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Energy intensity trend explained for Sao Paulo state

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ABSTRACT

A sectorial analysis and a logarithmic mean Divisia Index (LMDI) technique are used in this paper to decompose the energy intensity of the state of Sao Paulo from 1995 to 2012 into the economic activity effect and the energy efficiency effect. This study contributes the following observations: (1) The world energy intensity has decreased steadily, but the energy intensity of the Sao Paulo state has been volatile and has declined 2.3% since 1995. (2) In the period of study, declining energy intensity of the primary and tertiary sectors was observed. In contrast, the energy intensity of the secondary sector has been gradually increasing. (3) The energy efficiency effect was the primary driver of energy intensity change through 2007, and the economic activity effect subsequently had an increasingly more important role in the change. (4) The economic structure remained constant until 2004 when the services sector shift became more significant. It is hypothesized that the increasing energy intensity from 2005 to 2009 was caused by the growth of inefficient sugarcane bagasse consumption.

1. Introduction

Energy researchers use energy intensity, energy consumption divided by gross domestic product (GDP), as a measure of the ability of a particular economy to accomplish economic activities with minimal energy consumption. A country that consumes more energy than another country with the same GDP has higher energy intensity and is believed to be less energy-efficient. Energy intensity can be affected by many factors, such as economic development, climate, and energy price [1]. For example, countries with extremely cold winters such as Russia or Canada use sizable amounts of energy for heating; therefore, these countries are likely to have higher energy intensity compared to countries with milder weather.

As the seventh largest energy consumer and thirteenth largest CO2 emitter in the world [2], Brazil plays an important role in the global energy market, as well as in the climate change scene. Sao Paulo is the state with the highest GDP in Brazil and accounts for 33.9% of the total GDP of the country. Containing approximately a fifth of the Brazilian population, the GDP per capita of the state of Sao Paulo is well above the national average. The state is also generally more developed than other parts of the country, with more efficient transportation and the presence of infrastructures being considered to be the best in the country [3].

Brazil is a country with a unique energy profile, with renewable energy accounting for 42% of its total energy production and hydropower representing 70–80% of domestic electricity generation [2,4]. A major producer of ethanol from sugarcane, Brazil has the largest market for flexible fuel vehicles[2] in the world [5]. This market, together with the mandate to mix gasoline with anhydrous ethanol (20 – 25% mix), places Brazil at the forefront of the collective efforts to reduce fossil fuel consumption in transportation.

The energy profile of Sao Paulo differs from that of Brazil in the importance of sugarcane as an energy source. More than 60% of the sugar cane plantations in Brazil are located in Sao Paulo state [6], making it the largest producer of ethanol in the country. Compared with Brazil, this energy source in Sao Paulo comprises more renewable energy, that is, up to 52% of its total energy supply, as shown in Fig. 1.

The energy intensity in emerging countries, such as China, has been extensively studied by energy researchers [7–12], but few energy intensity analyses for Brazil have been completed [13,14], although Brazil is a BRICS (Brazil, Russia, India, China, and South Africa) country.

This paper presents three areas of pertinent research. Firstly, it is the first study to calculate and decompose the energy intensity at the state level in Brazil, with the focus being on Sao Paulo. Secondly, the study calculates the relative importance of economic activity to energy

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[2] Commonly referred as flex-fuel, they are vehicles that are able to use ethanol and gasoline interchangeably as fuels.

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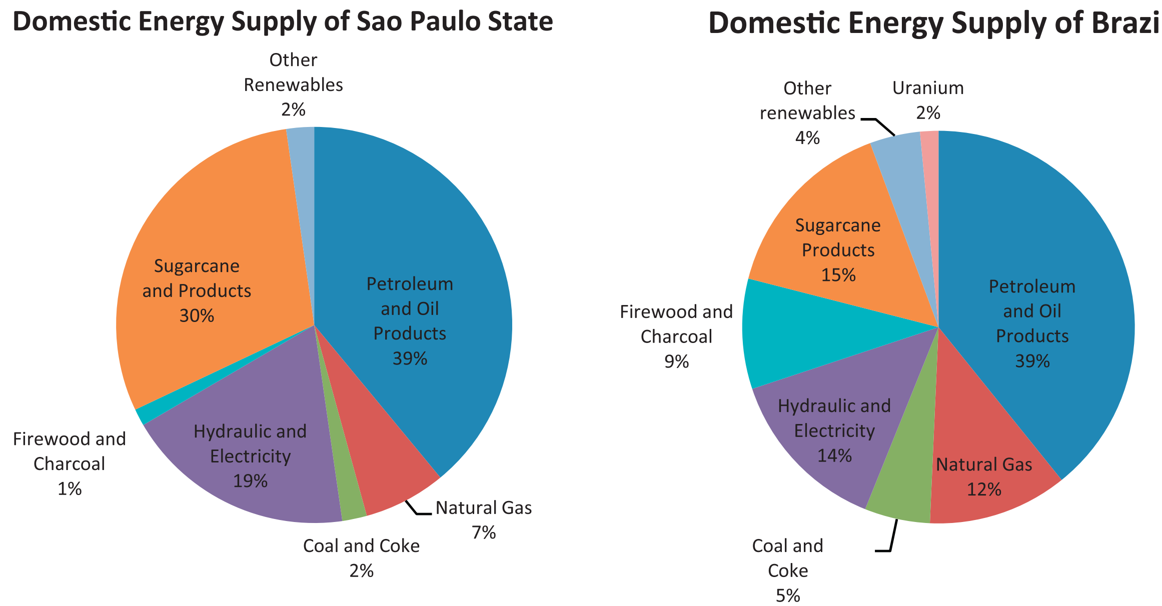

Fig. 1. Energy Domestic Supply of Sao Paulo and Brazil – 2012.
Source: Table 2.07 [13]; Table 1.3.b [4].Energy Domestic Supply is quantity of energy available to the state/country to be carried to the transformation processes and/or final consumption.

efficiency effect and provides logical explanations and hypotheses behind the energy intensity trend in Sao Paulo. Thirdly, the study highlights how federal and state policies as well as events occurring in the energy sector affected the energy intensity of the state. Based on the contributions from this study, policy makers will be able to examine how the past policies affected the energy intensity of the state and use that information to develop future policies accordingly.

In this paper, an index decomposition analysis is used to determine the causes of energy intensity change and to separate the causes into economic structural changes, commonly referred to as economic activity, and energy efficiency changes (improvement or decline).

The remainder of the paper is structured as follows. Section 2 describes the decomposition analysis method and the data and sources used. Section 3 provides an analysis of the results, which are divided into two parts, a sectorial analysis and a decomposition analysis. In Section 4, the findings are summarized and suggestions are discussed to improve the energy intensity and efficiency of the state based on the findings. Finally, this study's conclusions and future work are presented in Section 5.

2. Methods and data

2.1. Decomposition method

The logarithmic mean Divisia Index method (LMDI) is one of the most preferred decomposition methods for studying energy intensity [15,16]. Following the discussion in [17], it was concluded that the log mean Divisia Index method 1 (LMDI I) is the most suitable for the subject discussed in this paper. Firstly, this method satisfies factor-reversal and time reversal tests with no residual term; therefore, it is very desirable for long-term analyses. Additionally, the relationship between the multiplicative and additive forms can be established easily, making the choice between the two forms inconsequential [17]. Finally, the ease to apply the method and to understand the results makes LMDI I desirable for this study.

Let E be the aggregate energy consumption of Sao Paulo state, composed of energy consumption of the primary, secondary, and tertiary sectors such that $E = \sum_i E_i$ where i is the sector index.

Similarly, let Y be the total GDP of Sao Paulo state, $Y = \sum_i Y_i$

The energy intensity of sector i at year t is defined as $I_i^t = E_i^t/Y_i^t$ and percentage of GDP of sector i at year t to the aggregate GDP at year t, $S_i^t = Y_i^t/Y^t$ such that [16]:

$$E = \sum_i E_i = \sum_i Y \frac{Y_i}{Y}\frac{E_i}{Y_i} = \sum_i Y S_i I_i \tag{1}$$

As energy intensity is by definition is the energy consumption per GDP, aggregate energy intensity I is given by Eq. (2) [16]:

$$I = E/Y = \sum_i S_i I_i \tag{2}$$

The total energy intensity is affected by two factors, the share of the economy and the energy intensity of the sector. Therefore, through LMDI, the change in energy intensity can be attributed to either economic structural changes or efficiency improvement [18].

The decomposition method can be further divided into two types, multiplicative and additive. Both types are equally valid in analyzing energy intensity changes. The results obtained using both multiplicative and additive decomposition are shown in Section 3.2, but for the sake of brevity, only the detailed analysis from the multiplicative method is presented.

In multiplicative decomposition, the change ratio of the aggregate energy intensity from year 0 to year t is given by $D_{tot} = I^t/I^0$. Year 0 refers to the year 1995, as the sectorial GDP of Sao Paulo state can only be obtained since 1995. D_{tot} can be decomposed to give $D_{tot} = D_{str} D_{eff} D_{rsd}$.

In additive decomposition, the change in the aggregate energy intensity from year 0 to year t is given by $\Delta I_{tot} = I^t - I^0$ and is decomposed to give $\Delta I_{tot} = \Delta I_{str} + \Delta I_{eff} + \Delta I_{rsd}$.

D_{str} and ΔI_{str} give the estimated impacts due to economic activity, whereas D_{eff} and ΔI_{eff} give the estimated impacts due to change in sectorial energy efficiency. If D_{str} (D_{eff}) is greater or less than 1, the structural effect (energy efficiency) causes the energy intensity to increase or decrease. The further the values are from 1, the greater the contribution towards the change in energy intensity. Similarly, if ΔI_{str} (ΔI_{eff}) is greater or less than 0, the structural effect (energy efficiency) causes the energy intensity to increase or decrease, respectively. The greater the magnitudes of ΔI_{str} and ΔI_{eff}, the greater the contribution towards the change in energy intensity.

D_{rsd} and ΔI_{rsd} are the residual terms for multiplicative and additive decomposition, respectively, which always take the value of 1 in multiplicative decomposition and 0 in additive decomposition.