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Analysis of Income Elasticities of Brazil's Energy Matrix

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ABSTRACT

This study aims to estimate and analyze the income elasticities of Brazil's energy matrix, represented by the supply and consumption of energy. We sought to compare the income elasticities of both energy products and consumption through secondary sources and consumer sectors. This is an explanatory or relational research of an ex-post-facto nature, analyzing the period from 1970 to 2011, using the ANCOVA-EC estimation method. The results obtained from the estimates show that both for energy products, as in relation to industrial sectors, the elasticities are statistically different. The naphta, natural gas and ethyl alcohol had the highest elasticities in the energy matrix, and the industries ferro-alloy, non-ferrous metals and non-energy are the most sensitive to income growth. When elasticities are compared with the sectoral energy intensity index, there is evidence that less efficient sectors have higher income elasticities. In summary the results show that there is sectors or products that are more sensitive to economic growth where the energy-intensive and demand presented as the main factors to explain the sensitivity, there is also evidence to demonstrate that the level of efficiency is different compared the different sectors.

Keywords: Income Elasticity, Price Elasticity, Energy Matrix, Sector Demand for Energy
JEL Classifications: E3, G38, K23, M48, Q4

1. INTRODUCTION

The subject of energy is often only associated with the production/generation and supply of electricity (Taffarel et al., 2015). It should be noted that the concept of energy studied herein is in accordance with the descriptions of the National Energy Balance (Balanço Energético Nacional - BEN)[1], and also presented in publications of the international energy agency, where energy takes shape and flow. By "shape," we mean, being a primary energy source within an energy matrix (oil, natural gas, coal, uranium, hydraulic, firewood, and sugarcane, among others) and secondary sources (diesel oil, fuel oil, gasoline, gas, naphtha, kerosene, coal coke, electricity, charcoal, and alcohol, among others). Energy can be represented as a flow, in the sense that energy users cannot directly consume the primary sources, requiring energy to be processed into sources that meet the demand, which can be in the form of lighting, climatization, transportation, motive power, electrochemical reduction of materials, and so on (Perroni et al., 2015).

What should be produced from primary sources and what they should be processed into is part of the national energy policy, given that energy itself cannot be replaced (Tanaka, 2011; Moralejo et al., 2016). It is possible to replace the hydraulic force of plants with coal or gas to generate electricity, but not (at least not yet) replace

1 Published by the Ministry of Mines and Energy (MME); available from: http://www.mme.gov.br.

electricity itself (an industrial electric motor runs on electricity, it does not work without it; in this case, there is no approximate viable replacement).

This process moves a considerable part of national economies, forming a concept described by Pinto and de Almeida (2007) as energy chains. For example, the oil chain begins from the discovery of the product in the well, and moves on to taking care of a transportation need or the need to make polyvinyl chloride linings for a home - A process that includes production, processing, transportation, and trade.

What justifies energy chains is precisely the non-perfect substitution between energy sources, at least in the short term. Some chains have taken new directions since the '90s, reflecting a change in the technological trajectory as explained by Dosi (1982). With both processing and consuming devices that use more than one energy source, it may provide more flexibility to the system.

Until the '70s, energy was just another factor of production, but the oil crises changed the scenario:

> The impact of the Arab oil embargo and the subsequent emergence of OPEC as the most powerful cartel in history focused as never before on the issue of energy supply. OPEC has contributed wonderfully to concentrate efforts - in this case, on the adequacy of energy supplies to the maintenance of a continuous economic growth (Rosenberg, 1982. p. 132).

In their classic book on innovation, Freeman and Soete (1997) present a schematic summary of the main characteristics of Kondratieff[2] long waves, where on the fifth wave (information and communication Kondratieff), which starts in 1980, energy appears as a limitation of the techno-economic paradigm, i.e., the limitation of energy intensity may be a delay factor in the development of societies.

A wide range of studies, especially after the turn of the millennium, have discussed energy efficiency measures and the adoption of more efficient technologies, noting the existence of what was addressed in the literature as energy efficiency gap. The existence of this gap is confirmed by the non-implementation of measures for the efficiency or conservation of energy, even though they were evaluated as cost-effective by techniques such as payback, internal rate of return, or net present value (Jaffe and Stavins, 1994; Decanio, 1998; Anderson and Newell, 2004; Vieira and Veiga, 2009; Backlund et al., 2012; Cagno et al., 2013; Ciscato et al., 2016; Harzer et al., 2016).

Based on the importance of energy problem discussed, this paper aims to estimate the income elasticities of each BEN energy series for Brazil, i.e. domestic energy supply, consumption by source, and consumption by sectors of the economy. The main objective is to compare these elasticities in order to answer the following questions: What energy sectors or products are more sensitive to economic growth? If there are differences, what could explain such differences? Is it possible to conclude that there are sectors that are more efficient than others? The goal, then, is to shed light on these issues. We also intend to present the sectoral energy intensity index in order to compare it with the results obtained. According to the international energy agency (IEA, 2014a. p. 17) the energy intensity index is an economic indicator, being the amount of energy consumed per activity.

The remaining part of this article is divided into three sections. The second section presents the literature review. The third presents the methodological process, tying the previous parts of the work. Finally, we show a graphical presentation of the results, from the application of the methodology, along with a conclusion.

2. LITERATURE REVIEW

As discussed anteriorly, this work offers a broader analysis of energy, keeping in mind that technological changes cannot stay out of the evaluation process; in fact, they need to be incorporated as an explanatory factor. A survey of papers related to energy demand and economic growth showed that the vast majority of studies on energy in Brazil are concerned with electricity.

As per Garcez and Ghirardi (2003), the quantitative methods most used to understand power consumption are: Linear transfer function, autoregressive models with distributed lags, partial adjustment models (PAM), vector autoregressive models-vector error correction (VAR-VEC), and cointegration models (Kudlawicz et al., 2016; Moreira et al., 2016; Veiga et al., 2015).

One of the classic works in Brazil is by Modiano (1984), who uses a PAM based on the Koyck transformation (Gujarati and Porter, 2011). In this work, the author estimated the income elasticity of electricity consumption for the residential, industrial, and commercial sectors, to reach long-term elasticities of 1.17%, 1.67% and 1.15%, respectively, with corresponding price elasticities of −0.46%%, −0.001%, and −0.23%.

Andrade and Lobão (1997), as identified by the authors of this article in order to update the work by Modiano (1984), used more efficient econometric methods to estimate the residential demand for electricity: (1) Ordinary least squares (OLS), (2) two-stage least squares with instrumental variables, and (3) VAR-VEC. As per the authors' analysis, the results obtained by the three different methods converge to a long-term income elasticity of around 0.21% for residential electricity consumption, diverging from Modiano's work (1984) for being inelastic, even in the long term. Price elasticity was at the same level, i.e., −0.17%.

In another study that covered the 1994-2002 period for the state of Bahia, Garcez and Ghirardi (2003) found income elasticities ranging from 0.13% to 0.40%, confirming the inelastic demand of residential electricity consumption. Using VAR-VEC modeling, Schmidt and Lima (2004) found a 1.72% income elasticity of industrial electricity consumption for the period 1969-1999.

Irffi et al. (2009), covering the period 1970-2003, drew on a model of dynamic OLS, finding inelastic results in the short term

2 Kondratieff, Nicolai Dmitrievitch (1892-1930) - Russian economist and statistician who had his name associated with the study of the long economic cycles.

and elastic results in the long term. Later, Amaral and Monteiro (2010), using the OLS model but with correction of the dummy variable, found an income elasticity of 0.61% after a blackout and of 0.74% before the blackout.

Regarding gasoline, Roppa (2005) used a model of cointegration and found lower income elasticities for the long term compared to the short term - 0.47% and 0.16%, respectively. Chart 1 is a summary of the estimated elasticities for the studies evaluated:

Note, in Chart 1, the income elasticity of residential electricity consumption tends to be inelastic, and that of industrial consumption to be elastic, since price elasticity tends to be inelastic. The only disagreement is the work of Irffi et al. (2009), which talks about a very high price elasticity.

As a reference, this article also highlights the work of those who are considered evolutionists[3]: Nelson and Winter (1977), Dosi (1982), Rosenberg (1982), Mowery and Rosenberg (2005) and Freeman and Soete (1997).

In Rosenberg (1982), for example, one characteristic of industrialization is the use of increasing amounts of energy, which is governed by the operation of a dynamic technological system. The author argues for the non-perfect substitution of alternative technologies in energy, which implies not using a cheaper source in the short term. For the author, technological innovation happening through product or process determines the supply of energy, which in turn determines the long-term real gross domestic product (GDP). Long-term here does not refer to the partial equilibrium adjustment from one period to another, but can mean decades. Rosenberg (1982) makes a case study of metallurgy, where iron and steel, albeit less abundant in the Earth's crust than aluminum, were more widely used due to the immense amount of energy required to produce the latter. According to Rosenberg, the search for improved fuel efficiency was so intense in metallurgy that: (1) The input-output coefficients are not stable from one decade to another; and (2) an understanding of what was shaping the sector's structure and performance could not be focused only on the aggregate demand for energy and the final bulk product.

Against the background of what has been discussed above, Pinto and de Almeida (2007) reported several studies that sought to measure the relationship between energy and economic growth. Some of these studies reported an elasticity close to the unit. Janosi and Grayson (1972) confirmed the strong relationship between economic growth and energy consumption, but it ranged from 2.07% (Philippines) to 0.48% (UK). In general, the conclusion of the later studies is that energy consumption is not fully explained by economic activity, when different countries are compared. Energy consumption in countries with the same level of income may be different.

The contemporary model to explain total energy consumption takes into account the activity effect (economic growth), the structure effect (sector relative share), and the content effect (technological process in each energy-consuming product), which is known as the index decomposition analysis (IDA) approach (Ang and Xu, 2013). An IDA method, widely used in the literature, is the logarithmic mean divisia index (LMDI[4]) (Ang, 2013). Based on the decomposition equation shown in Ang:

$$E = \sum_i E_i = \sum_i Q \frac{Q_i}{Q} \frac{E_i}{Q_i} = \sum_i Q S_i I_i \tag{1}$$

Where E = Total energy consumption; Q = Global activity; E_i = Energy consumption of sector i; Q_i = Activity of sector i; S_i = Participation of sector i in activity; I_i = Energy intensity of sector i.

Equation (1) can still be broken down as defined in (2), where 2a (content effect), 2b (structure effect) and 2c (activity effect) plus an error variable. The ΔEC is the variation in energy consumption and GDP.

$$\Delta EC = \left(\sum_i \Delta \left(\frac{EC_i}{GDP_i} \right) \times \frac{GDP_i}{GDP} \times GDP \right) \tag{2a}$$

$$+ \left(\sum_i \frac{EC_i}{GDP_i} \times \Delta \left(\frac{GDP_i}{GDP} \right) \times GDP \right) \tag{2b}$$

$$+ \left(\sum_i \frac{EC_i}{GDP_i} \times \frac{GDP_i}{GDP} \times \Delta \left(GDP \right) \right) + \varepsilon \tag{2c}$$

The Equation (2) shows that the energy consumption from one period to another depends on: (a) The sector energy content, which is somewhat connected to the technological developments over time; (b) the structure or participation effect of each sector in the total output over time, which is linked to the strategic options of a country; and (c) the activity effect, i.e., country's level of growth and an error value that can be represented by other factors without major impact on the long-term model.

3. METHODOLOGICAL PROCEDURES

This work asserts that any chosen analysis method has to explicitly or implicitly consider the factors considered in the previous step of the work.

3.1. Characterization of Research and Data Collection

From what has been discussed, the objective of this work is to estimate the income elasticities of the national energy matrix of energy consumption by sector and energy consumption by source, taking into account that the activity effect is not the only force that influences total energy consumption due to the wide nature of the work.

This is an applied research of explanation or relational nature, as it seeks to better understand the behavior of several variables and elements that influence a particular phenomenon. In addition, it is

3 Current thought influenced by the works of Joseph Alois Schumpeter (1883-1950).

4 The additive LMDI formula would be

$$\Delta E_{act} = \Sigma_i\, w_i \ln\left[\frac{Q^t}{Q^0}\right]; \Delta E_{str} = \Sigma_i\, w_i \ln\left[\frac{S^t}{S^0}\right]; \Delta E_{int} = \Sigma_i\, w_i \ln\left[\frac{I_i^t}{I_i^o}\right]$$

where $W_i = E_i^t - E_i^0 / \ln E_i^t - \ln E_i^o$

Chart 1: Estimates of income and price elasticities by author

Authors	Method	Period	Price elasticity	Income elasticity
Modiano	Partial adjustment	1963-1981	$-0.001_{\text{industrial}}$	$1.67_{\text{industrial}}$
Andrade and Lobão	OLS-2SLS-VAR	1963-1995	$-0.17_{\text{residential}}$	$0.21_{\text{residential}}$
Ghirardi and Garcez	Cointegration	1994-2002	$-0.07_{\text{residential}}$	$0.39_{\text{residential}}$
Schmidt and Lima	VAR-VEC	1969-1999	$-0.13_{\text{industrial}}$	$1.72_{\text{industrial}}$
Roppa	Cointegration	1979-2000	$-0.32_{\text{industrial}}$	$0.16_{\text{industrial}}$
Irffi et al.	DOLS	1970-2003	$-3.71_{\text{industrial}}$	$0.39_{\text{industrial}}$
Amaral and Monteiro	OLS-dummy	1974-2008	$-0.43_{\text{residential}}$	$0.61_{\text{residential}}$

DOLS: Dynamic ordinary least squares, 2SLS: Two-stage least squares with instrumental variables

an ex-post-facto study, since the observations made in this study are done after the research in order to prevent any interference from the researcher.

To estimate these elasticities, we intend to use the data obtained from the National Energy Balance Historical Series (Séries Históricas Balanço Energético Nacional)[5] for the period 1970-2011, published on Ministry of Mines and Energy's (MME) website, which is developed in association with the Energy Research Company (Empresa de Pesquisas Energéticas). For information on the GDP, we will use data from IPEADATA's[6] website on the real GDP for the same period. Chart 2 shows the items in the National Energy Balance.

Chart 2 shows the items to be considered in the estimation of income elasticities. The first column in Chart 2 contains both renewable and non-renewable energy sources. The second and third columns show the energy demand by energy sources and sectors, respectively.

3.2. Econometric Modeling

As specified in the theoretical basis, there are different methods of estimating the elasticities of the items in Chart 2. Considering that the central objective is to compare the elasticities, we started to estimate constant elasticities using a basic method as described by Varian (2010), Wooldridge (2010), and Gujarati and Porter (2011), according to the specifications of model (3).

Model (3) is based on a simple linear equation where EC_t is the amount of energy consumed in time t, and depends on GDP_t, which is the income in period t.

$$EC_t = \beta_1 + \beta_2 GDP_t \tag{3}$$

The income elasticity is expressed in Equation (4).

$$\frac{dEC_t}{dGDP_t} \cdot \frac{GDP_t}{EC_t} = \beta_2 \cdot \frac{GDP_t}{EC_t} = \beta_2 \cdot \frac{GDP_t}{\beta_1 + \beta_2 GDP_t} \tag{4}$$

The problem is that elasticity changes with change in variables within period $t+n$, therefore taking the form of an exponential equation, as can be seen in (5).

5 The unit of measure of the BEN items is the TOE, which represents an energy content of 10.000 kcal; of this series of items, piped gas presents the lowest periodicity for the period from 1970 to 2002, and Uranium from 1984 to 2011.

6 Data on the GDP can be found on Available from: http://www.ipeadata.gov.br.

Chart 2: National energy balance items

Energy source	Consumption by source	Consumption by sector
Non-renewable	Coal	Non-energy final consuption
	Firewood	Energy final consuption
Oil and its products	Sugarcane bagasse	Energy sector
	Other renewable primary sources	Residential
Natural gas	Coke oven gas	Commercial
	Coal Coke	Public
Coal and its products	Electricity	Agriculture
	Charcoal	Consumption in transportation
Uranium (u3o8) and its products	Ethyl alcohol	Road
	Other secondary and tar	Rail
Renewable	Petroleum products	Air
	Diesel oil	Water
Hydraulic and electricity	Fuel oil	Industrial consumption
	Gasoline	Cement
Firewood and charcoal	Liquefied petroleum gas	Pig iron and still
	Naphta	Iron-alloy
Sugarcane products	Kerosene	Mining and pelletizing
	Piped gas	Non-ferrous and other metals
Other renewables	Other secondary petroleum	Chemicals
	Non-energy petroleum products	Food and beverage
		Textile
		Pulp and paper
		Ceramics
		Other industries

Source: Séries Históricas Balanço Energético Nacional, 1970-2011

$EC_t = \beta_1 GDP_t^{\beta_2} e^{u_t}$ In linear, it becomes

$$\ln EC_t = \ln \beta_1 + \beta_2 \ln GDP_t + u_t \tag{5}$$

Taking the constant income elasticity over the period $t+n$, we get an algebraic expression (6):

$$\frac{d \ln EC_t}{d \ln GDP_t} = \beta_2 \tag{6}$$

Based on the model defined in (3), the income elasticities of the items in Chart 2 were estimated, obtaining a confidence level that was above 95% of the β_2 estimated, with R^2 being close to the unit. The problem is that, as described in the classic work by Granger (1974), a Durbin-Watson statistic that was near-zero was obtained for the majority of cases, featuring an evidence for spurious regression and a non-stationarity of the time series.

The solution to this as perceived by Gujarati and Porter (2011) and raised by Maddala (2003) involves obtaining the first difference in the equation whenever statistic d (Durbin-Watson) is $<R^2$. Granger (1974) recommend: (a) Including lagged dependent variables; (b) obtaining the first differences of the variables involved; and (c) setting an autoregressive model of the first order for the waste. With these alternatives, the series become stationary and the traditional student's t-test can be applied normally without bias.

Based on the above, it is important to know whether the series are stationary or non-stationary (Veiga et al., 2016). For this work, there is evidence, according to the Durbin-Watson statistics, that at least the majority of the series are non-stationary. If the series are stationary, it is said that they are integrals of order $I(0)$. If the series are integrals of order $I(d)$, it means that the series must be differentiated times to make them stationary, as exposed in Bueno (2013).

To test whether the series are stationary, the Dickey and Fuller test (1979) is used, considering a white noise of the residuals. However, due to the problem of autocorrelation of the residuals, the augmented Dickey-Fuller (ADF) test is applied[7]. Another important concept that arises is the non-stationary, but cointegrated, stochastic process. It is said that a stochastic process is cointegrated, according to Engle and Granger (1987), if the series are integrated of the $I(d)$ order, but there is a vector which is a linear combination of the series that establishes a long-term relationship. In practice, a regression of these variables produces stationary residuals. The cointegration test of Engle-Granger[8] was developed to determine whether the series are cointegrated.

Given what had been discussed in the study, we went for a new approach, which is cointegration. The basic plan is that a model that considers income as the only variable may be poorly specified. In view of this, we started from the elementary theory of demand, where the demand for energy is explained by both income and price. We adopted the ANCOVA-EC model, or an ANOVA model, with covariates plus structural correction, as specified by Gujarati and Porter (2011), Andy (2009), and as found in (7).

$$\ln EC_t = \ln\beta_1 + \beta_2 \ln GDP_t + \beta_3 \ln P_t + a_1 D_t + a_2 TCH_t + a_3(TCH_t.GDP_t) + u_t \quad (7)$$

Where $lnEC_t$ is the logarithm of energy consumption; $lnGPD_t$ s the logarithm of the GDP; lnP_t is the logarithm of price of an oil barrel[9] as proxy of the energy price; D_t is a dummy variable that assumed the value of 0 when the price series was increasing (1970-1980/1999-2011) and 1 when the series was decreasing (1981-1998); TCH_t is a dummy variable assuming the value of 0 for the first half of the period (1970-1990) and 1 for the second half (1991-2011); while $TCH_t.GDPt$ is an interaction dummy variable related to income.

In fact, $a_2TCH_t+a_3(TCH_t.GDP_t)$ is the method of binary variables for the Chow test[10], which will reveal whether there was a structural break in relation to income from one period to another, or otherwise an intuitive approach of the effect of the content change and structure on energy consumption represented by Equation 2a and 2b. In practice, since it is difficult to measure the content and structure effects over time, the method should be indicative of the action of the structure and content effect over time.

The base model then estimates Equation (7) as a cointegration equation and applies the ADF test on the residuals in order to verify the evidence of a unit root, as can be seen in (8).

$$u_t = \ln EC_t - \ln\beta_1 - \beta_2 \ln GDP_t - \beta_3 \ln P_t - a_1 D_t - a_2 TCH_t - a_3(TCH_t.GDP_t) \quad (8)$$

As per Gujarati and Porter (2011), by verifying that u_t is $I(0)$, it can be affirmed that the traditional regression method can be applied.

The partial derivatives become long-term partial elasticities of the series, as in (9).

$$\beta_2 = \frac{\partial lnEC_t}{\partial lnGDP_t};\beta_3 = \frac{\partial lnEC_t}{\partial lnP_t};a_1 = \frac{\partial lnEC_t}{\partial lnD_t};a_2 = \frac{\partial lnEC_t}{\partial lnTCH_t};a_3 = \frac{\partial lnEC_t}{\partial lnTCH_t.GDP_t} \quad (9)$$

Therefore, β_2 is income elasticity; β_3 is price elasticity; a_1 gives the indicative of the change in the growth rate when the energy price (oil) was decreasing (1981-1998); a_1 is the change in the growth rate during the periods 1970-1990 and 1991-2011; and a_1 shows whether there was a change in income elasticity between the previous periods.

4. DATA PRESENTATION AND ANALYSIS

When presenting the results, a greater emphasis will be given on income elasticities, considering that this is part of the main objective of this work.

7 In practice, according to Gujarati and Porter (2011), the Dickey-Fuller test uses statistics (tau) τ to verify whether the series is a random walk (with and without detachment or time trend) considering a white noise of the error values. Given a simple random walk $Y_t=\rho Y_{(t-1)}+u_i$ ransforming $Y_t-Y_{(t-1)}=(\rho-1)Y_{(t-1)}+u_i$, whereas $\delta=(\rho-1)$, testing the null hypothesis H_0: $\delta=0$ is the same thing as testing H_0: $\rho=1$. For the case in which the regression errors exhibit autocorrelation, the lagged values of the dependent variable are added, and so the test is called augmented Dickey-Fuller, and the equation representing a complete detachment and time trend is correlacionados adiciona-se os valores .

$$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \sum_{i=1}^{m} \alpha_i \Delta Y_{t-i} + \varepsilon_t$$

8 Basically, it is the application of the Dickey-Fuller or augmented Dickey-Fuller test on the residual of the regression of the variable in level using the Engle-Granger statistics. If the residuals are white noise, it is said that the series are cointegrated, although non-stationary.

9 Real price of the oil barrel published by BP Statistics.

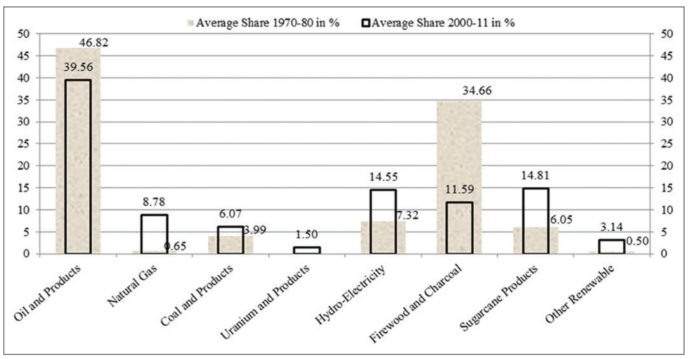
10 Study presented to the magazine Econometrica in 1960 "Test of Equality Between Sets of Coefficients in Two Linear Regressions."

4.1. The National Energy Matrix

Based on the last report by IEA, Key World Energy Statistics (2014), 81% of the energy used in the world comes from fossil fuels (coal 29%; oil 31.4% natural gas 21.3%), but the energy is not equally consumed around the world. According to the same report, the per capita consumption in the industrialized countries of the OECD, with the year 2012 as a basis, was 4.19 tonne of oil equivalent (TOE), while in Brazil, the per capita consumption was 1.42 TOE, which indicates, as per similar analysis in Goldemberg (2000), that there is still a long way to go. Figure 1 shows the change in the energy matrix between the 1970s (1970–1980) and the 2000s (2000-2011) for Brazil and Figure 2 shows the change in the energy matrix between 1973 and 2012 for World.

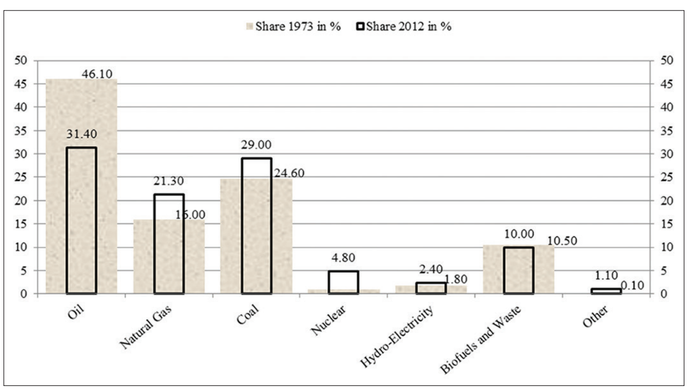
It is important to note that Brazil's Energy Matrix has certain peculiarities, due to both the choices made and allocation of natural resources. As per Pinto and de Almeida (2007), unlike the World Energy Matrix, Brazil has a cleaner Energy Matrix, using approximately 55% of fossil fuels, with the year 2005 as a reference. Figure 1 was constructed based on the average share of the primary energy source in the total domestic energy supply, measured in the TOE for each decade. For example, in the 1970s, the average share of oil and its products in the domestic energy supply was approximately 46.8% in Brazil.

Figure 1: Change in Brazil's energy matrix



Source: Séries Históricas Balanço Energético Nacional 1970-2011

Figure 2: Change in world's energy matrix



Source: World energy statistics-2014

From Figure 1, some characteristics can be noted. In the 1970s, compared to the 2000s, there was a reduction in oil products from 46.8% to 39.6%; a reduction in the use of firewood and charcoal from 34.7% to 11.6%; an increase in the share of electricity from 7.3% to 14.6%; and an increase in the share of sugarcane products from 6.1% to 14.8%. Furthermore, the use of natural gas intensified, although it was hardly ever used earlier. In general, it can be said that, except for firewood and charcoal, the share of all renewable energy sources such as hydraulic and sugarcane products grew, particularly replacing firewood.

Based on Goldemberg (2000), and Lucon and Goldemberg (2009), we can highlight a shy change in other renewables, such as biomass, eolic, solar, and geothermal, from 0.5% in the 1970s to 3.1% in the 2000s, if the Brazilian potential in this area is considered.

As per the report from the MME, "Matriz Energética Nacional 2030" (2007. p. 168), changes in the Energy Matrix shown in Figure 1 should continue until 2030. Based on predictions made in the report and on the data in Figure 1, we can see that the change expected for Brazil's Energy Matrix for the period 2000-2011 to 2030 should be: Oil and products (39.6-28%); natural gas (8.8-15.5%); coal and products (6-6.9%); uranium and products (1.5-3%); hydraulics and electricity (14.6-13.5%); firewood and charcoal (11.6% to 5.5%); sugarcane products (14.8-18.5%); and other renewables (3.1-9.1%).

According to the report's forecasts, the highest growth in shares will occur in sugarcane products and other renewables, which together should add up to 27.6% of Brazil's Energy Matrix in 2030.

4.2. Model Estimates' Results

Table 1 presents the estimates of the ANCOVA-EC model for energy supply during the 1970-2011 period, considering the income, price, and auxiliary variables of Brazil's energy supply.

Table 1: Estimates of elasticities in income, price, and auxiliary variables of the energy supply

Energy supply	GDP	P	D	TCH	TCH.GDP	R^2	F	DW	ADF-C	ADF-CT
Non-renewable	1.09***	−0.02	−0.12***	0.28***	−0.00***	0.99	937	1.10	0.006	0.029
Oil and products	0.89***	0.01	−0.13***	0.45***	−0.00***	0.97	224	0.57	0.113	0.317
Natural gas	3.63***	−0.27***	−0.04	−0.23	0.00	0.98	316	0.61	0.098	0.285
Coal and products	1.78***	−0.14***	0.12**	0.55***	−0.00***	0.97	212	0.92	0.001	0.002
Uranium/products	−2.56	0.19	−1.48**	−2.52	−0.00	0.66	8	1.75	0.001	0.007
Renewable	0.65***	−0.07***	0.09***	−0.61***	0.00	0.97	271	0.82	0.020	0.076
Hydro-electricity	1.79***	−0.07***	0.10***	0.47***	−0.00***	0.99	1054	1.15	0.000	0.001
Firewood/charcoal	−0.06	0.03	0.00	−0.44***	0.00	0.77	24	0.73	0.022	0.102
Sugarcane products	1.73***	−0.15***	0.34***	−0.63***	0.00***	0.97	270	1.04	0.004	0.021
Other renewables	2.42***	−0.12*	0.17**	−0.32	0.00**	0.98	394	0.62	0.010	0.037

Source: Estimates are based on data from BEN, IPEADATA and BP-STATISTICS using the GRETL package. ***Significant at 1%, **Significant at 5%, *Significant at 10%. GDP: Gross domestic product, ADF: Augmented Dickey-Fuller, BEN: Balanço Energético Nacional

Table 2: Estimates of elasticities in income, price, and auxiliary variables of energy consumption by source

Source	GDP	P	D	TCH	TCH.GDP	R^2	F	DW	ADF-C	ADF-CT
Natural gas	4.02***	−0.14*	−0.02	0.42	−0.00	0.98	440	0.73	0.052	0.175
Coal	3.31***	−0.16	0.43*	−0.22	−0.00	0.89	61	0.41	0.014	0.133
Firewood	−0.55***	0.07***	−0.05**	−0.73***	0.00***	0.96	178	1.38	0.001	0.004
Sugarcane bagasse	1.34***	−0.09**	0.22***	−0.63***	0.00***	0.97	269	1.08	0.007	0.034
Other prim. renew	2.59***	−0.12**	0.12*	0.13	0.00	0.99	520	0.75	0.024	0.079
Coke gas	1.88***	−0.16***	0.18***	0.66***	−0.00***	0.96	186	1.07	0.000	0.000
Coal coke	1.83***	−0.14***	0.15**	0.81***	−0.00***	0.96	187	1.17	0.000	0.000
Electricity	1.77***	−0.08***	0.08**	0.26**	−0.00	0.99	948	0.83	0.001	0.004
Charcoal	1.34***	0.01	0.09	0.49**	−0.00***	0.87	50	0.84	0.025	0.099
Ethyl alcohol	3.36***	−0.37***	0.69***	−0.19	−0.00	0.95	127	0.86	0.000	0.003
Other sec. tar	1.35***	−0.02	0.32***	0.77***	−0.00***	0.94	114	1.29	0.001	0.006
Diesel oil	1.40***	−0.00	−0.02	0.38***	−0.00***	0.99	2082	0.94	0.003	0.021
Fuel oil	0.21	0.18**	−0.19**	1.95***	−0.00***	0.70	17	0.42	0.027	0.105
Gasoline	−0.18	0.07	−0.23***	−0.09	0.00*	0.80	29	0.63	0.014	0.064
Liq. petroleum gas	1.50***	−0.13***	0.07**	0.62***	−0.00***	0.98	462	1.03	0.004	0.017
Naphta	5.06***	0.25	−0.23	4.12***	−0.00***	0.86	45	0.96	0.000	0.000
Kerosene	0.72***	0.03	−0.04	0.33	−0.00*	0.82	33	0.65	0.104	0.312
Piped gas	0.75***	−0.01	0.20*	5.78***	−0.00***	0.93	70	1.08	0.000	0.006
Other sec. oil	2.68***	0.00	−0.26***	0.70**	−0.00***	0.98	334	1.10	0.059	0.240
Non-energ. oil	1.01***	0.14***	−0.06	−0.03	−0.00	0.95	133	1.35	0.000	0.003

Source: Estimates are based on data from BEN, IPEADATA, and BP-STATISTICS using the GRETL package. ***Significant at 1%, **Significant at 5%, *Significant at 10%.
GDP: Gross domestic product, ADF: Augmented Dickey-Fuller

In general, it can be seen that income elasticities (GDP) are characterized as elastic and were statistically significant, except uranium and firewood, which are not significant. Most of the items for supply have a negative sign to its elasticity, this can be explained because the long-run supply might be being determined by demand, since the oil price influences the price of the composition of other supply intens.

As for the variable (D), which can be interpreted as a change in the growth rate in the downturn in oil prices during 1981-1998, the signs are negative for non-renewable energy sources and positive for renewable, which is contrary to what was expected, given that the oil price decreased and the growth rate of the supply was lower during this period[11].

As for the estimators of the Chow test for TCH and TCH. GDP income, the change did not occur in the slope of TCH. GDP curves. Although significant, the values are close to zero, but occurred in the TCH constant, as the data are in logarithms, and represent a change in the growth rate during the period 1970-1990 to 1991-2011. Looking at these two periods, the growth rate of non-renewable sources other than electricity increased during the 1991-2011 period.

Given the small probability value (p-value) of the ADF test cases with constant ADF-C and augmented Dickey-Fuller with constant and trend ADF-CT, there is evidence for the vast majority of cases that the model is cointegrated.

11 The original intention of variable D was to isolate the periods of growth and non-growth of the oil price series. However, the curious fact is that just as the price series was decreasing during 1981-1998, Brazil had very low GDP growth rates, according to IPEADATA. The average growth rates of the GDP during the respective periods were: (1970-1980: 8.83%), (1981-1998: 2.07%) and (1999-2011: 3.36%). Thus, there is also the income effect on variable D. The price effect may cause variable D to present a positive sign, but the income effect may cause variable D to present an opposite sign.

Table 2 presents estimates of the ANCOVA-EC model for the elasticities in income, price, and auxiliary variables for consumption by energy source.

Again, from the results in Table 2, we see that in most cases, the income (GDP) and price (P) elasticities have the expected signs - most cointegrated models, taking into account the probability values (P-values), are considered small.

The D estimates show mostly positive signs, while respecting the fact that when the signs are negative, there may be an income effect. For TCH, most estimates have positive signs, i.e., a significant change in the growth rate from one period to another, and TCH.GDP, although significant, has values close to zero.

Table 3 shows estimates of the ANCOVA-EC model for energy consumption per sector in the period considered.

Most income (GDP) and price (P) elasticities have the expected signs. As for D, it can be seen that most industrial sectors had the lowest growth rate during the period in which the per-barrel price of oil was decreasing, or GDP slowing. Through the TCH estimates, it was also confirmed that there was a structural break in the growth of the series. The ADF-C and ADF-CT tests failed to accept the null hypothesis for the unit root of the residues for most cases.

4.3. Graph Presentation of Elasticities

In this stage of the study, we show a graphic representation of income elasticities (GDP), as this factor has the most weight in terms of elasticity in the model, along with the graphing of the share of each item in total. Figure 3 shows the behavior of the income elasticity of the supply and share of energy sources in total.

Figure 3 shows that the largest proportional share of oil and derivatives in the supply, and in general, renewable sources with

Table 3: Estimates of elasticities in income, price, and auxiliary variables energy consumption by sector

Sectors	GDP	P	D	TCH	TCH.GDP	R^2	F	DW	ADF-C	ADF-CT
Non-energy	2.01***	−0.02	0.04	0.76***	−0.00***	0.98	434	1.38	0.000	0.000
Energy	1.95***	−0.05	0.26***	−0.01	−0.00	0.98	389	1.06	0.000	0.001
Residential	−0.16***	0.02**	−0.07***	−0.32***	0.00***	0.94	108	1.47	0.000	0.000
Commercial	1.33***	−0.08***	−0.02	−0.01	0.00	0.99	575	0.86	0.001	0.004
Public	1.57***	−0.10***	−0.04	0.49***	−0.00**	0.99	532	0.99	0.013	0.058
Agriculture	0.26***	−0.05***	−0.00	−0.48***	0.00***	0.98	431	1.62	0.001	0.006
Total transportation	0.90***	−0.02	−0.04	−0.03	0.00*	0.99	702	0.84	0.016	0.080
Road	0.95***	−0.05***	−0.05**	−0.04	0.00**	0.99	773	0.87	0.022	0.089
Rail	0.04	0.13***	0.11**	−0.87***	0.00***	0.70	17	0.77	0.047	0.177
Air	1.03***	0.02	−0.01	0.43**	−0.00**	0.92	78	0.58	0.128	0.356
Hydro	0.15	0.42***	0.16*	0.09	−0.00	0.76	23	1.06	0.000	0.000
Total industrial	1.12***	−0.03**	−0.05***	0.03	−0.00	0.99	1439	0.80	0.001	0.004
Cement	0.63***	0.09	−0.15**	0.03	−0.00	0.80	28	0.61	0.004	0.026
Pig iron and still	1.62***	−0.09**	−0.02	0.63***	−0.00***	0.97	241	1.32	0.000	0.000
Iron-alloy	2.27***	−0.01	0.21***	0.64**	−0.00***	0.97	252	0.95	0.010	0.041
Mining and pelletizing	1.77***	0.12***	−0.17***	0.63***	−0.00***	0.99	504	1.30	0.001	0.005
Non-ferrous and other metals	2.09***	−0.08**	0.04	0.57***	−0.00***	0.99	606	1.01	0.001	0.006
Chemicals	1.43***	0.01	−0.05	0.50***	−0.00***	0.98	328	0.44	0.035	0.035
Food and beverage	0.54***	−0.02	−0.05	−0.68***	0.00***	0.97	238	1.02	0.014	0.066
Textile	0.37***	0.03	−0.03	0.18*	−0.00***	0.78	25	0.79	0.034	0.127
Pulp and paper	1.47***	−0.03	0.00	0.05	0.00	0.99	1077	1.00	0.005	0.021
Ceramics	0.66***	−0.02	−0.05**	−0.45***	0.00***	0.97	240	1.46	0.001	0.003
Other sectors	0.97***	0.04*	−0.19***	0.08	−0.00*	0.97	269	1.19	0.003	0.014

Source: Estimates based on data from BEN, IPEADATA, and BP-STATISTICS using the GRETL package. ***Significant at 1%, **Significant at 5%, *Significant at 10%. GDP: Gross domestic product, ADF: Augmented Dickey-Fuller, BEN: Balanço Energético Nacional

higher elasticities. Uranium, although not significant in the model, also had a lower frequency during 1984-2011.

Figure 4 shows the behavior of income elasticities (GDP) in relation to the share of energy consumption by source in relation to total consumption.

Notably, according to Figure 4, diesel fuel and electricity have a share of 17.8% and 16.8%, respectively, in consumption per source, representing approximately 35% of the total. It is clear that diesel fuel and electricity are the most consumed energy products, despite having intermediate elasticities when compared with other energy products.

Naphtha had the highest elasticity, as can also be seen in Figure 4. A possible explanation could be related to the change in the growth rate of naphtha during the period from 1991 to 2011, as measured by the TCH estimate, which was 4.12, as shown in Table 3.

Figure 5 shows the behavior of income elasticities (GDP) by sector of economic activity and their shares in total consumption.

In the analysis of consumption by sector, the largest share of consumption appears to be that of the road transportation sector, which confirms the higher share of diesel, as shown in Figure 4, and indicates that the largest elasticities are in the industrial sector, in industries considered energy-intensive. It may be also noted that all sectors that had positive change in growth from the last two decades, as measured by TCH in Table 3, have higher elasticities.

4.4. Evaluation based on Energy Intensity Index

According to Philipsen et al. (1997), energy efficiency can be defined as the amount of services (lighting, heating, transportation,

Figure 3: Elasticity of supply and participation sources in relation to total

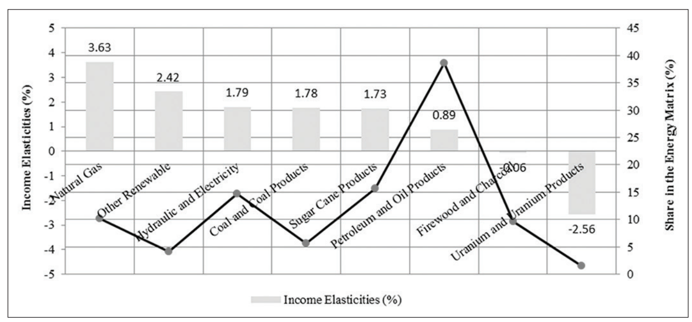
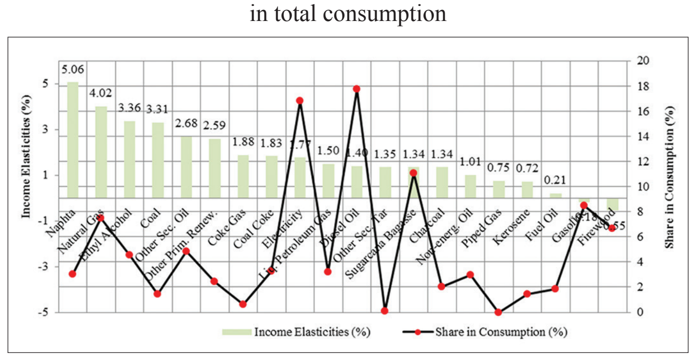


Figure 4: Energy consumption elasticities by source and participation in total consumption



etc.) provided per unit of energy used. Thus, the energy is related to the quality of a system or equipment. Usually, an energy efficiency indicator is used as an approximate factor for measuring this efficiency. This indicator, in turn, is represented by a numerator and a denominator (measurement of activity *versus* measurement of energy consumption). Philipsen et al. (1997) present two general energy efficiency indicators: Economic (energy intensity) and physical (specific energy consumption). The economic indicators are more applicable in an aggregate level, and the physical indicators in a disaggregated level. Figure 6 shows the graph of the energy intensity index measured in terms of TOEs per USD 1,000.

Note that the bars in Figure 6[12] can be interpreted as showing how much energy each sector spends to generate USD 1,000 of GDP.

Through Figure 6, it becomes clear that there is a considerable difference between the industrial and non-industrial sectors. Through Figure 6 and Table 3, it can also be observed that the sectors with the highest energy intensity have higher income elasticity. Figure 7 shows the evolution of the energy intensity index during the period 2002-2011.

In Figure 7, the numbers show that this indicator has increased year after year in Brazil, i.e., with each year, more energy is spent to produce the same monetary value in various sectors. The signatures of Figures 6 and 7 are in accordance with Lucon and Goldemberg (2009), who reported that, in terms of energy intensity, Brazil was the only country to regress (stay above the 100% line) during the period 1990-2005. In a study of the energy content of the exports of 30 countries, Amador (2012) notes that the energy content of exports from Taiwan, China, India, and Brazil grew to be above the world average. In a energy analysis of pulp and paper industry through an energy decomposition Fracaro et al. (2012) estimated there is still a potential reduction of 146.2 PJ and 7.8 PJ in fuels and electricity consumption, respectively.

It can be argued that if there is an increase in efficiency, the elasticities tend to be smaller, given that a growth in income does not cause an explosive growth in consumption. One factor to consider in developing countries such as Brazil is the "pent-up demand" factor, meaning many people's needs remain unmet. This can be seen clearly when comparing the energy consumed per capita in developed countries - USA (6.81 TOE), Finland (6.15 TOE), Sweden (5.27 TOE), the Netherlands (4.69 TOE), Germany (3.82 TOE), and Denmark (3.10 TOE)-with the energy per capita of developing countries-South Africa (2.68 TOE), China (2.14 TOE), Brazil (1.42 TOE), and India (0.64 TOE) (IEA, 2014b). The pent-up demand factor can cause elasticity consumption to increase, even in the hypothesis of greater efficiency.

5. CONCLUSION

The aim of this paper was to estimate and analyze the income elasticities of Brazil's energy matrix, represented by the supply and consumption of energy. The following questions were dropped: What energy sectors or products are more sensitive to economic growth? If there are differences, what could explain such differences? Is it possible to conclude that there are sectors that are more efficient than others?

12 Non-metals corresponds to the cement and ceramics industries, metallurgy corresponds to the iron, steel, iron-alloys and non-ferrous metallurgical and other metallurgical products.

Figure 5: Energy consumption elasticities by sector and share in total consumption

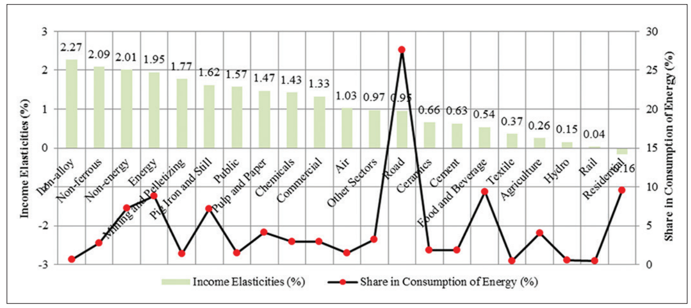
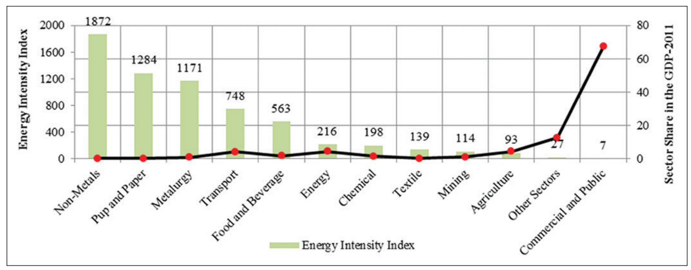
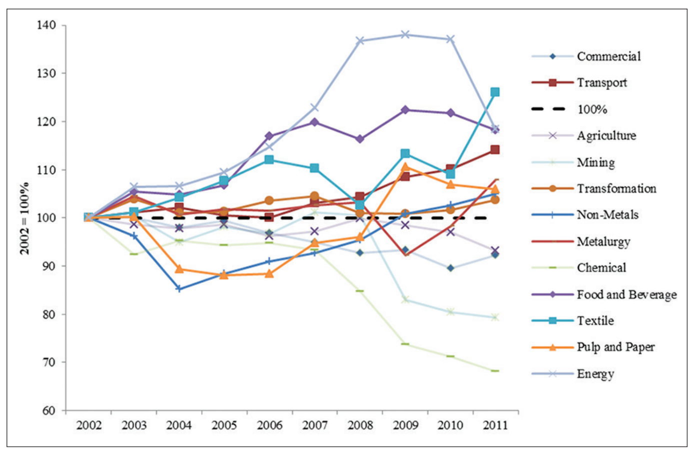


Figure 6: Sector energy intensity index and sector share in the gross domestic product



Source: Compiled from Balanço Energético Nacional's historical data

Figure 7: Energy intensity comparison based on the year 2002



Source: Compiled from Balanço Energético Nacional's historical data

In a general context, the ANCOVA-EC model was satisfactory to compare elasticities, mainly income and price. The signatures of the elasticities can be compared in Chart 1, where different methods were used, but also in general, to estimate the elasticities of electricity.

The estimate D can be considered a viable alternative, given the limitation that it can only be interpreted through the income effect and the price effect, although the income effect tends to beat the price effect due to its greater elasticity. Regarding the Chow test, significant change from one period to another can be confirmed with respect to the growth rate, although there was no evidence of changes in the slope, i.e., in the very elasticities when compared to income (GDP). A cointegration was found in most estimates, one that had not been found before, with a simple regression that considered only the variables' income (GDP) and energy consumption.

We can conclude that we have reached the main objective of the study, which was to compare elasticities while supporting our specific objectives. What energy sectors or products are more sensitive to economic growth? If visually analyzed through the charts (3 to 5), elasticities were different among all groups calculated, i.e., supply and demand by source or sector. We found that there are energy sectors and products more sensitive to economic growth, such as the naphtha, natural gas and ethyl alcohol for energy products or iron alloy, non-ferrous and non-energy for sectors, throwing light on the first specific purpose.

Considering the second question: What could explain such differences? The task of explaining the differences was accomplished by identifying that the elasticities were higher in the energy-intensive sectors, and that energy products had the greatest growth in Brazil's Energy Matrix. Is it possible to conclude that there are sectors that are more efficient than others? Still, visually speaking, in Figures 5 and 6, the shape of distribution of elasticities is similar to the shape of distribution of the energy intensity index. It could be the beginning of evidence that the least efficient sectors, energy-wise, have higher elasticities. The chart in Figure 7 identifies that industries like Chemical and Mining increased their efficiency, but on the other hand, several sectors are above the line of 100%, as: Energy, Food and Beverage, Transport, Pulp and Paper, No-Metals, Metallurgy and Transformation, generating generating evidence to conclude that some sectors are more efficient than others.

This study was not intended to exhaust all possibilities of analysis on the implementation of the ANCOVA-EC model, given the sectorial specificities. We recognize that the modeling of many stochastic processes, although limited to some homogeneous point, has been a surprise in the significance items, adjustment, and the residuals stationarity test.

We suggest future studies with other comparative methods, or even targeting some sectors such as industry and transportation, using a production efficiency and elasticity approach by applying methods such as data envelopment analysis (DEA) or stochastic frontier analysis (SFA). Possible studies could compare, for example: Why do paper and pulp have an energy intensity index greater than metallurgy, which includes pig iron, steel, iron-alloys, and non-ferrous, which historically demand more energy?

The comparison of the sectorial energy efficiency is recognized as a major project involving the development of specific methodologies for this aim, given the difficulty of establishing a threshold parameter between energy efficiency and inefficiency when working with sectors.

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