Spatial Interactions between Energy and Energy-Intensive Sectors in the Brazilian Economy: a field of influence approach

Gervásio F. Santos
Eduardo Amaral Haddad
Joaquim J. M. Guilhoto
Denise Imori

Preliminar Version

The objective of this paper is to evaluate the spatial interactions among energy-intensive sectors and the Brazilian regional economies. Energy-intensive sectors play an important role in the economy due the strong links with the other economic sectors. For this reason, the knowledge about spatial interactions between these sectors and regional economies allows a more accurate evaluation of the regional impacts of disturbances from energy markets or energy policy. To evaluate these interactions were considered the spatial heterogeneity of both economic activity and the Electricity-intensity of economic sectors. Based on the field of influence method, electricity-intensity coefficients were used to extract the analytically important sectoral and spatial energy links in the Brazilian economy. The results showed that, despite of the fact that the energy-intensive sectors in Brazil are spatially concentrated in the Center-South o Brazil, the most important spatial energy links are not located in this region.

Key words: Energy-intensive sectors; energy field of influence; spatial energy links.

1. Introduction

Brazilian economy is considerably heterogeneous and marked by a high degree of spatial concentration. Despite the government policies designed to decrease this concentration, the real effects of this policies were modest (Haddad (1999). Into these policies, energy-intensive sectors and energy sectors were in the core of the development policies of the country in the 1970's. As a consequence, these sectors strengthened the sectoral and spatial links in the Brazilian economy. Specifically regarding the electricity sector, it has been under reforms that are changing sharply the price levels. On the other hand, energy policy has stimulated energy diversification to increase the inter-fuel substitution. These policies might have changed the sectoral and regional electricity-intensity in Brazil. Into this context, the paper is concerned to find spatial energy links in the Brazilian economy considering the spatial heterogeneity of the economy.

Spatial concentration of energy-intensive sectors in Brazil follows the same pattern of the spatial concentrations of the whole economy. In 2004, 82.6% of the value-added of the energy-intensive sectors were located in the Center-South region (South-East and South) of Brazil. However, electricity consumption of these sectors represented 70.6% of the total amount consumed by the energy-intensive sectors. This 10% difference is regard to a set of regional factors such as energy diversification, product differentiation which increase value-added, economies of scale and more efficient use of energy. For this reason, there is a considerable spatial heterogeneity of the electricity-intensity in energy-intensive sectors. The question that emerges in this paper is: what are the most important sectoral and spatial energy links in the Brazilian economy?

After this introduction, Section Two describe the energy-intensive sectors in the context of energy supply and demand in Brazil. In the Section Three, the spatial distribution of energy-intensive sectors and respective electricity-intensity is presented. The Section Four is designed to present the methodology of energy field of influence used to extract sectoral and spatial energy links in the Brazilian economy. Data requirements are presented in the Section Five. The results are discussed in the Section Six. Finally, in the Section Seven, some final remarks are summarized.

2. Energy and Energy-Intensive Sectors

Energy-intensive sectors have played an important role in the Brazilian economy. In the 1970's, after the first oil shock, the government strategy to strength the national industry places the intermediate goods, energy and transport sectors in the core of the development process[1]. The goals were to transform natural resources in currency, substitute imported for domestic goods and minimize the problems from the first oil shock. To implement this strategy, government and private investments were channeled towards the energy sectors (Petroleum, Coal and Gas, Electricity) intermediate goods (Metallurgy of Iron, Steel, Aluminum and Others; Chemical;

[1] This strategy was institutionally introduced into the government plan entitled "II National Plan of Development" from 1975-1974. This plan succeed another plan, the "I National Plan of Development" from 1972-1974.

Non-metallic Minerals; Paper and Pulp), capital goods (Transport Equipments, Mechanical and Electric, and Others), Transport Services (Road, Railroad, Ports, Airports and Others) and Communications (Batista, 1987, p. 70). Besides the changes in the structure of the energy supply, this strategy also strengthened the links among industrial sectors and regions in Brazil.

Despite the persistence of industrial concentration in the Center-South of Brazil, the development strategy in the 1970's had strong implications for the industrialization process. Table 01 shows the structure of the Brazilian industry from 1970 to 1980. As can be seen, the energy-intensive sectors (Products of Non-metallic Mineral, Metallurgical, Mechanics, Paper and Pulp and Chemistry) increased the share in the industrial production. Furthermore, the capital goods (Mechanics and Electrical Equipment and Communications) also increased the share in the industrial production.

Table 01: Shares of the industry sectors in the Industrial Production Value (1970-1980)

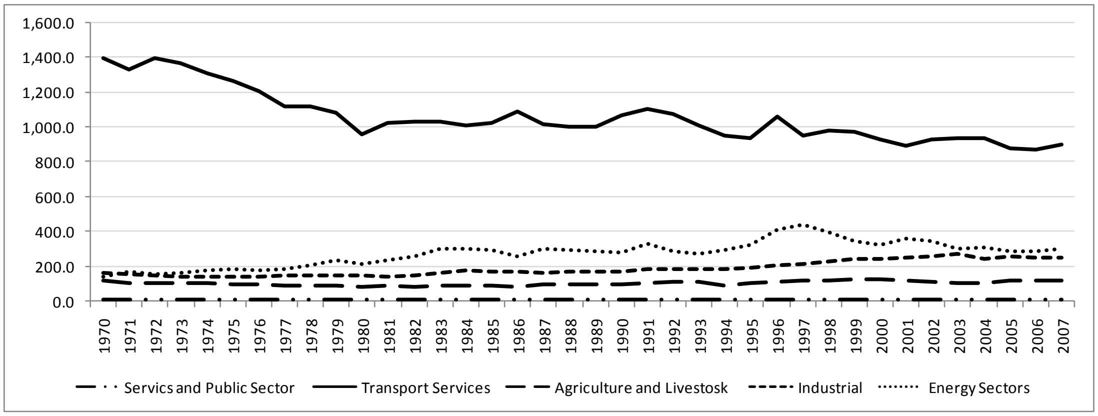
Sectors	1970	1980	Variation
Mining Industry	1.6%	1.4%	-
Food, Beverages and Tobacco	22.7%	15.4%	-
Products of Non-metallic Minerals	4.1%	4.2%	+
Metallurgical (Iron, Steel and Aluminum and Copper)	12.3%	13.7%	+
Mechanics	5.6%	7.6%	+
Electrical Equipment and Communications	4.6%	5.2%	+
Transport Equipments	8.1%	7.8%	-
Paper and pulp	2.4%	2.7%	+
Chemistry	10.7%	19.2%	+
Textiles, clothing and footwear	12.5%	10.3%	-
Other	15.5%	12.5%	-
Total	**100.0%**	**100.0%**	

Source: Brazilian Institute of Geography and Statistics.

A part from the import substitution and the strengthening of sectoral links of the economy, the structural change in the Brazilian industry led to a considerable increasing in the industrial energy consumption. From 1970 to 1980, the share of final energy consumption (from all sources) by industrial sector in Brazil increased from 27.7% to 35.9% of total consumption. After a period of stagnation of Brazilian industry in 1980's and 1900's, which maintained this share around 35.0%, the industrial energy consumption started to increase again in 2000 and in 2007 it was 38.0% of national consumption.

Because the oil shocks, the period from 1970 to 1980 was a period of adjustment of energy consumption in Brazil. In this period, the energy-intensity coefficient (TOE/(10^6 US$ GDP))[2] for the whole economy (sectoral and household total energy consumption) decreased from 202.8 to 149.0. However, after this period the energy-intensity started a mild increase and in 2007 it was of 164.1.

Figure 01: Energy-intensity (TOE/10^6 US$ GDP) in Brazil (1970-2007)



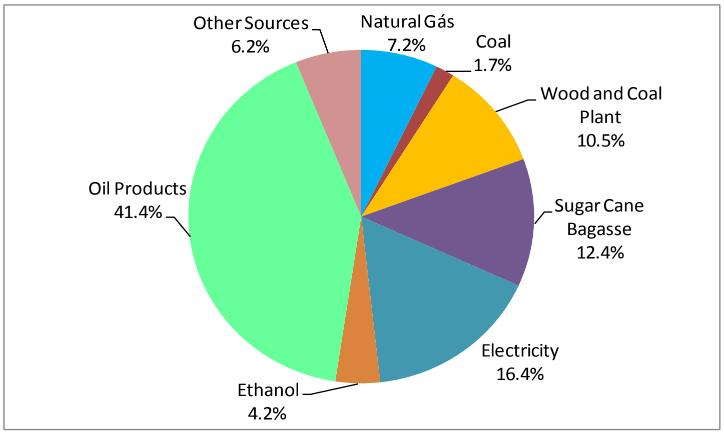
Source: Brazilian Energy Balance.

At the sectoral level, as can be seen in the Figure 01, transport services and industrial sectors presented a considerable adjustment between 1970 and 1980. The more efficient energy use and the investments in infrastructures contribute to decrease the energy-intensity coefficient of transport services sectors from 1,395.7 in 1970 to 961.2 in 1980. This coefficient remained at the same level in the last two decades and in the 2007 was at 899.5. Regarding the industrial sectors, the energy-intensity decreased from 161.5 to 147.4 from 1970 to 1980. In 2007 it was at 248.7.

The main cause of reduction of energy-intensity coefficient in Brazil in the 1970's was the national policy to substitute fossil fuel for renewable energy sources; specially hydroelectricity and ethanol form sugar cane. Although there was a considerable economic growth in that period, the share of renewable resources in the total of energy supply was maintained at 80.0% by 1980 when it started to decrease. In 2007 this share was at 50.0% which is still high, comparing to the other countries. For this reason, the success of the strategy was to postpone of increase of the share of fossil fuel in the Brazilian energy supply. In this context, the importance of hydroelectricity might be highlighted.

[2] The TOE refers to Ton of Oil Equivalent and GDP is valued at US$ of the 2007 year.

Figure 02: Structure of Energy Consumption in Brazil in 2007.



Source: Brazilian Energy Balance.

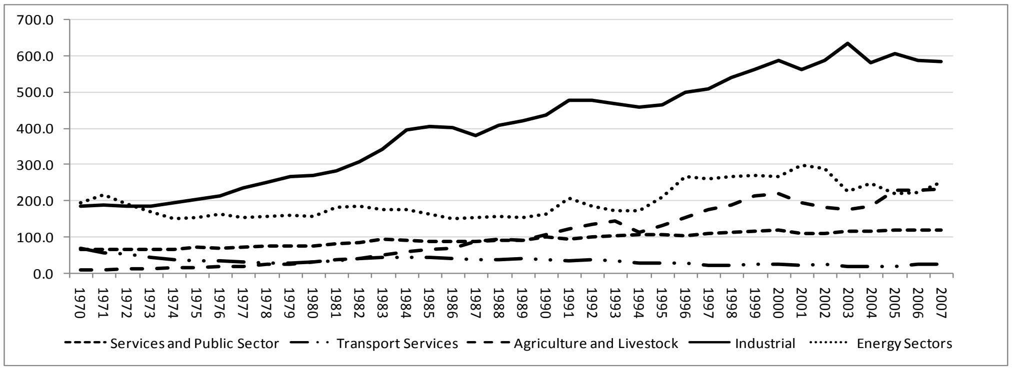
The investments in large hydroelectric plants such as Itaipu in the South region and Tucuruí in the North region increased the importance of electricity for the energy supply in Brazil. From 1970 to 1980 the final consumption of electricity increased 116.0% and its share in the total energy supply increase from 5.5% to 10.1%. Because of the continuity of investments, in 2007 this share was at 16.4% (Figure 02).

The industrial sectors are responsible for a significant amount of electricity consumption in Brazil. In 2007, the total consumption amounted 412.1 million of Megawatts hour (MWh). The industrial consumption represented 46.7% of this amount. This share always remained about 50.0% 1970 to 1995, depending on the period of discontinuity of economic growth. However, after 1995, the share rigidly remained below 48.0%. This happened because of two main reasons. The first was the economic recession from 1995 to 2002. The second was substitution process by other sources such as natural gas and sugar cane bagasse in the Center South of Brazil after 1999 and the energetic efficiency programs.

The electricity-intensity coefficient (MWh/(10^6 US$ GDP))[3] in Brazil presented a increasing trend in the last years. I was at 129.5 in 1970 and increased to 313.7 in 2007. At the sectoral level, the Figure 03 shows that the industrial sector presented a considerable increasing of electricity-intensity. It was at 183.5 in 1970 and in 2007 at 584.7. However, although it presented a historic increasing trend, it has declined after 2003.

[3] The MWh refers to Megawatt hour and the GDP is valued at US$ of the 2007 year.

Figure 03: Electricity-intensity (MWH/10^6 US$ GDP) in Brazil (1970-2007)



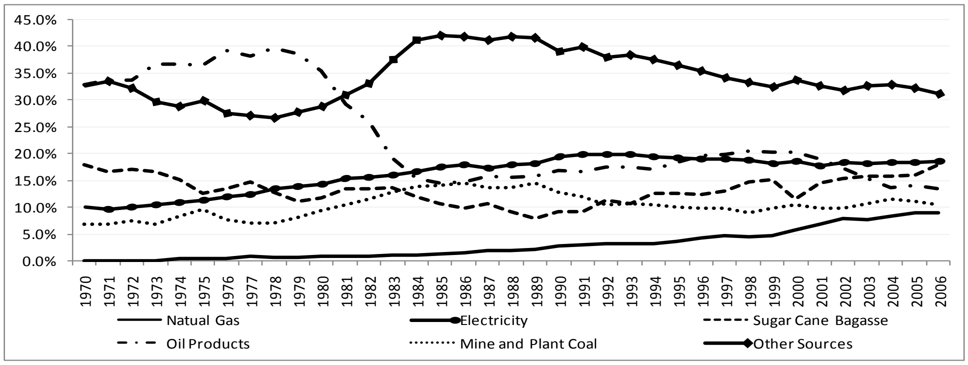
Source: Brazilian Energy Balance.

The recent declining of electricity-intensity coefficient in the industry sectors (from 633.6 in 2003 to 584.7 in 2007) might be explained by a set of interdependent elements that have impacted the electricity supply. The first one is the prices increases of industrial electricity because of the finance recovery of the electric sector during the reforms initialized in 1995. The electricity average prices for industrial sectors increased 396.9% from 1995 to 2007. As a consequence, there were some reactions such as: more efficient use of electricity into the production process; displacement to more elaborated products into the same sectors (diversification) to increase the value-added of the production; increase of economies of scale and; substitution of electricity for cheaper sources of energy[4].

On the other hand, Brazilian energy policy is characterized by diversification of energy sources. Into this policy, the substitution of electricity for natural increased continuously in the last years. Further the increase of national production, in 1999 Brazil started to import natural gas from Bolivia. The location of pipelines which transport the product from Bolivia is strategic on the Brazilian economic space. It intersects the states of Mato Grosso do Sul, Rio de Janeiro, São Paulo, Paraná, Santa Catarina and Rio Grande do Sul. This region is responsible for 71% of the energy consumption of the country, 82% of the industrial production and 75% of the national GDP. As a consequence, the consumption of natural gas by industrial sectors increased considerably, after 1999.

[4] Apart from these elements, the year of 2002 was market by uncertainties of supply because of the electricity rationing, which led the industrial consumers to increase the substitution of electricity for other sources.

Figure 04: Industrial consumption of energy in Brazil (1970-2007)



Source: Brazilian Energy Balance.

Figure 04 shows the evolution of the consumption of different energy sources in the industrial energy consumption in Brazil. As can be seen, the share of natural gas has increased from 0.0% in 1970 to 9.0% in 2007. In the same period, the share of electricity increased from 9.8% in 1970 to 19.8% in 1993 and after that has stopped around 18.0%. This fact, jointly with the factors described in the above paragraphs, lead to conclude that declining of electricity-intensity of industrial might represent a structural change in the Brazilian industry regarding electricity consumption.

It might be hypothesized that disturbances in energy supply impact differently the economic activity on the space. In the Brazilian economic space, the spatial heterogeneity founded in the high concentration of the industrial activity in the Center-South of Brazil always must be considered in regional studies. Apart from this, the considerable diversification of energy sources, which are substitutes for electricity by industrial sectors, also are marked by the spatial heterogeneity in the Brazil. For this reason it is possible to remark that spatial heterogeneity of electricity-intensity must be considered to evaluate regional impacts of different energy policy in Brazil.

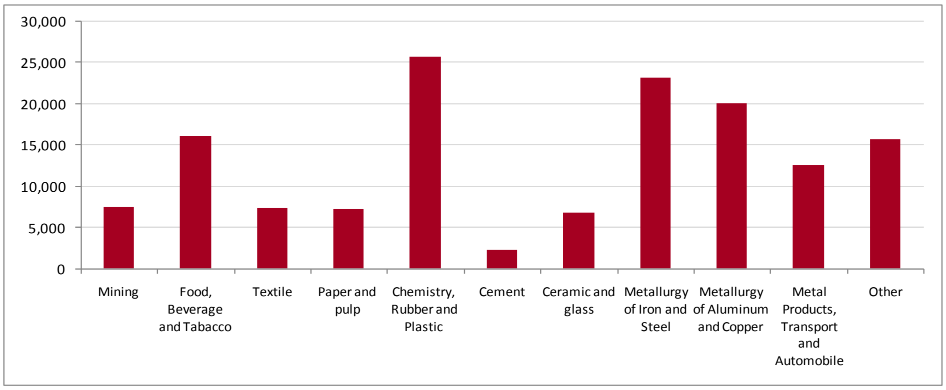
3. Spatial heterogeneity of Industrial sectors and Electricity-intensity

In this paper, the energy-intensive sectors are the sectors which energy represents more than 10% of the intermediate inputs costs. These sectors in Brazil are: Mining (ore, coal and other minerals); Food and Beverage and Tobacco[5]; Textile; Paper and Pulp; Chemistry, Rubber and

[5] The presence of Tobacco is due to the level of aggregation of National Accounts used in the paper.

Plastic Products; Cement; Ceramic and Glass; Metallurgy of Iron and Steel; Metallurgy of Aluminum and Copper and; Metal Products (less energy-intensive). The industrial production in Brazil was responsible for 25.1% of the national GDP in 2007 and the energy-intensive-intensive sectors represented 40.6% of this industrial production

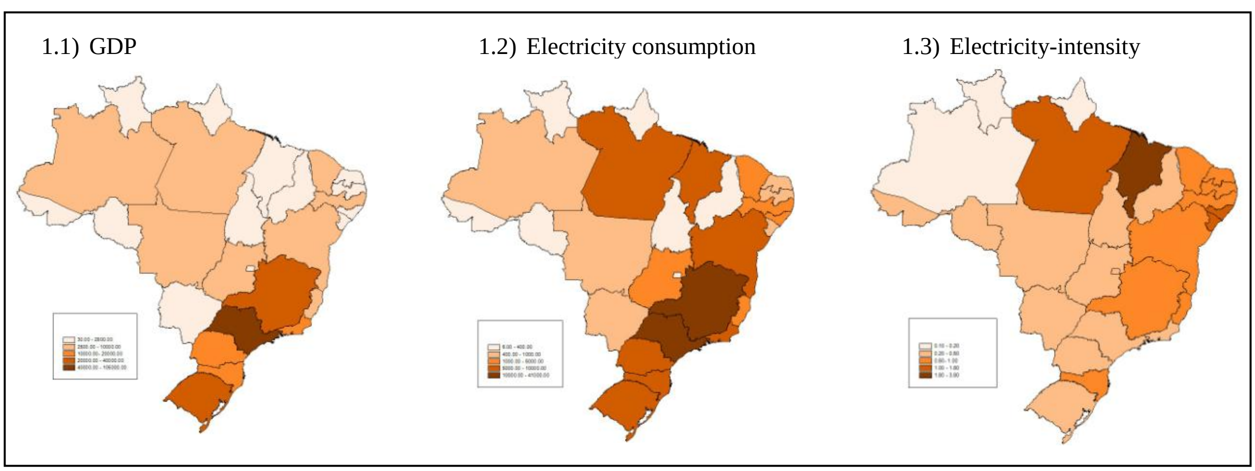
Figure 05: Electricity Consumption (GWH) of industrial sectors in Brazil (2004)



Source: Brazilian Electricity Regulatory Agency.

The electricity consumption of these sectors represents 80.0% of industrial consumption and 37.3% of national consumption. Figure 05 shows this electricity consumption in GWh in Brazil. As can be seen, Chemistry, Rubber and Plastic Products are the greatest consumers, followed by the Metallurgic sectors and Food, Beverage and Tobacco. The distribution of this consumption on the space might bring interesting spatial patterns of Electricity-intensity.

Figure 06: GDP, Electricity consumption and Electricity-intensity of energy-intensive sectors in Brazil - 2004



The Figure 06 shows the spatial distribution of GDP, electricity consumption and electricity-intensity (GWh/GDP) of energy-intensive sectors in 2004, using data from Brazilian Electricity Regulatory Agency and National Accounts. As can be seen, the GDP of energy-intensive sectors is considerable concentrated in the Center-South of Brazil. However, the electricity consumption is less concentrated. As a result, the largest electricity-intensity coefficients are located in regions more distant from Center-South, in the states of the North and Northeast regions. The same phenomenon is verified in individual sectors.

The implications of this spatial heterogeneity of electricity-intensity face to the magnitude of production value of the energy-intensive constitute an important element to be analyzed. In the next section a method to use these set of information to extract the important energy links in the Brazilian economy will be described.

4. Energy field of influence

The field of influence method is belongs to the disequilibrium-based methods. The starting point of these methods departs from disturbances in as existing system to generate a new equilibrium comparable to the original one. Commonly known as sensitivity analysis, under field of influence approach, it usually has two main uses. First, one might consider small coefficient changes in order to assess how "influential" a coefficient or a set of coefficients is to the system as a whole; secondly, for known structural changes, one might be interested in assessing the impacts of given functional changes. It is important to notice that disequilibrium-base methods all have corresponding changes in the equilibrium-based methods, as the former is rooted in the comparison of various equilibrated systems.

The concept of field of influence (Sonis and Hewings, 1989, 1992) is mainly concerned with the problem of coefficient change, namely the influence of a change in one or more direct coefficients on the associated Leontief inverse. Since, given an economic system, some coefficients are more "influential" than others, the sectors responsible for the greater changes in the economy can be determined. In the simplest case, *i.e.*, the case in which a small enough change, ε, occurs in only one input parameter, a_{ij}, the basic solution of the coefficient change problem may be presented as follows. Define:

$A = \|a_{ij}\|$ is the matrix of direct input coefficients;

$E = \|\varepsilon_{ij}\|$ is the matrix of direct input coefficients;

$B = (I - A)^{-1} = \|b_{ij}\|$ is the Leontief inverse before changes;

$B(\varepsilon) = (I - A - E)^{-1} = \|b_{ij}(\varepsilon)\|$ is the Leontief inverse after changes;

Using the notion of inverse-important input coefficients, which is based on the conception of the field of influence associated with the change in only one input coefficient, assume that this change occurs in location (i_1, j_1), that is,

$$\varepsilon_{ij} = \begin{cases} \varepsilon & i = i_1, j = j_1 \\ 0 & i \neq i_1, j \neq j_1 \end{cases} \qquad (1)$$

The field of influence can be derived from the approximate relation:

$$F(\varepsilon_{ij}) \cong \frac{[B(\varepsilon_{ij}) - B]}{\varepsilon_{ij}} \qquad (2)$$

Where $F(\varepsilon_{ij})$ is the matrix of the field of influence of the change on the input coefficient, a_{ij}. For every coefficient, a_{ij}, there will be an associated field of influence matrix. In order to determine which coefficients have the greater field of influence, reference is made to the rank-size ordering elements, S_{ij}, from the largest to the smallest ones. Therefore, for every matrix $F(\varepsilon_{ij})$, there will be an associated value given by:

$$S_{ij} = \sum_{k=1}^{n} \sum_{l=1}^{n} [f_{kl}(\varepsilon_{ij})] \qquad (3)$$

Thus, from the values of S_{ij}, a hierarchy can be developed of the direct coefficients based on their field of influence, *i.e.*, ranking sectoral relations in terms of their sensitivity to changes, in a sense that they will be responsible for more significant impacts on the economy.

The field of influence method has been used for different purposes in the regional science (Guilhoto, *at ali*, 1999, Sonis and Hewings 1992). Haddad and Hewings (2007) used the method to extract the analytically important transportation links in the Brazilian economy. The authors concluded that is possible to use the method identify strategic transportation links in the context of an interregional system. The finding of Haddad and Hewings will be used to extract sectoral and spatial strategic energy links in the Brazilian economy.

Based on energy consumption and the production value of each sector, it is possible to find an energy-intensity vector g_j. Taking the diagonal vector $\hat{g}$, it is possible to obtain

$$G = \hat{g} * (I - A)^{-1} = \|g_{ij}\| \quad (4)$$

where G is an $n \times n$ energy matrix, which $\|g_{ij}\|$ matrix represents the direct and indirect energy requirements incorporated in each economic transaction from i to j.

Based on the field of influence concept and in the small change ε in the coefficients a new matrix might be extracted,

$$G(\varepsilon) = \hat{g} * (I - A - E)^{-1} = \|g_{ij}(\varepsilon)\| \quad (5)$$

which is the energy matrix after changes.

In the same way that the traditional field of influence, the energy field of influence can be finally derived from the approximate relation:

$$H(\varepsilon_{ij}) \cong \frac{[G(\varepsilon_{ij}) - G]}{\varepsilon_{ij}} \quad (6)$$

The $H(\varepsilon_{ij})$ is the matrix of the energy field of influence of the change on the input coefficient, a_{ij}, so that for every coefficient, a_{ij}, there will be an associated energy field of influence matrix. This method allows to determine which coefficients have the greater energy field of influence using the same rank-size ordering elements, J_{ij}, from the largest to the smallest ones, where

$$J_{ij} = \sum_{k=1}^{n} \sum_{l=1}^{n} [h_{kl}(\varepsilon_{ij})] \quad (3)$$

As a result, the method will allow finding the most analytically important energy links in the economy, at the sectoral or spatial level, depending on the use of a single region or interregional input-output model used to calculate the field of influence.

5. Data requirements

An interregional input-output table disaggregated to representing the Brazilian economy in 30 sectors and 27 regions was used to obtain the technical coefficient matrix *A.* In addition, physical units of Electricity consumption in GWh also were obtained from the Brazilian Electricity Regulatory Agency. Using this data, it was calculated the vector $\hat{g} = GWH/(Gross\ Production\ Value)$ for each sector and region.

Table 02 presents the sectors of the interregional input-output table.

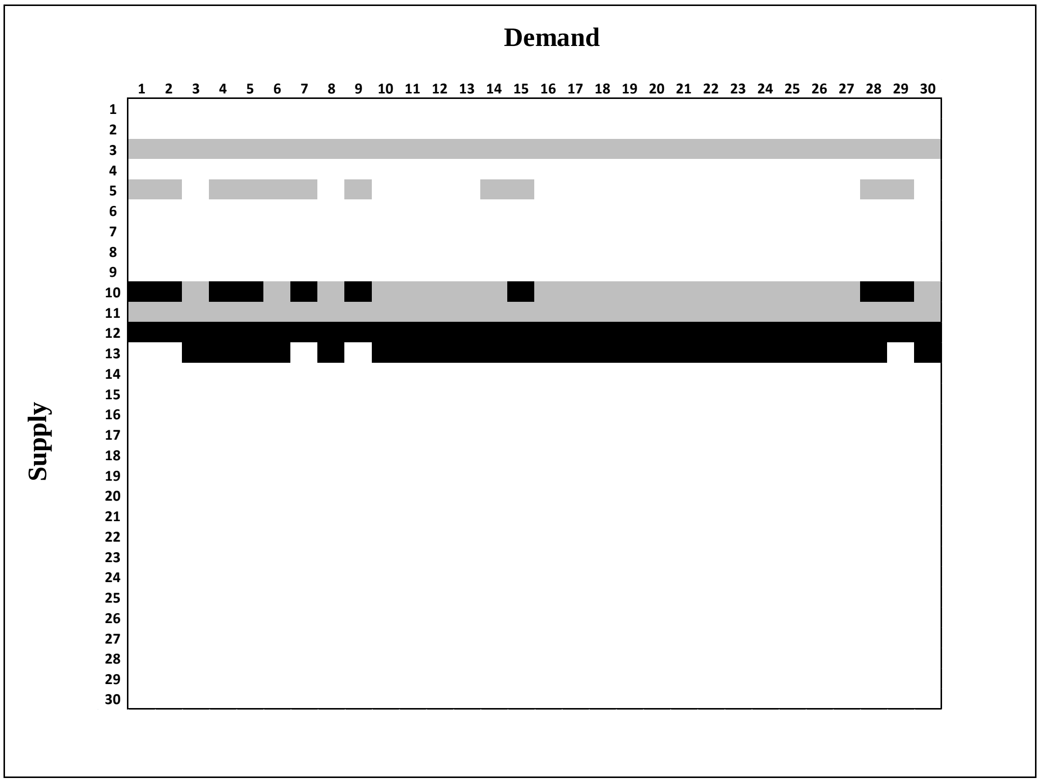
Table 02: Sectors of interregional input-output table

Order	**Sectors**	**Average of Electricity- intensity**
1	Agriculture and Livestock	0.072
2	Mining (Oil and Gas)	0.021
3	Mining (Ore, Coal and Other Minerals)	0.249
4	Food, Beverage and Tobacco	0.064
5	Textile	0.213
6	Paper and Pulp	0.192
7	Oil Refining	0.013
8	Ethanol	0.018
9	Chemical, Rubber and Plastic	0.122
10	Cement	0.329
11	Ceramic and Glass	0.275
12	Metallurgy of Steel and Iron	0.339
13	Metallurgy of Aluminum and Cooper	0.958
14	Metal Products	0.054
15	Other Industries	0.061
16	Electricity – Hydro	0.037
17	Electricity - Thermo Fuel Oil	0.037
18	Electricity - Thermo Coal	0.037
19	Electricity - Thermo Diesel	0.037
20	Electricity - Thermo - Natural Gas	0.037
21	Electricity - Thermo - Sugar Cane Bagasse	0.037
22	Electricity - Thermo Other Sources	0.037
23	Utility - Electricity Distribution	0.037
24	Utility - Gas Distribution	0.037
25	Utility -Water distribution and Sanitation	0.037
26	Construction	0.006
27	Trade	0.045
28	Transport Services	0.006
29	Services	0.043
30	Public	0.082

6. Empirical results

Figure 07 shows the sectoral energy field of influence for 30 sectors of Table 02. As can be seen, the most important links (in black) in the Brazilian economy are created by the sector 10,12 an13. Other important links are created by the sectors 3,5 and 10. All this sectors has the higher electricity-intensity among the 30 sectors.

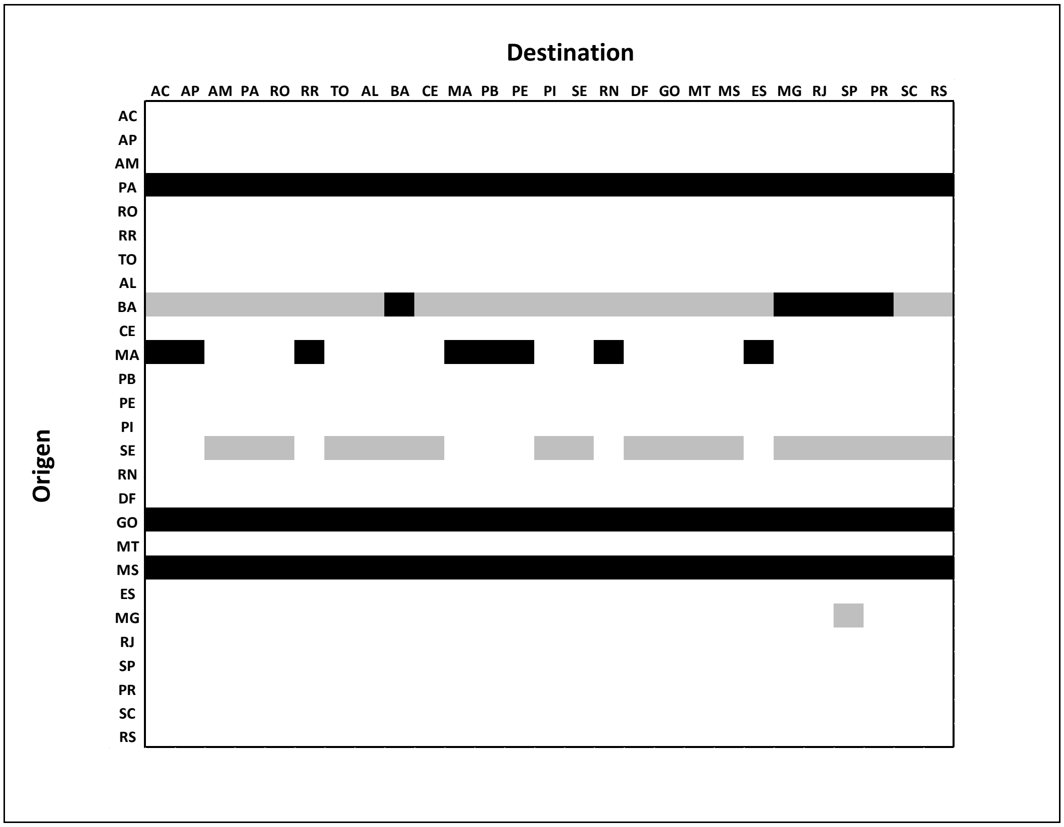
Figure 07: Sector Energy Field of Influence



Regarding the spatial energy links, figure 08 shows the links among Brazilian states. As can be seen, five states have the most important energy links in the Brazilian economic space. Pará (PA), Bahia (BA), Maranhão (MA), Goiás (GO) and Mato Grosso do Sul (MS) have the most important links with all states. Less important links are established by BA and Sergipe (SE). It must be highlighted that all these states are producers or electricity-intensity products. An odd result were the links created by GO and MS, because the two states are not large electricity-intensity producers. However, although these states produce just a small quantity of Cement, this production has the highest electricity-intensive of the country. On the other hand, although the states of the Center-South of the country - São Paulo (SP), Minas Gerais (MG), Rio de Janeiro

(RJ), Paraná (PR), Santa Catarina (SC) and Rio Grande do Sul (RS) – are the largest electricity-intensity producers, they have no important energy links. This result is a direct consequence of the small electricity-intensity coefficient of these states in the energy-intensive production because the high inter-fuel substitution (See Figure 06).

Figure 08: Spatial energy Field of Influence



The results above show that the methodology might bring some problems into the results. Both sectoral and spatial energy links are strongly influenced by the electricity-intensity coefficient. As a consequence, the sectors and states with the largest coefficients were responsible for the most important links. Although the use of different coefficients for the same sector in different states is a correct proceeding, the sensitivity of the results to the electricity-intensity coefficient minimizes the importance production value of the states. For this reason, a qualitative sensitivity analysis is necessary to extract some conclusions about the results.

7. Final Remarks

In this paper it was highlighted the importance of energy-intensive sectors and energy sectors for the Brazilian economy. Data about industrial energy consumption showed that the structure of electricity consumption has changed in the last years. In addition, also it was verified that there is a considerable spatial heterogeneity in the production of energy-intensive products and in the electricity-intensity of the respective sectors. The field of influence method was used to extract the sectoral and spatial energy links in the Brazilian economy.

The results showed that the sectoral energy links are created by the energy-intensive sectors as direct consequence of the electricity-intensity. Regarding the spatial energy links, despite of the fact that the energy intensive production is concentrated in the Center- South of Brazil, there is no important energy link in the region. This is consequence of the low electricity-intensity coefficient of energy-intensive sectors in this region. However the results are no robust because the strong influence of the electricity-coefficient on the results, which minimizes the importance of the production value of the large producers.

References

Balanço Energético Nacional (2008). Ministério de Minas e Energia. Brasília – DF.

Batista, J. C. (1987). "A estratégia de ajustamento externo do Segundo Plano Nacional de Desenvolvimento". *Revista de Economia Política*, Rio de Janeiro, v.7, nº 2, p. 66-80.

Haddad, E. (1999) Regional Inequality and Structural Changes: Lessons from the Brazilian Economy. Ashgate, Aldershot.

Haddad, E., Hewings, G. (2007) Analytically Important Transportation Links: A Field Of Influence Approach To Cge Models. Proceedings of the 35th Brazilian Economics Meeting - Brazilian Association of Graduate Programs in Economics.

GUILHOTO, J. J. M. ; SONIS, Michael ; HEWINGS, Geoffrey J D (1999). Multiplier Product Matrix Analysis for Interregional Input-Output Systems: An Application to the Brazilian Economy. Discussion Papers Regional Economics Applications Laboratory University Of Illinois, Urbana, Illinois, EUA, v. 99-T12.

Sonis, M. and Hewings, G. J. D. (1989). “Error and Sensitivity Input-Output Analysis: A New Approach”. In: R. E. Miller, K. R. Polenske, ande A. Z. Rose, (Eds.). Frontiers of Input-Output Analysis. New York, Oxford University Press.

Sonis, M. and Hewings, G. J. D. (1992). “Coefficient Change in Input-Output Models: Theory and Applications”. Economic Systems Research, 4:143-157.