption in Colombia over the period 1971 to 2011. However, drivers of the decoupling or coupling processes between energy consumption and economic growth were not included in the above literature. The literature also offers results from LMDI decomposition analysis including Colombia in the sample of countries analysed. These are the cases of Timilsina and Shrestha [36] and Sheinbaum et al. [42]. Malpede [43] developed a Multi-Regional analysis with diverse IDA methods focused on $CO_2$ emissions, but not on energy consumption. Ang [10] included Colombia in his global analysis of the changes in the aggregate carbon intensity for electricity, relating $CO_2$ emissions to electricity production in each country. More recently, Román et al. [44] conducted a LMDI decomposition analysis for the specific case of Colombia for the period 1990 to 2012. Nevertheless, all of these papers focused on decomposing $CO_2$ emissions changes but not on energy consumption changes.

We take advantage of the previous decomposition analysis and try to analyse not only the driving factors of energy consumption changes during one period but also the effort needed to achieve decoupling between energy consumption and economic growth. This latter information will show us the success of previous decoupling policies carried out in Colombia. Some papers have applied a decoupling index for analysing $CO_2$ emissions [45–47]. Our proposal is to apply as a novelty a decoupling index for energy consumption that, as far as we are aware, is being carried out for the first time in Colombia.

The contribution of this paper to the specialised literature is based on the following points: i) The combination of three methodologies - the elasticity index, the LMDI analysis and the decoupling index - is applied for the first time, as far as we are aware, to analyse the energy consumption changes in Colombia over the period 2000–2015, ii) a more comprehensive updated dataset analysis dissagregated at the sectoral level that contributes to better understanding energy consumption changes in Colombia, iii) the analysing of past decoupling-oriented policy measures and the proposal of energy policy recommendations.

The results are interesting not only for researchers but also for policy-makers. In fact, this paper speaks directly to the authorities of Colombia and the policy agenda regarding several issues, mainly energy saving.

The paper is structured as follows. After the introduction, the methodological approaches are described in Section 2. Section 3 describes the database used. The results are presented in Section 4. In the light of the results, past policies are commented upon in