# Brazilian productive structure and CO2 emissions

Imori, Denise and Guilhoto, Joaquim José Martins
University of São Paulo

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# Brazilian Productive Structure and $CO_2$ emissions

**Denise Imori**
*Institute for International Relations – University of São Paulo (IRI – USP)*

**Joaquim José Martins Guilhoto**[1]
*Economics Department of FEA – University of São Paulo*
*Regional Economics Applications Laboratory (REAL) – University of Illinois*
*CNPq Researcher*

**Abstract**

This paper analyzes the relation between economic performance and $CO_2$ emissions in Brazil, in the year 2004. The contribution of the productive sectors to total emission is established, taking into account the technological structure of the economy, the interrelations among sectors, the sectoral capacity of generating value-added and the participation of final demand in the national sectors. For this purpose, an input-output model is used to analyze the impact of income generation and final demand on the emissions. This approach allows one to study the impacts caused by sectoral mitigation policies. The main results show that, both from a production and a demand perspective, the same key productive sectors stand out, especially the Transport sector.

Key words: Environmental Economics, $CO_2$, Brazil, Productive Structure, Input-Output.

## 1. Introduction.

One of the more pressing questions in the contemporary world is, incontestably, the climatic change of the planet and its disastrous implications. In consequence, several international regulations, more or less successfully, intend to restrain emissions of greenhouse gases, especially the $CO_2$. Although Brazil, as a developing country, does not join the group of countries obliged to control their emissions in the contemporary normative framework, the uncertainty about the environmental negotiations and the modifications in its energy matrix imply some worries about its generation of carbon.

Pollution can be alleged, in great measure, as a by-product of the economic sectors – more particularly, of the energy use necessary to these processes.[2] In order to estimate the costs of pollution control, in terms of decrease in production value and other economic aggregates, it is necessary, therefore, to analyze the productive structure of the economy,

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[2] According to Ministry of Science and Technology (2004), in 1994 the energy consumption and industrial processes were responsible for only 24.6% of the total $CO_2$ emissions in Brazil – three quarters of the emissions of this pollutant, in that year, originated from the activity of preparation of agricultural areas and from the deforestation to other uses. Such result can be related to the fact that, in Brazil, there is a large utilization of renewable energy sources, which are less polluting than fossil fuels, as well as to the intensity of deforestation. This parcel of emission, originated mainly in the forest fires, could not be taken into account in the present work, which analyzed only the pollution consequential to the sectoral energy consumption and to the industrial processes.

as well as the costs of that control, resulting from, for example, the implementation and operation of supervision instruments for the execution of the environmental policies.

The present work intends to understand the relations between the economic activities and the $CO_2$ emissions in Brazil, in the year 2004. One analyses the participation of the several productive sectors in these emissions, taking into account the technological structure of the economy, the sectoral interrelations, the capacity for the generation of value added and the final demand of the national sectors.

In view of this, the input-output methodology will be applied, under both production and consumption perspectives, in order to analyze the impact of income generation and final consumption on the $CO_2$ emissions of the economy.

### 1.1. World energy consumption and environmental framework.

In relation to climatic change, the risks imposed by the current energy consumption are alarming – in 1998, about 80% of the world consumption of primary energy were composed by fossil fuels (coal, petroleum and natural gas). The majority of scientists agree that the greenhouse gases, mainly carbon dioxide, produced in the burning of these fuels, are greatly responsible for the harmful changes in the Earth's climate. If one is correct when forecasts that, in 2050, the $CO_2$ emissions will be doubled in relation to the current levels, it is indicated that the average world temperature will increase between 1 and 3.5% until 2100 (Global Environment Facility, 2002).

The most probable effects of global warming involve degradation of productivity in agricultural, forestal and fishing activities; change in the geographical distribution of diseases; rising sea levels; increase in the number of extreme climatic events. There were numerous climatic disasters in 2005. In that year, floods were common in China, India and East Europe. In America, a record number of thunderstorms and hurricanes took place. Heat waves and serious droughts afflicted many parts of the world. In the Artic, one could observe an astonishing glacier retreat during the summer season. It is estimated that 2005 was the year with the largest financial losses as results of climatic disasters: more than US$ 200 billions (ONU, 2006).

In consequence of the seriousness of the global climatic questions, the United Nations Conference on Environment and Development was held in 1992. Then, a large number of countries signed the United Nations Framework Convention on Climate Change, which established as goal decreasing, or at least stabilizing, the concentration of greenhouse gases, besides settling a precedent to future actions.

In the Third Conference of the Parties, in 1997, the Kyoto Protocol was adopted. According to it, the industrialized countries should decrease their emission by, at least, 5% in respect to 1990 levels, until the period between 2008 and 2012 (Hilgemberg, 2004). Although the United States president had publicly rejected the Protocol, weakening it in great measure, in February 2005 it entered into force – the ratification of Russia was enough to satisfy the condition that the Protocol should be accepted by 55 countries which responded for 55% of the total emissions of greenhouse gases.

However, as a distressful opposition to these initiatives of the international community, one verifies that the $CO_2$ emissions continued to be intensified in the 1990s. This tendency was particularly strong in Asia, as result of its fast economic growth, and in North America. In the former Soviet Union, however, the emissions have substantially decreased, in reason of the reformation and decline of its economy, while in Europe, Latin America and Africa the emissions were stable (ONU, 2002).

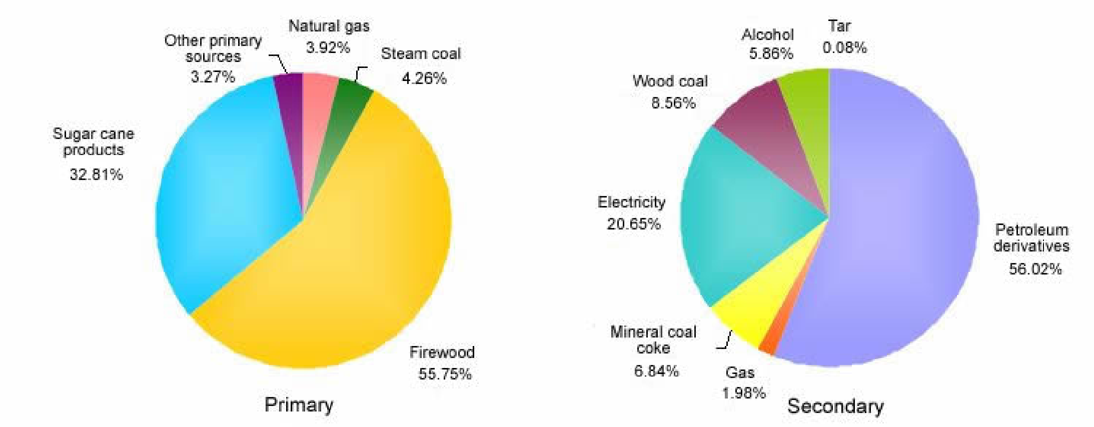
Concerning the relation between income and $CO_2$ emissions, in global level, one can indicate that rich populations are the greatest responsible for the environmental degradation, as they consume about 70% of world energy. In the same time, the harming effects of climatic changes affect more intensely the underdeveloped countries, causing losses that correspond to 5-9% of their gross domestic product (Global Environment Facility, 2002). However, one can properly mention that there is the expectative that two thirds of the future energy consumption will take place in those countries, as answer to the basic energy demand required by economic growth.

### 1.2. Brazilian energy profile.

In the analysis of the constitution of energy consumption, it is necessary to distinguish between the primary energy sources and the secondary ones. The primary sources are that found directly in the nature, being then destined to transformation centers, where they are converted in one or more varieties of secondary energy, or to final use. The secondary sources, therefore, are destined to the several consumption sectors or, eventually, to another transformation center.

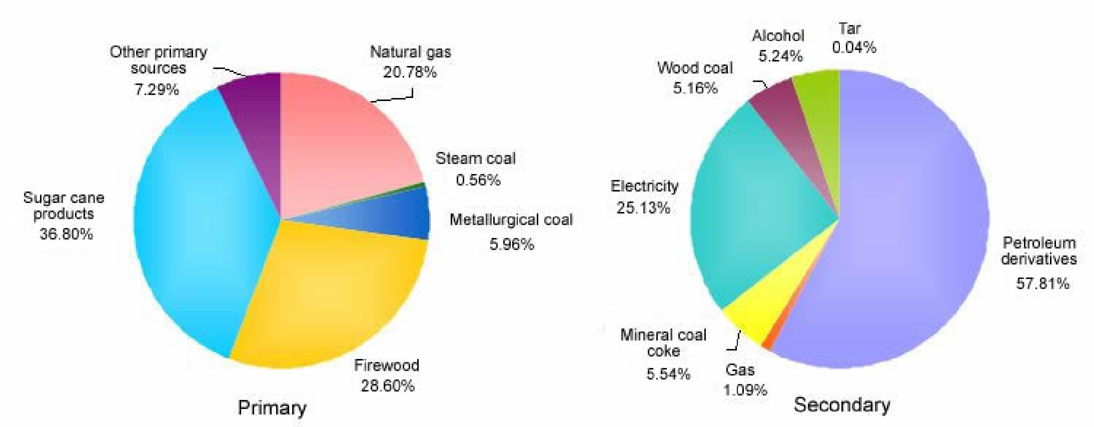
This distinction being made, Figures 1 and 2 present the energy profile in Brazil, in 1985 and 2004, respectively.

Figure 1 – Primary and secondary final energy consumption in Brazil, in 1985.




Source: Brasil, 2006.

Figure 2 - Primary and secondary final energy consumption in Brazil, in 2004.




Source: Brasil, 2006.

Analyzing these compositions of Brazilian energy consumption, concerning the primary sources, the great decrease in the participatin of firewood, between 1985 and 2004 (27.15 percent points) outstands. In fact, in this period, there was also a significant decrease in the total firewood consumption, from 19 922 * $10^8$ toe to 15 752 * $10^8$ toe in its final consumption. This is a present tendency in the country since the early 1970s, when firewood was the main energy source, being destined to the production of wood coal, or to households, industrial and agricultural sectors. Since then, the exhaustion of native forests near the consumption centers and the appearance of other sources caused the reduction in firewood's participation in the Brazilian energy profile (Hilgemberg, 2004).

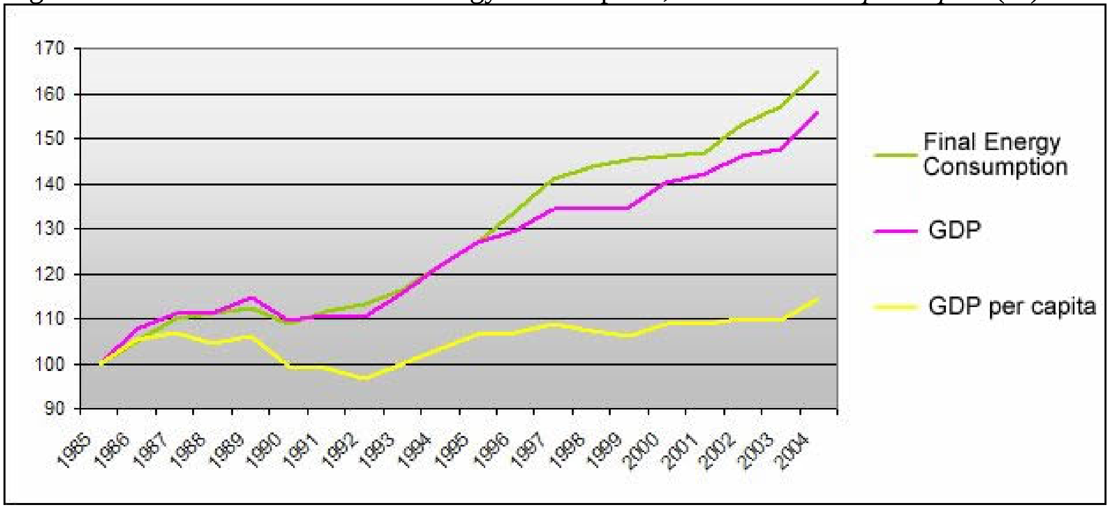
In 2004, the sugar cane products were responsible for the largest portion of primary energy consumption in Brazil. On the other hand, the increase in the parcel of natural gas (16.86 percent points)[3] and the uprising of metallurgical coal as an important primary energy source are significant facts between 1985 and 2004.

In relation to the composition of final consumption of secondary energy, there was no marked alteration between 1985 and 2004. Petroleum derivatives were responsible, in both years, for more than 50% of the final consumption of secondary energy. In the following, electricity registered a small decrease (4.48 percent points) in the period. It is valuable to indicate the reduction of the share of wood coal, parallel to the sharp decrease of the participation of firewood as a primary source.

It is worthwhile to analyze the relation between the increase in the final energy consumption and the Brazilian GDP, which is illustrated in figure 3. The relation between the two variables, between 1985 and 2004, is clearly positive – the final energy consumption is mainly determined by the economic activity level. So that, both final energy consumption and GDP decreased in the early 1990s. After the economic stabilization, the growth of both variables was acentuated, being decelerated in the end of the decade. At last, the recovery of the GDP since 2000 was followed by greater energy consumption. It is valuable to indicate that, since 1996, the increase in the final energy consumption surpassed that of the Brazilian GDP (Figure 3).

[3] The increase in the natural gas consumption faced a dilemma in 2006, when aroused the political crisis with the government of Bolivia, fundamental supplier of this fuel to Brazil. The nationalization of the Bolivian oil and gas sector, that affected Petrobrás, has exposed the Brazilian dependency in relation to the natural gas imports and has put into question the viability of the expansion of thermal power plants to produce electricity, launched in the early 2000.
On the other hand, one can verify increasing investments of Petrobrás in new gas mines, especially in the Santos Basin, which comprehend the Brazilian coast, from Rio de Janeiro to the north Santa Catarina, and contains large stocks of gas. It is intended that, with the triplication of the diary gas production in the Basin, until 2010, the Brazilian dependency in relation to the imports of thit fuel will decrease from the current 50% to about 30%.

Figure 3 – Evolution of total final energy consumption, GDP and GDP *per capita* (%).




Sources: Brasil, 2006; IPEADATA, 2006.

Figure 4 illustrates the evolution, between 1985 and 2004, of final energy consumption of natural gas, alcohol and petroleum derivatives (diesel oil, fuel oil, gasoline, LPG and kerosene). To the present work, it is important to verify the tendencies of each one of them, since they have distinct $CO_2$ coefficients, determinant factors of the total emissions in the economy.

It is visible that, in the years immediately after the economic stabilization, the greater growth of the Brazilian economy stimulated the consumption of all these energy sources. The increase in the final consumption of natural gas was quite significative in the second half of the 1990s and, specially, since the year 2000.[4] In relation to alcohol, its consumption has oscillated in the period, after having attained its highest level in 1989 – in that year, as a result of the Brazilian Alcohol National Program, the automobiles that used alcohol as fuel responded for 90% of the sales of light vehicles (Hilgemberg, 2004).[5] The consumption of petroleum derivatives, in its turn, after having increased slightly in the former decade, was stabilized since 1998, on account of the deceleration verified in the Brazilian economy.

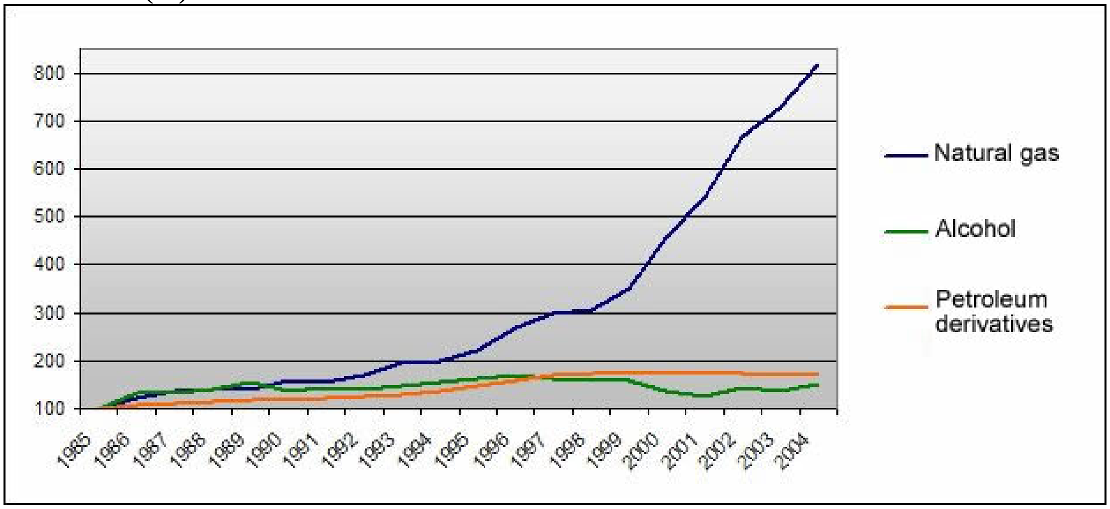
[4] See note 2 above.

[5] Between 2000 and 2002, the petroleum prices reassumed a rising trajectory. With the highest prices and the heavier tax burden on the fossil fuel, the automobile industry in Brazil was motivated to invest in the development of a new technologic pattern to its vehicles: the “flex-fuel”. This technology allows the owners to choose between gasoline, alcohol or a mixture of both as fuel, basing the decision on economic and environmental factors, as well on considerations about the performance of the vehicle. The approval of that new technology by the consumers has been quite successful. While in 2003, the year of the introduction of the “flex” car in the national market, 4.6% of the automobiles produced in Brazil utilized alcohol as fuel, in 2006 this participation, added to that of “flex” cars, had increased to 53.3%, in detriment of the production of cars that exclusively used gasoline – from 85,4%, its share declined to 37.4% (Anfavea, 2007).

This modification in the automobile sector certainly have reflections in the sugar cane and alcohol production, which will be intensified in the near future, in view of the increasing tendency of growth in the participation of “flex” automobiles in the Brazilian assembly lines.

In the point of view of $CO_2$ emissions, alcohol presents the positive point of being a renewable energy source and causing less pollution than the petroleum derivatives. However, if the harvest is not mechanized, the serious problem of the burning of sugar cane, in order to facilitate the manual harvest, emerges.

Figure 4 – Evolution of final energy consumption of natural gas, alcohol and petroleum derivatives (%).



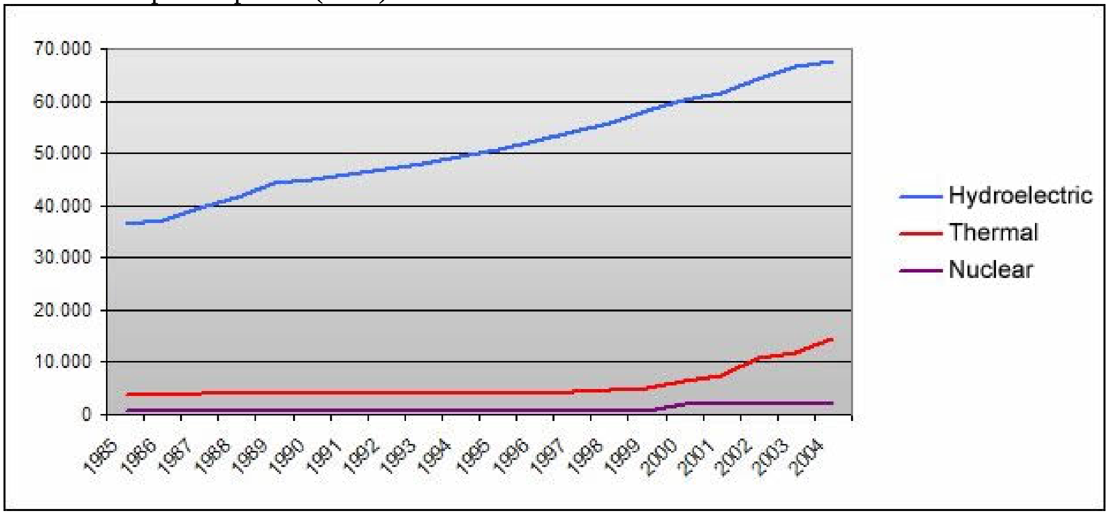

Source: Brasil, 2006.

Concerning the relation between the energy profile and the $CO_2$ emissions, it is also valuable to indicate that an important distinguishing mark of the Brazilian electric energy system is the predominance of hydroelectric power plants. In 2004, they responded for 80.34% of the installed generating capacity, while the nuclear plants responded for 2.39%. The other 17.27% corresponded to thermal power plants (Brasil, 2006). This fact withstands the world pattern, in which the power plants that make use of coal are predominant (Hilgemberg, 2004). In the point of view of the present work, this information is important, since the $CO_2$ emissions of the Industrial Services of Public Utility sector correspond, almost entirely, to the generation of electric energy by means of fuel combustion.

However, according to Figure 5, since the year 2000 the increase of hydroelectric power plants has been surpassed by the two others modalities of energy generation.[6] The thermal power plants – which can be installed relatively fast and possibly near consumption centers – have increased their installed generating capacity since the Brazilian energy crisis, in 2001. In its turn, the increase of the nuclear plants in 2000 was result of the opening of operations in the Angra 2 plant.

[6] Figure 5 seems to be indicating that, in medium and long terms, the country will be more dependent of polluting fossil fuels, as the exploitation of new sources of hydroelectric energy becomes more expensive (Hilgemberg, 2004). However, it is valuable to point the late development of new technologies, which make possible the generation of electricity from hydric resources which had hitherto been unserviceable – this is the case of the current exploration of the hydroelectric potential in the Brazilian northeast. Besides this, the Decennial Plan of Electric Energy Expansion 2006-2015 (PDEE), launched by the government in the beginning of 2007, foresees the persistence of the hydroelectric power plants prevailing in the national energy profile. So that, the cited Plan defines new studies to evaluate the national hydroelectric potential.
Concerning the thermal power plants, it is necessary to put in relief the already pointed natural gas dilemma. Besides this, one needs to indicate that, in Brazil, there is a significant potential for the generation of electric energy based on biomass, produced especially from wastes of the sugar and alcohol industry. The exploitation of that potential could bring environmental benefits, since it involves a renewable energy source and presents relatively low costs.
Regarding to the nuclear power plants, there are clear perspectives to the increase of their generation of electricity. The PDEE foresees the opening of the operations of Angra 3 – endowed with a nuclear reactor identical to that of Angra 2 – in 2012. According to the National Plan of Energy 2030, Brazil will build more 4 nuclear power plants until 2030.

Figure 5 – Evolution of installed generating capacity in Brazil, in hydroelectric, thermal and nuclear power plants (MW).




Source: Brasil, 2006.

Regarding to Kyoto Protocol, Brazil does not join the group of developed countries obliged to control their greenhouse gases emissions. However, it is worthwhile to study the effects that these restrictions would cause in the Brazilian economy, since there is no consensual definition in the international framework about the way to deal with the climatic questions.[7] Besides this, as indicated above, there is some uncertainty about the future of the energy profile of the country. The application of input-output models to the analysis of climatic problems is quite valuable, therefore, since the solution is invariably – although not exclusively – related to the operation of the economy.

## 2. Methodology.

The present section intends to present the methodology that was adopted in order to enable the identification of the key sectors in the $CO_2$ emissions in the Brazilian economy, from both production and demand perspectives.

### 2.1. Data basis.

The work made use of the national input-output table for the year 2004, obtained according to the methodology present in Guilhoto and Sesso Filho (2005), and estimated from the system of national accounts, based in 2000 (IBGE, 2007). As fundamental basis to the $CO_2$ emissions, the present work employs the data utilized in Guilhoto *et al* (2002), brought up to 2004, following the inflation of the period. One considered that the economy would be composed by sixteen sectors, as follows:

[7] Rejecting the Protocol, in February 2002, the president of the USA has launched his own strategy. Called *Bush Initiative*, it is based in the assumption that economic growth is not the cause of the climatic problems, but their solution. Contrasting to the quantitative targets established in the Kyoto Protocol, it adopts a strategy of decreasing the intensity of greenhouse gases, with their gradual separation from the productive resources.

Table 1 – Sectors that have been considered in the work.

| |
|---|
| 1 – Agriculture |
| 2 – Mining |
| 3 – Metallurgy |
| 4 – Machinery Industries |
| 5 – Electric Equipment |
| 6 – Transportation Equipment |
| 7 – Wood, Furniture and Paper |
| 8 – Chemicals and Pharmaceuticals |
| 9 – Textiles, Clothing and Footwear Industries |
| 10 – Food Industries |
| 11 – Miscellaneous Manufacture |
| 12 – Industrial Services of Public Utility (ISPU) and Communications |
| 13 – Construction |
| 14 – Wholesale and Retail Trade |
| 15 – Transport |
| 16 – Services |

## 2.2. The input-output model.

The input-output model has the fundamental goal of analyzing the interdependence between the sectors of an economy. It consists of a system of linear equations, each of them representing the distribution of the output of a sector to the others, as inputs, and to the final demand, composed by final consumption by households, government, fixed capital formation and exports.

According to Miller and Blair (1985), the model assumes the existence of a fixed relation between outputs and inputs in the sectors – known as technical coefficient –, so that the input-output system operates under constant returns to scale. In consequence, the model assumes that the sectors utilize inputs in fixed proportions and their production functions can be represented by:

$$X_j = \min\left(\frac{z_{1j}}{a_{1j}}, \frac{z_{2j}}{a_{2j}}, \ldots, \frac{z_{nj}}{a_{nj}}\right) \qquad (2.1)$$

Where:

$X_j$ is the total production of sector *j*;

$z_{ij}$ is the input flows from *i* to *j*;

$a_{ij}$ is the technical coefficient, which indicates the quantity of input of sector *i* that is needed to the production of an unit of final output of sector *j*.

Therefore, a fundamental assumption of the model is that the intersectoral flows from *i* to *j* depend exclusively on the total output of the *j* in the period.

## 2.3. Essential model.

In matrix terms, the intersectoral flows can be represented by the following system:

$$AX + Y = X \qquad (2.2)$$

Where:

*A* is the *(n x n)* matrix of direct input coefficients.

*X* and *Y* are *(n x 1)* vectors, with values, respectively, of total production and final demand of each sector.

Treating the final demand as exogenous to the system, i.e., assuming that the total production vector is determined uniquely by the final demand vector, there is:

$$X = BY \tag{2.3}$$
$$B = (I - A)^{-1} \tag{2.4}$$

Where:
*B* is the *(n x n)* matrix of direct and indirect coefficients – the Leontief inverse matrix –, where the element $b_{ij}$ must be interpreted as the total output of sector *i* that is necessary to produce a unit of final demand of sector *j*.

2.4. Elasticity of $CO_2$ emissions, from a production perspective.[8]

The following methodology intends to identify the relation between the $CO_2$ emission and the generation of value added in the economy. Starting from the following identity:

$$X = \hat{X}A'i + V \tag{2.5}$$

Where:
*X* is the *(n x 1)* column vector with values of total production for each sector.
*A* is the *(n x n)* matrix of direct input coefficients.
*i* is the *(n x 1)* column vector of one's.
*V* is the *(n x 1)* column vector with values of value added for each sector.

Premultiplying both sides of (2.5) by $\hat{X}^{-1}$, we obtain:

$$i = A'i + S \tag{2.6}$$
$$i = (I - A')^{-1} S \tag{2.7}$$

Where:
*S* is the *(n x 1)* column vector of the value added coefficients, which indicate the relation between this variable and the total production of the corresponding sector, i.e., $v_i / x_i$.

This expression allows the distribution among the sectors of any variable related to the production, accordingly with the productive structure and the income participation in the total production value of each sector.

Let *C* be the *(n x 1)* column vector of sectoral direct $CO_2$ emissions. Multiplying both sides of (2.7) by $\hat{C}$, we obtain:

$$C = \hat{C}(I - A')^{-1} S \tag{2.8}$$

[8] This section and the subsequent follow the concept of elasticity and the methodology to identify the key sectors responsible for $CO_2$ emissions found in Alcántara and Padilla (2003) and (2006). It is valuable to indicate that this procedure is in parallel with the Leontief Price Model (Miller and Blair, 1985).

Defining $G$ as the *(n x 1)* column vector whose elements indicate the sectoral participation in the total $CO_2$ emission in the economy, so that the sum of them be 1, we obtain:

$$C = TG \tag{2.9}$$

Where:
$T$ is the scalar that indicates the total level of $CO_2$ emissions in the economy.

Therefore,

$$C = T\hat{G}(I - A')^{-1} S \tag{2.10}$$

Premultiplying both sides of (2.10) by *i'*, we obtain:

$$T = TG'(I - A')^{-1} S \tag{2.11}$$

Departing from this, we can establish a relation between the variation of value added participation and the increase in total emissions:

$$\Delta T = TG'(I - A')^{-1} S\alpha \tag{2.12}$$

Premultiplying both sides of (2.12) by $T^{-1}$:

$$T^{-1}\Delta T = G'(I - A')^{-1} S\alpha \tag{2.13}$$

With the diagonalization of $S$ in (2.13), we obtain the following vector:

$$\varepsilon' = G'(I - A')^{-1}\hat{S}\alpha \tag{2.14}$$

whose elements indicate the proportional change in (direct and indirect) sectoral total emissions in relation to a proportional change in income. They can be interpreted as elasticities. Therefore,

$$\varepsilon_i = \frac{\Delta T / T}{\Delta v_i / v_i} \tag{2.15}$$

The elements of (2.14) express, thus, the income elasticities of total emissions, which will be considered as measures of sectoral impact. Intending to clarify the results, we can also diagonalize vector *G'* and assume $\alpha$ = 1%:

$$E^v = \hat{G}(I - A')^{-1}\hat{S} \tag{2.16}$$

The element $E_{ij}^{v}$ from (2.16) indicates the percent increase in the emissions of sector *i* (with respect to total emissions) in response to a 1% increase in value added generated in sector *j*, so that it can be interpreted as elasticity.

From an environmental perspective, it is important to comprehend the various ways in which the income generation affects the environment. Accordingly with the present methodology, the productive structure, the capacity to generate value added and the intensity of direct emissions are determinant elements to evaluate the environmental impact of the several sectors in the economy. So that, the key sectors are identified in the present work as those that emit a larger quantity of $CO_2$ per value added unit and whose emissions increase more significantly in response to the growth in the economy.

The importance of the identification of key sectors is clear in the elaboration of policies intending a reduction in the energy consumption and, consequently, in the $CO_2$ emissions. In these policies, besides the intensities of sectoral emissions, the respective value added capacities must be considered, in order to not implicate excessive costs in terms of income in the economy.

The sum by rows of the (2.16) matrix, i.e.,

$$\sum_{j}^{n} E_{ij}^{v} \tag{2.17}$$

shows the sectoral distribution of the emissions and indicates the impact that a 1% global economic increase would have in the emissions of each sector (distributive impact).

In its turn, the sum of the elements of the sector *j* column of (2.16), i.e.,

$$\sum_{i}^{n} E_{ij}^{v} \tag{2.18}$$

expresses the percent variation in the $CO_2$ emission of the economy resulting from a 1% increase in the value added of sector *j* (total impact).

Departing from the distributive (2.17) and total (2.18) impacts, we can define a taxonomy for the economic sectors, in order to indicate their importance to the $CO_2$ emissions. Being $E_{d}^{v}$ and $E_{t}^{v}$ the median values of distributive and total impacts, respectively, we can classify the sectors in accordance with their position in relation to them. The key sectors in the $CO_2$ emissions will be those whose distributive and total effects are larger than the median values in the economy.

2.5. Elasticity of $CO_2$ emissions, from a demand perspective.

Complementing the previous section, the following methodology intends to identify the relation between the $CO_2$ emission and final demand in the several sectors of the economy.

Starting from the essential input-output model (2.4), we can consider:

$$T = P'X = P'(I - A)^{-1}Y \tag{2.19}$$

Where:

$P'$ is the *(1 x n)* row vector whose elements represent the volume of $CO_2$ emitted per unit of sectoral production.

Differentiating (2.19) and expressing the increase in final demand as a proportion of this demand,

$$\Delta T = P'\Delta X = P'(I - A)^{-1} Y\alpha \tag{2.20}$$

Defining the *R*, the *(nx1)* vector that represents the participation of final demand in the total sectoral production, as

$$R = \hat{X}^{-1} Y \tag{2.21}$$

we can rewrite (2.20) and premultiply the expression by $T^{-1}$:

$$T^{-1}\Delta T = T^{-1} P'(I - A)^{-1} \hat{X} R\alpha \tag{2.22}$$

We obtain, thus, the total increase in the $CO_2$ emission, in relation to the increase in the final demand. Defining *G'* as previously, we obtain:

$$P' = TG'\hat{X}^{-1} \tag{2.23}$$

And, thus, rewriting (2.22), we obtain:

$$T^{-1}\Delta T = G'\hat{X}^{-1}(I - A)^{-1} \hat{X} R\alpha \tag{2.24}$$

We can consider that

$$\hat{X}^{-1}(I - A)^{-1} \hat{X} = (I - D)^{-1} \tag{2.25}$$

Where:

$d_{ij} = Z_{ij} / X_i$. Therefore, *D* is the *(n x n)* matrix of horizontal, or distribution, coefficients of the input-output table. In its turn, $(I - D)^{-1}$ is the so called Ghosh matrix, approached, for example, in Dietzenbacher (1997).

Substituting (2.25) in (2.24), we obtain

$$\varepsilon' = G'(I - D)^{-1} \hat{R}\alpha \tag{2.26}$$

whose elements indicate the proportional variation in (direct and indirect) sectoral total emissions in relation to a proportional change in demand. Then, the expression can be rewritten:

$$E^{y} = \hat{G}(I - D)^{-1} \hat{R} \tag{2.27}$$

The element $E_{ij}^{y}$ of (2.27) indicates the percent increase of the emissions of sector *i* (in relation to total emissions) in response to a 1% increase in the final demand of sector *j*, and it can be interpreted as elasticity. In this way, the sum by rows of this matrix reproduces the sectoral distribution of emissions and indicates the impact that a 1% economic growth would have in the emissions of each sector (distributive impact). In its turn, the sum of the elements of the sector *j* column expresses the percent change in the $CO_2$ emissions of the economy, in response to a 1% increase in the final demand of sector *j* (total impact).

The taxonomy of the economic sectors, in accordance with these impacts, is analogous to that utilized for the elasticities of $CO_2$ emissions from production perspective, indicated above. [9]

## 3. Results.

This section presents the results obtained in the analysis of the initial data utilized in the work and also these obtained from the application of the described methodology. Initially, we will analyze the participation of the considered sectors in the economy and their $CO_2$ emission coefficients. Subsequently, the matrixes of income and demand elasticities of emissions will be presented, for the year 2002. At last, the key sectors for the emissions in the Brazilian economic structure will be identified.

### 3.1. Sectoral $CO_2$ emission coefficients.

Table 2 shows the participation of the sectors, in the Brazilian economy, in production value, value added, final demand and $CO_2$ emissions.

It can be observed from Table 2 that some sectors present larger participation in the emissions than in the other analyzed aggregates. This is the case of Agriculture, Metallurgy, Food Industries, Industrial Services of Public Utility (ISPU, which include energy generation in thermal power plants) and, especially, the Transport sector, whose $CO_2$ emissions responds for almost 40% of the total of the economy. On the other hand, the Services sector, to which corresponds about a third of production value in Brazil, is responsible for only 1.34% of the emissions.

[9] An alternative approach to identify the key sectors from a demand perspective would be the analysis of the multipliers of $CO_2$, emission, as indicated in Miller e Blair (1985, p. 237). The sectors that present the greatest multiplier values are, in large extent, the same as those indicated as key ones in the methodology applied in the present work.

Table 2 – Sectoral participation in production value, value added, final demand and $CO_2$ emissions, in 2004.

| | Production value | Value added | Final demand | $CO_2$ emissions |
|---|---|---|---|---|
| 1 – Agriculture | 5.92% | 6.56% | 3.86% | 12.75% |
| 2 – Mining | 2.38% | 2.09% | 1.11% | 1.19% |
| 3 – Metallurgy | 4.75% | 4.12% | 2.33% | 14.99% |
| 4 – Machinery Industries | 1.67% | 1.26% | 2.15% | 0.07% |
| 5 – Electric Equipment | 2.55% | 2.00% | 2.86% | 0.10% |
| 6 – Transp. Equipment | 3.96% | 2.36% | 4.69% | 0.16% |
| 7 – Wood, Furniture, Paper | 3.09% | 2.63% | 2.40% | 2.25% |
| 8 – Chemicals and Pharm. | 9.38% | 6.75% | 4.46% | 3.44% |
| 9 – Text. Clothing and Foot. | 2.42% | 1.86% | 2.66% | 0.40% |
| 10 – Food Industries | 7.34% | 3.52% | 8.80% | 11.26% |
| 11 – Miscellaneous Manuf. | 0.33% | 0.29% | 0.32% | 0.53% |
| 12 – ISPU and Commun. | 6.00% | 6.27% | 3.71% | 11.36% |
| 13 – Construction | 4.58% | 4.83% | 6.78% | 0.18% |
| 14 – Wholesale, Retail Trade | 7.59% | 9.92% | 7.18% | 0.65% |
| 15 – Transport | 4.31% | 4.33% | 3.39% | 39.34% |
| 16 – Services | 33.71% | 41.19% | 43.29% | 1.34% |
| Total | 100.00% | 100.00% | 100.00% | 100.00% |

Source: research data.

These sectors that are outstanding in Table 2 also have high values of $CO_2$ emission coefficients. Thus, for example, the Transport sector, for each one thousand reais (2004 values) of its production value, is responsible for the emission of about 1.19 tonnes of $CO_2$. Concerning the value added and the final demand of this sector, it would emit 2.06 tonnes and 2.63 tonnes of $CO_2$, respectively, per one thousand reais (Table 3).

Table 3 – $CO_2$ emission coefficients (tonnes per R$ 1000, 2004 values)

| | $CO_2$ emission / Production value | $CO_2$ emission / Value added | $CO_2$ emission / Final demand |
|---|---|---|---|
| 1 – Agriculture | 0.2802 | 0.4413 | 0.7493 |
| 2 – Mining | 0.0648 | 0.1287 | 0.2417 |
| 3 – Metallurgy | 0.4102 | 0.8269 | 1.4597 |
| 4 – Machinery Industries | 0.0052 | 0.0120 | 0.0070 |
| 5 – Electric Equipment | 0.0052 | 0.0115 | 0.0081 |
| 6 – Transp. Equipment | 0.0052 | 0.0152 | 0.0076 |
| 7 – Wood, Furniture, Paper | 0.0946 | 0.1940 | 0.2128 |
| 8 – Chemicals and Pharm. | 0.0477 | 0.1159 | 0.1755 |
| 9 – Text. Clothing and Foot. | 0.0216 | 0.0492 | 0.0344 |
| 10 – Food Industries | 0.1997 | 0.7279 | 0.2907 |
| 11 – Miscellaneous Manuf. | 0.2088 | 0.4130 | 0.3760 |
| 12 – ISPU and Commun. | 0.2463 | 0.4114 | 0.6961 |
| 13 – Construction | 0.0052 | 0.0086 | 0.0061 |
| 14 – Wholesale, Retail Trade | 0.0111 | 0.0148 | 0.0205 |
| 15 – Transport | 1.1878 | 2.0612 | 2.6336 |
| 16 – Services | 0.0052 | 0.0074 | 0.0070 |

Source: research data.

## 3.2. Matrices of elasticities of $CO_2$ emissions.

Figures 6 and 7 represent, respectively, the matrices of income and demand elasticities of $CO_2$ emissions in the Brazilian economy. The values of their elements are found in Tables 4 and 5.

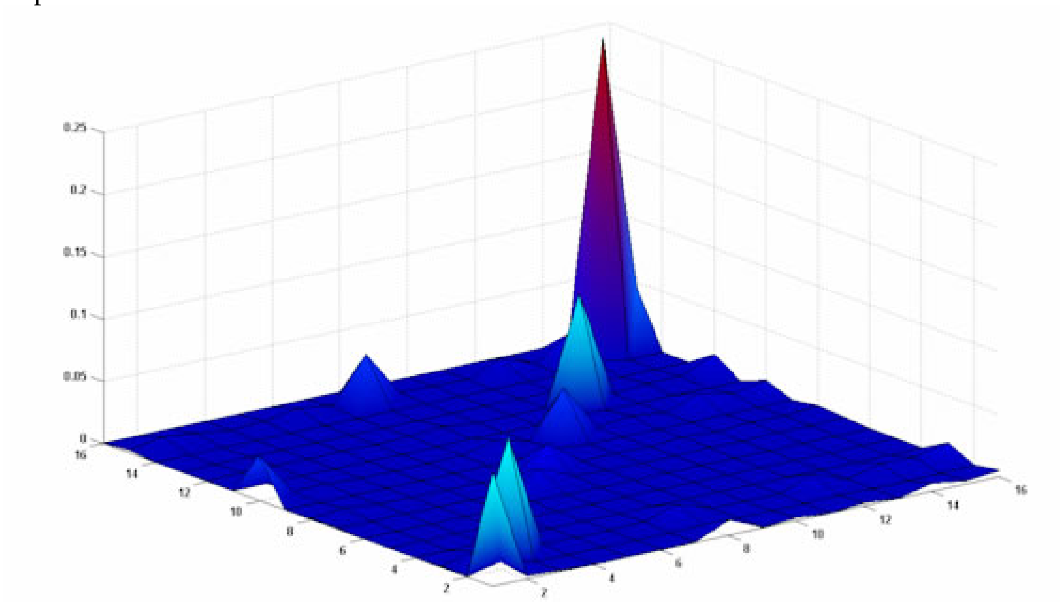
One can verify that the matrices present some similar aspects. Although with different intensities, some of the main “peaks”, i.e., the highest elasticities values, are situated in the same places of the matrices, thus corresponding to the same pairs of sectors.

Both in the income elasticities matrix and in the demand elasticities matrix, the Transport sector is the most outstanding one. In both cases, the largest value corresponds to the percent change in the emissions of Transport sector in response to 1% increase in value added or final demand, respectively, of this sector. Moreover, as a similar aspect in both Figures 6 and 7, one observes that the greatest “peaks” are situated in the main diagonal of the matrices, so that the increase in the emissions of a given sector occurs principally as a response to the growth of this same sector.

On the other hand, one can also observe significative differences between the aspects of the matrices. Regarding the elasticities matrix resulting of the analysis from a production perspective, it is noticeable the percent increase in emissions of the Transport and Food Industries sectors that would occur in response to a 1% expansion in value added in Chemicals and Agriculture sectors, respectively. In both cases, one notices that the sector whose emissions would significantly increase demands inputs from the other, in which it is assumed that the value added expanded.

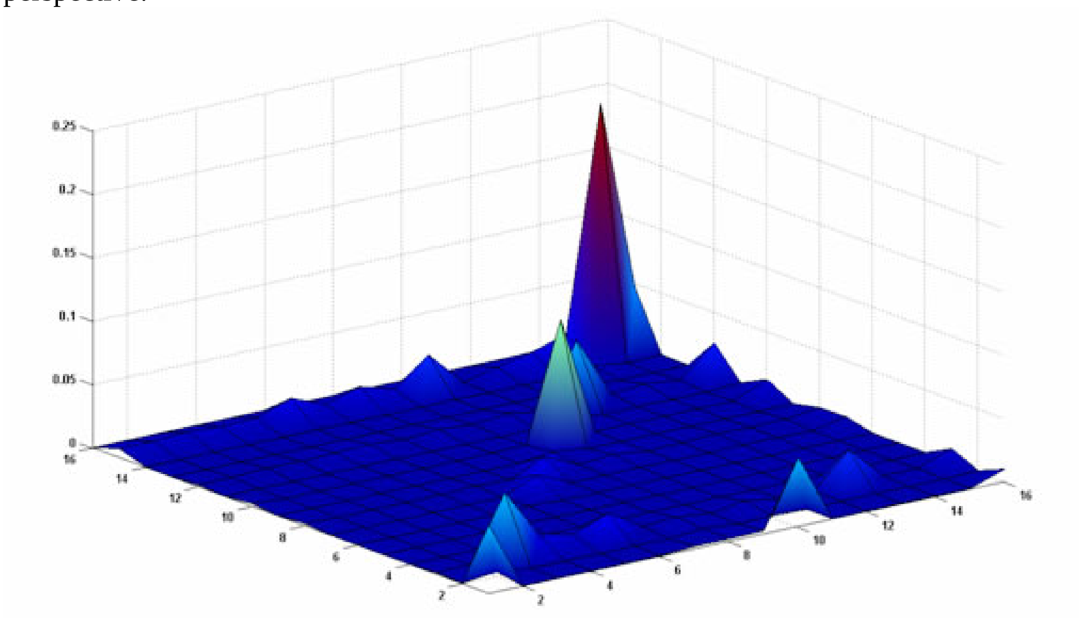
Concerning the elasticities matrix from a demand perspective, it is valuable to indicate the percent increase in the emissions of Agriculture, Metallurgy and Services sectors that would occur in response to a 1% expansion in final demand of Food Industries, Construction and Industrial Services of Public Utility sectors, respectively. In the three cases, the sector whose emissions would noticeably increase is an important supplier of inputs to the production of the other, whose final demand was supposedly expanded.

Figure 6 – Graphic representation of the elasticities of emissions matrix, from production perspective.




Source: research data.

Figure 7 - Graphic representation of the elasticities of emissions matrix, from demand perspective.




Source: research data.

Starting from this data, it was possible to calculate the distributive and total impacts of the several sectors on the $CO_2$ emissions, in the Brazilian economy.

Table 4 – Elasticities of emissions matrix, from production perspective.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0916 | 0.0024 | 0.0010 | 0.0002 | 0.0002 | 0.0002 | 0.0005 | 0.0121 | 0.0003 | 0.0024 | 0.0000 | 0.0024 | 0.0001 | 0.0065 | 0.0026 | 0.0050 | **0.1275** |
| 2 | 0.0001 | 0.0064 | 0.0005 | 0.0001 | 0.0001 | 0.0000 | 0.0001 | 0.0006 | 0.0000 | 0.0000 | 0.0000 | 0.0009 | 0.0001 | 0.0004 | 0.0008 | 0.0016 | **0.0119** |
| 3 | 0.0008 | 0.0070 | 0.0927 | 0.0012 | 0.0005 | 0.0003 | 0.0014 | 0.0095 | 0.0004 | 0.0002 | 0.0003 | 0.0101 | 0.0004 | 0.0069 | 0.0061 | 0.0120 | **0.1499** |
| 4 | 0.0000 | 0.0000 | 0.0001 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | **0.0007** |
| 5 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0005 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0001 | 0.0000 | 0.0001 | **0.0010** |
| 6 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | 0.0000 | 0.0007 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0001 | 0.0001 | 0.0002 | **0.0016** |
| 7 | 0.0009 | 0.0003 | 0.0006 | 0.0001 | 0.0001 | 0.0000 | 0.0135 | 0.0017 | 0.0002 | 0.0001 | 0.0000 | 0.0010 | 0.0000 | 0.0015 | 0.0007 | 0.0018 | **0.0225** |
| 8 | 0.0008 | 0.0034 | 0.0008 | 0.0002 | 0.0001 | 0.0001 | 0.0004 | 0.0200 | 0.0001 | 0.0002 | 0.0000 | 0.0017 | 0.0001 | 0.0019 | 0.0013 | 0.0033 | **0.0344** |
| 9 | 0.0002 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0003 | 0.0024 | 0.0001 | 0.0000 | 0.0002 | 0.0000 | 0.0004 | 0.0001 | 0.0003 | **0.0040** |
| 10 | 0.0357 | 0.0016 | 0.0018 | 0.0003 | 0.0003 | 0.0002 | 0.0011 | 0.0078 | 0.0003 | 0.0376 | 0.0001 | 0.0036 | 0.0002 | 0.0098 | 0.0039 | 0.0083 | **0.1126** |
| 11 | 0.0001 | 0.0001 | 0.0003 | 0.0000 | 0.0001 | 0.0000 | 0.0003 | 0.0006 | 0.0001 | 0.0000 | 0.0028 | 0.0002 | 0.0000 | 0.0004 | 0.0001 | 0.0003 | **0.0053** |
| 12 | 0.0004 | 0.0015 | 0.0008 | 0.0002 | 0.0011 | 0.0002 | 0.0011 | 0.0030 | 0.0001 | 0.0002 | 0.0001 | 0.0857 | 0.0003 | 0.0025 | 0.0022 | 0.0141 | **0.1136** |
| 13 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0011 | 0.0001 | 0.0000 | 0.0001 | **0.0018** |
| 14 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | 0.0050 | 0.0002 | 0.0006 | **0.0065** |
| 15 | 0.0023 | 0.0070 | 0.0037 | 0.0007 | 0.0020 | 0.0065 | 0.0024 | 0.0383 | 0.0015 | 0.0010 | 0.0003 | 0.0115 | 0.0009 | 0.0195 | 0.2506 | 0.0451 | **0.3934** |
| 16 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.0003 | 0.0000 | 0.0001 | 0.0000 | 0.0004 | 0.0001 | 0.0004 | 0.0002 | 0.0113 | **0.0134** |
| Total | **0.1330** | **0.0301** | **0.1029** | **0.0034** | **0.0051** | **0.0084** | **0.0211** | **0.0947** | **0.0055** | **0.0420** | **0.0036** | **0.1181** | **0.0036** | **0.0554** | **0.2689** | **0.1042** | **1.0000** |

Source: research data.

Table 5 – Elasticities of emissions matrix, from demand perspective.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0539 | 0.0001 | 0.0002 | 0.0002 | 0.0003 | 0.0005 | 0.0019 | 0.0019 | 0.0024 | 0.0542 | 0.0001 | 0.0003 | 0.0005 | 0.0005 | 0.0004 | 0.0099 | **0.1275** |
| 2 | 0.0004 | 0.0034 | 0.0006 | 0.0003 | 0.0003 | 0.0005 | 0.0002 | 0.0025 | 0.0002 | 0.0007 | 0.0000 | 0.0003 | 0.0007 | 0.0002 | 0.0003 | 0.0011 | **0.0119** |
| 3 | 0.0011 | 0.0016 | 0.0525 | 0.0134 | 0.0078 | 0.0186 | 0.0024 | 0.0037 | 0.0009 | 0.0050 | 0.0008 | 0.0010 | 0.0278 | 0.0014 | 0.0012 | 0.0108 | **0.1499** |
| 4 | 0.0000 | 0.0000 | 0.0000 | 0.0005 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | **0.0007** |
| 5 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0008 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | **0.0010** |
| 6 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0014 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | **0.0016** |
| 7 | 0.0001 | 0.0001 | 0.0002 | 0.0002 | 0.0003 | 0.0006 | 0.0123 | 0.0004 | 0.0003 | 0.0007 | 0.0001 | 0.0003 | 0.0009 | 0.0005 | 0.0002 | 0.0052 | **0.0225** |
| 8 | 0.0019 | 0.0003 | 0.0008 | 0.0006 | 0.0010 | 0.0019 | 0.0009 | 0.0132 | 0.0010 | 0.0031 | 0.0002 | 0.0005 | 0.0018 | 0.0009 | 0.0017 | 0.0047 | **0.0344** |
| 9 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0034 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0003 | **0.0040** |
| 10 | 0.0023 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0003 | 0.0002 | 0.0008 | 0.0012 | 0.0942 | 0.0000 | 0.0002 | 0.0003 | 0.0005 | 0.0003 | 0.0118 | **0.1126** |
| 11 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0030 | 0.0001 | 0.0002 | 0.0000 | 0.0000 | 0.0015 | **0.0053** |
| 12 | 0.0013 | 0.0015 | 0.0029 | 0.0022 | 0.0032 | 0.0042 | 0.0019 | 0.0041 | 0.0018 | 0.0051 | 0.0002 | 0.0507 | 0.0029 | 0.0047 | 0.0018 | 0.0251 | **0.1136** |
| 13 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0016 | 0.0000 | 0.0000 | 0.0002 | **0.0018** |
| 14 | 0.0001 | 0.0000 | 0.0001 | 0.0001 | 0.0001 | 0.0003 | 0.0001 | 0.0002 | 0.0002 | 0.0005 | 0.0000 | 0.0001 | 0.0002 | 0.0036 | 0.0001 | 0.0008 | **0.0065** |
| 15 | 0.0070 | 0.0068 | 0.0087 | 0.0069 | 0.0081 | 0.0173 | 0.0066 | 0.0148 | 0.0068 | 0.0280 | 0.0007 | 0.0064 | 0.0126 | 0.0208 | 0.1961 | 0.0459 | **0.3934** |
| 16 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0000 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0118 | **0.0134** |
| Total | **0.0684** | **0.0140** | **0.0662** | **0.0246** | **0.0222** | **0.0459** | **0.0266** | **0.0419** | **0.0184** | **0.1919** | **0.0052** | **0.0599** | **0.0499** | **0.0333** | **0.2023** | **0.1293** | **1.0000** |

Source: research data.

3.3. Key sectors in $CO_2$ emissions.

Starting from the elasticities matrices presented in the previous section, one can obtain the distributive impacts, given by the sum by rows, which express the percent increase in the emissions of each sector, as consequence of the 1% expansion in the value added or final demand in all the sectors of the economy. From these matrices, it is also possible to analyze the total impacts, which derive from the sum of the columns and indicate the percent increase in the emissions of the entire productive system, in response to a 1% expansion in the value added or final demand of the sector corresponding to the column. Thus, as illustration, the research results indicate that, in 2004, the 1% expansion in the value added of all sectors would cause a 0.1275% increase in the emissions of Agriculture, in relation to the global emission, while a 1% expansion in the value added of Agriculture would increase the emissions of the economy in 0.1330%.

The results, from both production and demand perspectives, are presented in Table 6. [10] The illustration of these results is given by Figures 8 and 9, respectively.

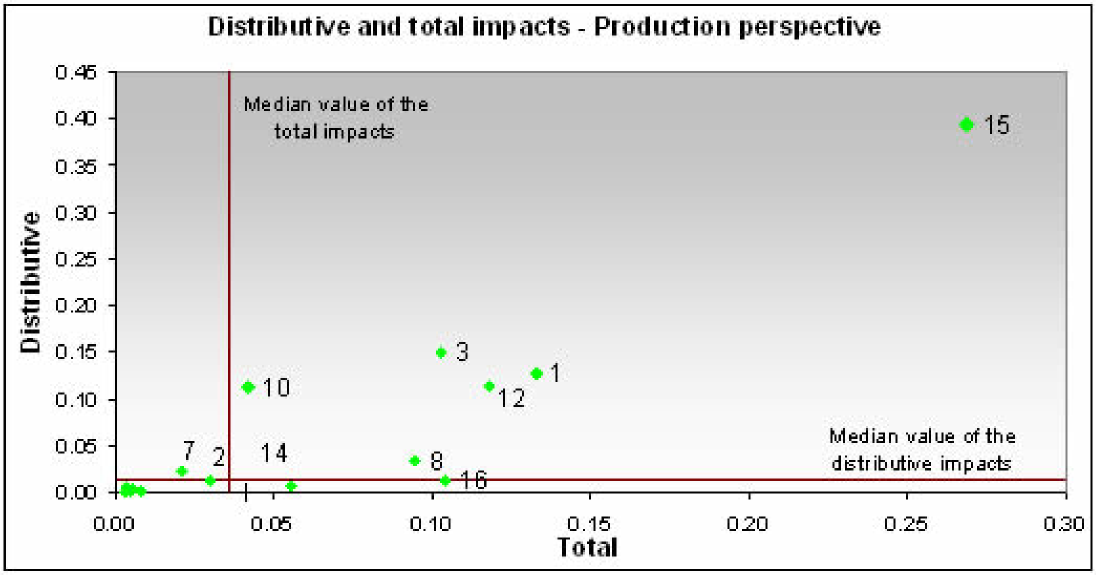
Table 6 – Distributive and total impacts, from production and demand perspectives.

| | Production | | Demand | |
|---|---|---|---|---|
| | Distributive impact | Total impact | Distributive impact | Total impact |
| 1 – Agriculture | 0.1275 | 0.1330 | 0.1275 | 0.0684 |
| 2 – Mining | 0.0119 | 0.0301 | 0.0119 | 0.0140 |
| 3 – Metallurgy | 0.1499 | 0.1029 | 0.1499 | 0.0662 |
| 4 – Machinery Industries | 0.0007 | 0.0034 | 0.0007 | 0.0246 |
| 5 – Electric Equipment | 0.0010 | 0.0051 | 0.0010 | 0.0222 |
| 6 – Transp. Equipment | 0.0016 | 0.0084 | 0.0016 | 0.0459 |
| 7 – Wood, Furniture, Paper | 0.0225 | 0.0211 | 0.0225 | 0.0266 |
| 8 – Chemicals and Pharm. | 0.0344 | 0.0947 | 0.0344 | 0.0419 |
| 9 – Text. Clothing and Foot. | 0.0040 | 0.0055 | 0.0040 | 0.0184 |
| 10 – Food Industries | 0.1126 | 0.0420 | 0.1126 | 0.1919 |
| 11 – Miscellaneous Manuf. | 0.0053 | 0.0036 | 0.0053 | 0.0052 |
| 12 – ISPU and Commun. | 0.1136 | 0.1181 | 0.1136 | 0.0599 |
| 13 – Construction | 0.0018 | 0.0036 | 0.0018 | 0.0499 |
| 14 – Wholesale, Retail Trade | 0.0065 | 0.0554 | 0.0065 | 0.0333 |
| 15 – Transport | 0.3934 | 0.2689 | 0.3934 | 0.2023 |
| 16 – Services | 0.0134 | 0.1042 | 0.0134 | 0.1293 |
| Total | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Source: research data.

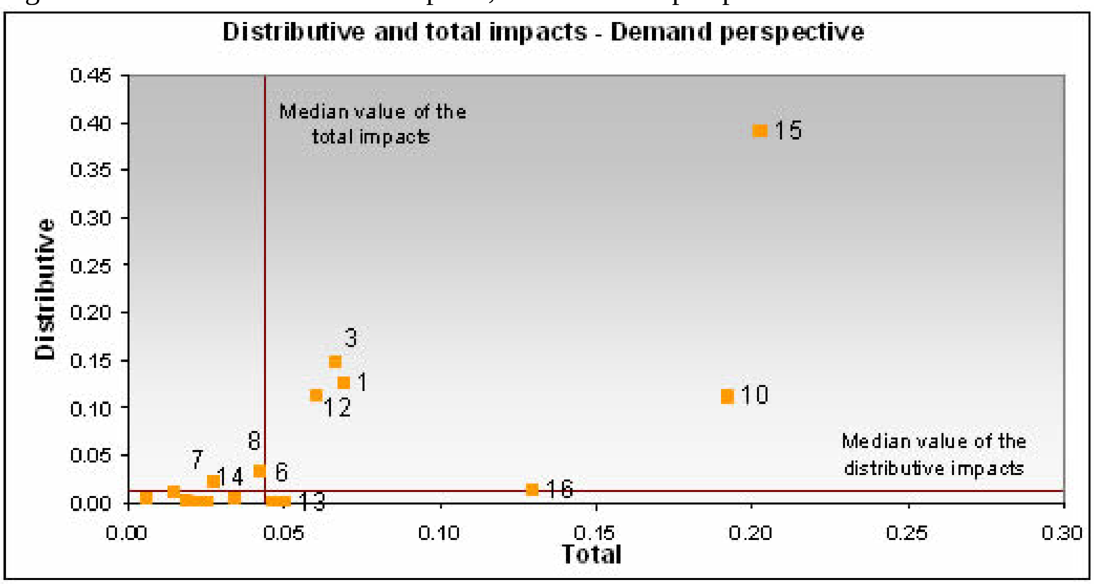
[10] One can observe that the distributive impacts are identical in the analysis from both production and demand perspectives. This is a consequence of the fact that, according to the methodology exposed above, the intensities of the distributive effects, in both cases, coincide with the sectoral participation in the total $CO_2$ emission of the economy.

Figure 8 – Distributive and total impacts, from production perspective.




Source: research data.

Figure 9 – Distributive and total impacts, from demand perspective.




Source: research data.

From this data, it is possible to define a sectoral taxonomy, which indicates the importance of the relation between the economic growth and the $CO_2$ emissions of a given sector. From production perspective, being $E_d^v$ and $E_t^v$ the median values of the distributive and total impacts, respectively, one can classify the sectors according to their position in relation to $E_d^v$ and $E_t^v$. The same procedure is applicable to the results obtained from a demand perspective. Tables 7 and 8 indicate the classification of the sectors, in accordance with this rule.

Table 7 – Sectoral classification of the distributive and total impacts, from production perspective.

| | Distributive impact ≤ $E_d^v$ | Distributive impact > $E_d^v$ |
|---|---|---|
| Total impact > $E_t^v$ | Wholesale and Retail Trade | Agriculture; Metallurgy; Chemicals; Food Industries; ISPU; Transport; Services |
| Total impact ≤ $E_t^v$ | Mining; Machinery; Electric Equipment; Transportation Equipment; Textiles; Miscellaneous Manufacture; Construction | Wood, Furniture and Paper |

Source: research data.

$E_d^v$ = 0,0126; $E_t^v$ = 0,0360.

Table 8 – Sectoral classification of the distributive and total impacts, from demand perspective.

| | Distributive impact ≤ $E_d^v$ | Distributive impact > $E_d^v$ |
|---|---|---|
| Total impact > $E_t^v$ | Transportation Equipment; Construction | Agriculture; Metallurgy; Food Industries; ISPU; Transport; Services |
| Total impact ≤ $E_t^v$ | Mining; Machinery; Electric Equipment; Textiles; Miscellaneous Manufacture; Wholesale and Retail Trade | Wood, Furniture and Paper; Chemicals |

Source: research data.

$E_d^y$ = 0,0126; $E_t^y$ = 0,0439.

The upper right boxes of Tables 7 and 8 contain the sectors with the greatest impacts in $CO_2$ emissions, both distributive and total. These are, therefore, the key sectors in the emissions of the pollutant.

From production perspective, as Table 7 shows, the indicated key sectors were Agriculture, Metallurgy, Chemicals and Pharmaceuticals, Food Industries, Industrial Services of Public Utility (ISPU), Transport, and Services. A 1% expansion in the value added of the economy would cause, then, an increase of 0.9447% in the total emission of these sectors. On the other hand, in the case of a 1% expansion in the income of these sectors, one would observe an increase of 0.8638% in the total emission of the economy.

According to Table 5, the sectors identified as the most important ones to the $CO_2$ emissions, from demand perspective, were Agriculture, Metallurgy, Food Industries, ISPU, Transport, and Services. From this perspective, the 1% expansion of the final demand of the economy would increase the total emission of these sectors in 0.9103%. The 1% expansion of the final demand of these sectors, in its turns, would cause a 0.7179% increase in the total emissions of the economy. The key sectors are responsible, therefore, for the largest share of the increase of the emissions in the economy.

From both perspectives, the most outstanding sector is Transport. The research data obtained shows that a 1% expansion in value added or final demand of the economy would cause an increase of 0.3934% in the total emissions of the Transport sector. The 1% expansion of its value added would increase the total $CO_2$ emissions in 0.2689%. In its turn, the 1% expansion in the final demand of the sector would cause a 0.2023% increase in the $CO_2$ emissions of the economy. Therefore, according to Figure 6, the value added generated by the Transport sector is clearly that one with the most important impact in the $CO_2$ emissions, so that special attention must be directed to it. On the other hand, as Figure 7 clearly shows, the total impact of the Food Industries sector is also outstanding. It results from the fact that this is a sector that directs its production primordially to the final demand of the economy.

Although it is valuable to indicate the preliminary nature of the applied taxonomy and the limitation resulting from the sectoral aggregation, comparing Tables 7 and 8, one can notice that most of the sectors continue in the same boxes. This fact implies the great relevance, for the policies of emission control, of the sectors indicated as key ones from both perspectives. Agriculture, Metallurgy, Chemicals and Pharmaceuticals, Food Industries, Transport and Services are sectors that, besides presenting high participations in the total emissions of the economy, greatly stimulate the $CO_2$ production from the other sectors, in the same time that their own emissions are induced by them.

However, it is important to indicate that, given the methodology applied in the present work, it was expected that the sectors considered as key ones from production and demand perspectives were, in great measure, coincident. This is a consequence of the fact that the economic structure considered in both cases was the same, implicating that identical intersectoral relations were incorporated in the analysis. A very relevant point is that, in the case of the analysis from the demand perspective, the emissions resulting directly from the energy consumption of the final demand were not considered. Thus, for example, the emission produced by households' automobiles, as well as by the domestic utilization of fuels, was not incorporated to the analysis. Therefore, it was not possible to evaluate the relation between the productive sectors and these parcels of emissions resulting from final demand.

In this way, in the scope of scheming policies that intend to control $CO_2$ emissions, it is valuable to analyze the elasticities of emissions from production perspective. The capacity of generating income – especially, it can be indicated, labor remuneration – must be considered by environmental policies, given the effects on economic growth of the imposed restrictions. A possible implication of the analysis accomplished in the present work is that, for example, one must evaluate that the imposition of an absolute restriction in the emissions of the sectors with the smallest total impact can implicate in higher costs, in terms of value added. This is the case of the sectors located in the bottom left box in Table 7 and that have relatively low values of $CO_2$ emissions coefficients in respect to their value added, according to Table 3. Policies of emission control imposed directly on Machinery Industries, Electric Equipment, Transportation Equipment, Textiles and Construction sectors would incur in more pronounced reductions of value added than in the case of the other sectors, since they, accordingly with the results obtained in the work, present a relatively weak relation between the $CO_2$ emissions and the value added generation.

The analysis of the $CO_2$ emissions elasticities from a demand perspective is also relevant to the elaboration of environmental policies. Here, the central point is the way the policies of emission control can affect the final demand, especially in what concerns the key sectors that direct their production mainly to final consumption. This is the case of the Food Industries sector, whose final demand would be probably affected by policies of emission control that enclose the economy as a whole.

According to Alcántara and Padilla (2003), since the total impacts include the effect in the own sector in which one considers the increase in value added or final demand took place (given by the main diagonal of the elasticity matrix), when this effect is significant, one must consider policies of $CO_2$ control that are particular to the sector. Thus, for example, in the case of the sectors indicated as key ones from the demand perspective, one observes that in Agriculture, Metallurgy, Industrial Services of Public Utility (ISPU) and Transport, the participation of the own sector in the corresponding total effect was relatively high: 78.9%, 79.3%, 84.5% e 96.9%, respectively. This means that, in these sectors, the impact of the final demand in the $CO_2$ emission affects mainly themselves, so that there is considerable margin to direct action. Control policies that are specific to these sectors – for example, the installation of control equipments imposed as obligation – have great possibilities to significantly decrease the $CO_2$ emissions of the economy, with relatively reduced costs in terms of supervision resources.

## 4. Final comments.

The present work presented the income and demand elasticities of $CO_2$ emissions, in Brazil, in 2004. Although the Brazilian energy profile is more positive than the world one in terms of its emissions (given the significative participation of renewable resources and hydroelectricity in its energy matrix), the present analysis is relevant, since one can observe, in the recent years, that the country has been presenting very significative increase rates in its emissions. They are linked to both the increase in the consumption of fossil fuels – given that the exploitation of hydroelectric sources becomes progressively less viable – and the development of the economy.

An improved comprehension of the relation between the emissions and the economic activity is undeniably important to the formulation of environmental policies intending to control the greenhouse effect, a pressing problem in the contemporary world. Given this, the methodology applied in the present work intends to operate as a tool to determine the relevance of the several economic sectors to the $CO_2$ emissions. Thus, it was possible to identify the key sectors in the emissions of this pollutant in the Brazilian economic structure, from both production and demand perspectives.

It was indicated that the productive sectors that should be object of greater attention in the process of scheming control policies do not differ substantially, from production and demand perspectives. Transport, Agriculture, Metallurgy, Food Industries, Industrial Services of Public Utility, and Services are the sectors that concentrate the largest share of the emissions caused by the intensification of economic activity, as well as those whose expansion in income or final demand increases in greater measure the total emissions of the economy. Therefore, these are the key sectors in the $CO_2$ emission in the Brazilian productive structure. However, it is worthwhile to indicate once again that such coincidence among the sectors that were pointed by both perspectives adopted in the analysis is a consequence, in a significative extent, of the methodology applied in the present work. Especially, it is necessary to advert that the emissions related to final demand have not included these that are not in a direct relation with the productive structure, i.e., that resulted straightly from households consumption, which is the case of the emissions resulting from automobiles utilization.

The elaboration of energetic and environmental policies must consider the impacts caused by $CO_2$ emissions from production perspective and also the effects that the several mechanisms of income generation have in the environment. In other words, the capacity of income generation, especially labor remuneration, of the several productive sectors, must be considered by these policies, which must examine the reduction in economic growth that may result from the imposition of limits to the $CO_2$ emissions. On the other hand, the demand perspective must also be considered, having in view the ways in which the control policies may affect the final consumers.

Therefore, in despite of the limitations resulting from the data unavailability, the analysis of the income and demand elasticities of the several sectors of the economy, accomplished in the work, is a relevant tool to the elaboration of emissions control policies. By properly considering both environmental and economic aspects, these policies may achieve the purpose of controlling the $CO_2$ emissions that result from the productive processes, avoiding excessive costs in terms of income and restrictions to final demand.

As suggestion for future works, one may indicate the utilization of more recent data about the sectoral $CO_2$ emissions, comprehending a large number of disaggregated sectors of the economy. An important procedure to be carried out is the incorporation of the emissions directly produced by final demand to the analysis, principally by households consumption. It is also quite important that the emissions related to agriculture and that were not considered in the present work – especially those resulting from forest fires – be taken into account, given the great participation of these activities in the Brazilian total emissions. One can also be interested in studying the specific relations between the elasticities of $CO_2$ emissions and the consumption of the several energy sources of the economy. Moreover, the application of the methodology in the analysis of the Brazilian regions would be relevant tool to the scheming of environmental policies in regional level.

## 5. References.

ALCÁNTARA, V.; PADILLA, E. An input-output analysis of the "key" sectors in CO2 emissions from a production perspective: an application to the Spanish economy. **Document de Treball**, Universitat Autònoma de Barcelona, Fevereiro de 2006.

______________________________. "Key" sectors in final energy consumption: an input-output application to the Spanish case. **Energy Policy**, 31, 2003. pp. 1673-1678.

ANFAVEA. http://www.anfavea.com.br/tabelas/autoveiculos/tabela10_producao.xls. (06 set. 2007).

BRASIL. Ministério de Minas e Energia. **Balanço Energético Nacional**. Brasília, 2006.

DIETZENBACHER, E. In vindication of the Ghosh Model: a reinterpretation as a price model. **Journal of Regional Science**. V. 37, no 4, 1997, pp. 629-651.

GLOBAL ENVIRONMENT FACILITY. **The Challenge of Sustainability:** an Action Agenda for the Global Environment. Washington, 2002.

GUILHOTO, J. J. M.; SESSO FILHO, U. A. Estimação da Matriz Insumo Produto a Partir de Dados Preliminares das Contas Nacionais. **Economia Aplicada**. Ribeirão Preto, v.2, no9, abr/jun 2005.

GUILHOTO, J.J.M.; LOPES, R. L.; MOTTA, R.S.. Impactos Ambientais e Regionais de Cenários de Crescimento da Economia Brasileira – 2002-2012. **Textos Para Discussão Ipea**. Rio de Janeiro, v. 892, 2002.

HILGEMBERG, E. **Quantificação e efeitos econômicos do controle de emissões de CO2 decorrentes do uso de gás natural, álcool e derivados de petróleo no Brasil:** um modelo interregional de insumo produto. 2004. 151 f. Tese (Doutorado em Economia Aplicada) – Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, Piracicaba, 2004.

IBGE. **Sistema de contas nacionais.** 2007.

IPEA. **IPEADATA**. http://www.ipeadata.gov.br (04 dez. 2006).

MILLER, R.; BLAIR, P. **Input-output analysis:** foundations and extensions. New Jersey: Prentice Hall, 1985, 464p.

MINISTRY OF SCIENCE AND TECHNOLOGY. **Brazil Initial Communication to the United Nations Framework Convention on Climate Change.** Brasília, 2004.

ONU. Departamento de Assuntos Econômicos e Sociais. **Global Challenge, Global Opportunity:** Trends in Sustainable Development. New York, 2002.

ONU. Programa das Nações Unidas para o Meio Ambiente. **Global Environment Outlook Yearbook 2006:** An Overview of Our Changing Environment. Quênia, 2006.