Structural Changes and Emissions of Greenhouse Gases: a subsystem application to Brazil between 2000 and 2009

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Abstract. The recent increase in worldwide concern over global warming has raised questions about the factors responsible for this weather phenomenon. In this context, this article analyses the impacts of structural changes in the Brazilian economy from 2000 to 2009 on the vector of greenhouse gases (GHG), properly built from the inventory of emissions and the Input-Output matrix of the Brazilian economy, from which the approach of vertically integrated sectors developed by Pasinetti (1973) is applied. The analysis concludes that Brazil advanced in environmental issues during that period, especially as regards the reduction of deforestation; that the energy and service subsystems generate more greenhouse gas emissions than their respective sectors; and that the environmental impact of energy sectors is more accentuated due to the recent change in the Brazilian energy matrix.

1. Introduction

The mean temperature of the atmosphere is increasing throughout the world. Scientists believe that a part of this warming is due to an enhanced greenhouse effect caused by the release into the atmosphere of certain greenhouse gases (GHGs)[1]. Many scientists believe human activities that release GHGs may be increasing the natural greenhouse effect and resulting enhanced greenhouse effect contributes significantly to the observed global warming, already has called in geological sense how "anthropocene".

Climate change is a difficult, complex, and challenging problem for several reasons. One reason is that Earth responds on different time scales than do political systems. Climate change will affect everyone, but the people who will suffer most are those who have done the least to bring it about. Indeed, when one looks at per capita or even total GHGs emissions by country, the rich nations of the North dominate. However, when one looks at the actual and expected damages from climate change, it is the poor nations of the South that do and will suffer the most. On the other hand, per capita emissions do not march in lockstep with gross domestic product, and, the atmosphere does not care where GHGs originate. From this perspective, climate change, rather than being caused by rich countries, is caused by rich people wherever they live.

Other important issue to highlight in this context is the concept of value in conventional economics, linked to the basic notion of scarcity of resources and to their pricing in the market system. Resources that are not scarce and are not exchanged have in principle no theoretical value. The real problem we have to face is to reformulate a definition of value where the basis for both economy and ecology is recognized as being the same; the best possible utilization and maintenance of human and natural resources for the well-being and for the wealth of nations (Giarini, 2014).

The aim of this article is the impacts of the structural changes in the Brazilian economy, using the notion of vertical integrated sectors (subsystems) developed by Pasinetti (1973), to

1 The principal Greenhouse Gases (GHGs) are water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3), CFCs (chloro-fluorocarbons), and hydro-fluorocarbons.

assess how the productive activities in the national level contribute for the changes in a vector of Greenhouse Gases (GHG).

After this considerations, the second section details the climate change issues, in particular, about recent past discussion and responses as well as the policy actions in Brazil and in the world to confronting this externality. The third section explains the Pós-keynesian approach and the importance of economic ecologic for the treatment of environment issues. At fourth section is made introduce to vertical integration concept. The fifth section describe the methodology in general and tackle the aggregation procedures for input-output matrix sectors and the obtainment of CO_2eq emissions vector and the carbon intensity of Brazilian economy. The sixth section show the results and realize the analysis for GHG vectors in 2000 and 2009 and to structural model constructed, in special to relation to vertical integrated sectors. Finally, in the seventh section explore the conclusions of the paper wich emphasizes the impacts of structural changes in a vertical integration approach of economy over GHG emissions.

2. Motivation

The Intergovernmental Panel on Climate Change (IPCC)[2] - the main international scientific authority on climate change, belonging to the United Nations - has shown that knowledge gaps still exist about the Earth's climate. However, there is no doubt about the negative influences of climate change on economic agents and the social welfare.

Initial uncertainties about which factors were responsible for climate changes prevented the advancement of effective actions to reduce GHG emissions. After that, a strong international pressure led to the signing of multilateral agreements for the mitigation of Greenhouse Gases emissions and the adaptation to climate change.

The mobilization of several countries around the United Nations (UN) in the attempt of reducing GHG emissions paved the way for the United Nations Framework Convention on Climate Change (UNFCCC) in the early 1990s. Historically, the first actions in response to climate change were discussed during the ECO-92 held in Brazil. A few years later, in 1995, the first emission inventories were disclosed. Only in 1997, during the Third Conference of the Parties (COP III) of the UNFCCC, in Japan, that the Kyoto protocol was adopted, establishing a target average reduction of 5.2% of emissions occurred in 1990 for the period between 2008 and 2012.

Since developing countries were not willing to commit to making reductions under the Kyoto Protocol,[3] Brazil was not formally committed to making reductions with any target compliance. The Brazilian government, however, adopted GHG voluntary target for reduced emissions between 36.1% and 38.9% compared to the stock of emissions projected by 2020.[4] This reduction ensures a comfortable position for Brazil in target negotiations that will replace

2 An organization that was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). It is open to all member nations of WMO and UNEP, and its task is to assess the scientific, technical, and socioeconomic information that is relevant to changes in climate that are caused by human activity and their consequences.

3 Developed countries are responsible for two thirds of current emissions and for three-quarters of historical GHGs emissions; they are largely responsible for the current anthropogenic stock. On ethical grounds it is therefore hard to argue that developing countries should bear the cost of limiting GHGs stocks. However, it is important that developing countries participate in efforts to limit GHGs emissions: the growth rate of GHGs emissions in developing countries is increasing, and their aggregate emissions are projected to exceed those of developed countries within a few decades. Even if developed countries manage to control their emissions, global stabilization of GHGs concentrations requires reductions in developing countries. In addition, their participation in plans to control the global stock may be essential in overcoming the resistance within developed countries to implementing the Kyoto Protocol (Karp and Liu, 2001).

the Kyoto protocol from 2020 (La Rovere, Dubeux and Pereira Jr., 2013). While some sectors have reduced their GHG emissions, such as crop/livestock and forestry, others have increased - industry and transport, for example - which reinforces the need for additional studies to identify Brazilian economy behaviors, including those related to structural changes, which are responsible for the increase of pollution, thus allowing that appropriate mitigation actions be implemented.

On the other hand, the statement from Brazil to COP-15 reported the breakdown of the target for reduced emissions: reduction of 24.7% for avoided deforestation, 7.7% emission reduction by energy sector, 6.1% by agricultural sector and 0.4% achieved by industrial processes and waste treatment. This division shows the effort concentration on controlling deforestation (Seroa da Motta, 2011: 34), while pointing out a low participation of technological innovation in the national effort.

3. Post-Keynesian approach

Economic discussions recognizing the importance of the environment and natural systems have slowly been evolving over the last century. The resource economists of the 1950s tended to regard the environment as a source of materials which required some specialized management, due to characteristics which differentiated them from manufactured goods. These economists can be viewed as being within the neoclassical school, and as having strong associations with agricultural economics. In the 1960s, environmental economics appeared in the US as a distinct discipline concerned with the growing pollution problems which were evident to the general public. Together, resource and environmental economics explained how neoclassical models were flawed and how corrections could be made to achieve efficiency gains (Spash, 1999).

In the late 1960s and early 1970s ecological economics seemed to be pushing the boundaries of economic analysis and challenges approaches to economics that aim to limit the use of ideas from ecology.[5] It is a trans-disciplinary field of study that addresses the relationship between ecosystems and ecological systems in the broadest possible sense. Ecological economics goes beyond conventional conceptions of scientific disciplines and attempts to integrate and synthesize many different disciplinary perspectives, in order to achieve an ecologically and economically sustainable world. By turning to materials balance theory, it brought in the laws of thermodynamics to economics as an alternative to the neoclassical model This implies a different methodology from the mainstream economic models, while allowing for a discourse on the development of a socioeconomic and ecological field of study (Holt and Spash, 2009; Spash, 1999).[6]

The distinguishing characteristic of ecological economics is that it takes as its starting point the recognition that the economic and environmental systems are interdependent, and studies the joint economy–environment system in the light of principles from the natural sciences, particularly thermodynamics and ecology (Baumgärtner et al., 2001).

4 The National Policy on Climate Change (NPCC) estimated the GHGs emission projections for 2020 at 3,236 million tons of CO_2eq (Mt CO_2eq). Applying the voluntary targets, the reduction in GHG emissions should be between 1,168 and 1,259 million tons of CO_2eq (Mt CO_2eq) (Brasil, 2009, 2010).

5 Ecology is that branch of biology dealing with the interrelationships between living organisms and between organisms and their environment. Contrary to other fields within biology, ecology focuses not on individual organisms or their evolution, but on their interaction within ecosystems as both organisms and their context (animate and inanimate) of change. The influence of ecology on economics is particularly evident in ecological economics, bio-economics and the debate surrounding sustainability and sustainable development. All seek to consider economics within the context of ecological or biophysical systems and the constraints of economic theory and valuation (O'Hara, 1999).

The application of thermodynamics is widely recognized as an essential element in much current ecological economics thanks to its applicability to all real production processes, which are the basis of economic activity. The laws of thermodynamics lead us to recognise that the human economy is an open subsystem embedded in the larger, but finite, system of the natural environment. The strength of the concept of joint production is that it allows us to incorporate this insight about economy–environment interactions into ecological economics (Baumgärtner et al., 2001).

The process of production could be described as a transformation of a certain number of inputs into a certain number of outputs, each of which is characterised by its mass and its entropy. From the laws of thermodynamics it then follows that every process of production is a joint production,[7] in addition to the intended products, also results in unintended outputs, which often are unnoticed, and they may be harmful to other producers, consumers, or to the natural environment. As a consequence, both the producer and the wider society demanding the desired principal product now face an ethical problem. Inattention to joint production may therefore easily result in ethical negligence (Baumgärtner et al., 2001).

The analysis of joint production actually has a long tradition in economics, but the modern literature on general equilibrium theory does not explicitly investigate the properties of economies characterised by joint production. Instead, it is focused on identifying the most general assumptions under which certain results hold, e.g. existence and optimality of general equilibrium (Baumgärtner et al., 2001).

4. The concept of vertical integration

Production is a time-consuming process which might be viewed in two ways. First, production can be conceived as a one-way avenue leading from primary (non-producible) inputs, such as labour or land, via intermediate products to consumer goods. Since intermediate goods are used up during the process of production, the latter can be described as a causal relation between one or more inputs of original factors and final products.[8] Second, the more general approach, production is viewed as a circular flow. Any *flow input-flow output* process is broken down into as many *point input-point output* processes as there are stages of production. Thus all processes

6 Post Keynesian economics, with its focus on the role of institutions, radical uncertainty, historical time and its criticism of gross substitution, questions the comprehensiveness of the three primary assumptions of the traditional neoclassical approach to environmental issues and sustainable development: reasonable market valuations can be made with non-market environmental goods for cost–benefit analysis; environmental externalities and other forms of market failure associated with the environment can be internalized and corrected by incentive-based policies; and, different types of capital can be substituted for each other to achieve sustainable development. This does not mean that mainstream economics cannot deal with many environmental issues, but its methodology limits its ability to deal with many of the complexities associated with environmental problems, which can lead to bad public policy (Holt and Spash, 2009).

7 Organisms and ecosystems, as open, self-organizing systems, necessarily take in several inputs and generate several outputs, just as an economy. Indeed, such natural systems are the earliest examples of joint production, even though it is not often expressed as a fundamental notion in ecology (Baumgärtner et al., 2001).

8 As soon as capital is taken into account it may happen that intermediate products, which emerge at a certain stage of production, are also required at preceding stages of the respective process. Thus circular processes, where a commodity enters directly or indirectly into its own production cannot in principle be avoided (Lager, 1999).

constituting a system of production can be represented by matrices of inputs and outputs respectively (Lager, 1999).

Sraffa (1960) proposed to subdivide the system of production in such a way that each of these subsystems is able to produce only one kind of final product. Formalizing Sraffa's subsystems, Pasinetti (1973) constructed vertically integrated sectors and demonstrated that prices of production can be subdivided into the costs of total labour embodied, plus the profits on the value of direct and indirect capital required for the production of the respective final product.

According to Sraffa (1960), vertical integration is a classification method in which the input-output models are organized according to the following principle: for each final product (consumer or capital goods), a single vertically integrated sector (or subsystem) will be built. For this, all the final demand components (excluding the sector to be built) are set to zero. Then all the inputs that are directly and indirectly required to produce a given quantity of the final product demanded will be calculated.

Unlike the input-output analysis, these types of vertically integrated sectors are not empirical buildings, but can be calculated from the input-output matrices. In so doing, the extended industry production relations disappear, since the subsystems are defined such that they are able to produce a final product autonomously.

In addition, the vertically integrated sectors - or, alternatively, subsystems - may be considered self-sufficient and independent structures, although disaggregated horizontally. Show no sectoral interdependence because they abstract all kinds of flows between sectors.

Although these vertically integrated sectors also describe the process of production of end products, they relate only to consumer goods. Each commodity is produced by labour and capital inputs. The production of fixed capital and is assigned to the corresponding consumer goods sector. Capital goods are produced to preserve and expand the capital stock in each sector vertically integrated. Once the model completely abstracts the intermediate products, each vertically integrated sector is perfectly closed and autarchic.

Vertical integration is found widely in many applications of economic theory and is particularly suitable for dynamic analysis.[9] According Pasinetti (1973), vertically integrated sectors are constructed in accordance with the requirements of the analysis of structural changes. Integrated vertically sectors must overcome certain conceptual problems of input-output models, in particular the change of technical coefficients in a multitude of interrelated sectors due to innovations - a phenomenon that is difficult to handle analytically.

5. Methodology

As the latest Input-Output Tables released by the Brazilian Institute of Geography and Statistics (IBGE) is from the year 2005, the calculations underlying the findings of this article have been carried out using the I-O Tables built by Guilhoto and Sesso Filho (2005, 2010). Thereby this paper used the matrices build by these authors for the years 2000 and 2009.

To assess the effects of the Brazilian economy on the GHG emission vector, it was required to reconcile the structure of sectors defined by UNFCCC for the Emission Inventories (six sectors) with the national accounting structure of the I-O Tables (56 sectors). The solution is to make adjustments through aggregation of the 56 sectors of the I-O Tables in 11 sectors of the economy.[10]

This section is divided in three subsections: first, we continues to describe de procedures for aggregation the sectors of I-O Tables in more appropriated form for match the inventories data;

9 Empirical studies in several areas were conducted using the concept of vertical integration, with applications ranging from international trade (Elmslie, 1988; and, Milberg, 1987) to labour productivity (Montressor and Marzetti, 2011; Costa Junior and Teixeira, 2010; De Juan and Febrero, 2000; Ochoa, 1986; Momigliano and Sinisclaco, 1982a, 1982b) including economic impact behind a cultural asset (Llop and Arauzo-Carrod, 2012), and the object of this research: environmental issues (Navarro and Alcántara, 2010; Alcántara and Padilla, 2008; and, Sánchez-Chóliz and Duarte, 2005, 2003).

the second subsection introduce the methodology to obtain the emission vector and explore the carbon intensity concept; the third subsection define the decomposition of subsystems in the vertical integration approach.

5.1 Aggregation Procedure for Input-Output Matrix Sectors

Following Miller and Blair (2009: 161), aggregation of I-O sectors is performed by defining a matrix $\mathbf{S}$, the aggregation matrix, to be a $k \times n$ matrix of ones and zeros, where k is the number of sectors in the to-be-created aggregated version of the input–output table and n is the number of sectors in the existing un-aggregated version of the table. The locations of ones in row i of $\mathbf{S}$ indicate which sectors of the un-aggregated table will be grouped together as sector i in the aggregated table.

We define the inter-industry transactions matrix, $\mathbf{Z}$, the vector of total final demands, $\mathbf{f}$, and the vector of total industry outputs, $\mathbf{x}$. The new transactions matrix $\mathbf{Z}^*$ is obtained from $\mathbf{Z}^* = \mathbf{SZS}'$ and the new final demand vector $\mathbf{f}^*$ is obtained from $\mathbf{f}^* = \mathbf{Sf}$. The new corresponding vector of total outputs $\mathbf{x}^*$ can be computed as $\mathbf{x}^* = \mathbf{Z}^*\mathbf{i} + \mathbf{f}^*$, where $\mathbf{i}$ is a column vector of ones.

From these formulations, "Agriculture" and "Forestry" sectors were obtained from the break-up of "Agriculture, forestry, and logging" activities and aggregation to "Livestock and fisheries" I-O sector, which resulted in the division of cash flows of agricultural and forest products. Proportionality was obtained from the Production Table (Resources) by Guilhoto and Sesso Filho (2010). Their values indicate a contribution of forestry and forestry product of 5.23% (2009) of the total agricultural and forest products. Therefore, 94.77% is the share of agricultural products, also included the "Fishing" I-O sector.

Another I-O sector which was spun off is "Electricity and gas, water, sewage and urban sanitation", sectioned in "Electricity", "Cooking gas" and "Water, sewage and urban sanitation". It was used the proportionality of Grottera (2013): 74.2% of the total on "Energy – electricity"; 7.4% of the total on "Residential and commercial gas", which will be included in "Energy - residential gas" and 18.4% of the total on "Water, sewage and urban sanitation", defined in the I-O matrix as the "Industry residues" sector.

Intentionally, "Energy" I-O sector were kept in the following sectors, involving primary and secondary sources of energy: (i) oil and gas; (ii) petroleum refining and coke; (iii) ethanol; (iv) residential and commercial gas; and (v) electricity (electric public utilities and auto-producers).

"Transport" sector comprises cargo transport activities and passengers, storage and mailing. "Manufacturing" sector brings all manufacturing activities, which includes various activities such as mining, quarrying, food and beverages, textiles, pulp and paper, metals, among others. "Service" sector includes all activities of provision of services such as education, health,

10 It is noteworthy that the sectorial structure of emission sources and sinks of CO_2eq was only possible from rules established in 2006 and still spend several methodological changes not technically completed by the IPCC, particularly with regard to changes in land use and forests. This rule have replaced the current rules of aggregation of productive sectors source and sinks defined by a series of legal instruments by the IPCC and approved under the UNFCCC in 1996. The goal is to guide the countries to formulate communications to the UNFCCC in a transparent, complete, comparable, consistent and accurate as the emissions of GHGs by emitting sectors.

maintenance and repair, financial intermediation, information, public administration, among others.

The closing of the matrix does the aggregation of lines domestic product, imports, direct and indirect taxes, wages, gross operating surplus, value added at factor costs, other taxes on production, gross value added (GDP), the value of production and employed persons. Along these lines, the aggregation was also performed by sectors in the manner described above, which resulted in 2009 I-O Table.

5.2 The CO_2eq emissions Vector and the carbon intensity

The flexibility of Input-Output Model allows developing matrices that show the structure of the economy both production and consumption. Thus, it becomes possible to also use it to account for the impact of these activities on the emission of pollutants by means of estimates of direct and indirect impacts of the economy. The methodology used is using in part the environmental input-output matrix theory building set in Miller and Blair (2009).[11]

From the inventories and GHGs emission estimates (MCTI, 2013) for Brazil are calculated emissions associated sectors treated in the proposed model. This is a consistent approach employed in line with the input-output model, whose function is to add to the input-output matrix the pollution generated in the form of GHGs emissions (CO_2eq). Therefore, it is necessary to establish the following simplifying assumptions about the MCTI data (2013):

(i) the emissions of CO_2eq of “Change of Use and Forests” sector, available for biomes, in Amazon biome are assigned to the “Forestry” sector, represented by legal activities of forest management of native species and deforestation for the establishment of agricultural and illegal deforestation activities. The emissions related to land use changes in other biomes (Cerrado, Caatinga, Pantanal, Atlantic Forest and the Pampas) were credited to the “Agriculture” sector, which also involves the forestry production for energy purposes of Pinnus and eucalyptus for some industries (steel and pulp and paper);

(ii) in the “Agriculture” sector, the emissions from the burning of sugarcane bagasse and rice husk were credited in the “Energy – Ethanol” sector related to the production of thermal energy in self-producers ethanol plants;

(iii) fugitive emissions from the energy sector recorded in MCTI (2013) associated with the extraction and transport of oil were recorded in the “Energy – Oil and Gas” and “Industrial gas” sector;

(iv) the emissions from the “Energy” I-O sector - oil and gas industry, registered in MCTI (2013), were split as share of total production of I-O Matrix and credited in the energy sector - oil and gas and industrial energy - refining and coke.

(v) the emissions from the energy subsector energy sector - power plants, charcoal and central self-producers, registered in MCTI (2013) were credited in the “Energy – Electricity” sector;

(vi) the releases for the energy sector, industrial sub-sectors, transport and residential, registered in MCTI (2013) were credited in the industry sector, the transport sector and the energy sector - residential and commercial gas, respectively in I-O Matrix;

(vii) the releases for the energy sector, commercial and public subsectors, registered in MCTI (2013) were credited in the “Services” sector on the I-O Matrix. Accounting for commercial subsector thus stems from the records of its production value in national accounts in the service sector; and

(viii) emissions from the energy sector agriculture subsector, registered in MCTI (2013), were divided between the agricultural sectors (92.06%) and forestry (7.94%) in proportion to

11 It should be considered that some authors have used the approach of input-output matrix and related models to verify the interrelationship between economic activity and environmental issues. In this respect can be seen Guilhoto, Lopes and Seroa da Motta (2002); Tourinho, Seroa da Motta and Alves (2003) and Hilgemberg and Guilhoto (2006).

their interest in the production value 2009 I-O Matrix. In the same way the other proportion was used for the production value in 2000 I-O Matrix.

In order to determine the CO_2eq emissions vector, we define a set of the organic products (pollution), that is, the CO_2eq emissions by productive sector. The corresponding vector of pollution output (CO_2eq emissions) flows is $\mathbf{g} \equiv \lfloor g_j \rfloor$, an element of which specifies the amount of pollution output (CO_2eq emissions) directly associated with the output of sector j.

Defining $\mathbf{q} \equiv \lfloor q_j \rfloor$, the vector of pollution output (CO_2eq emissions) coefficients, as $\mathbf{q} \equiv \hat{\mathbf{x}}^{-1}\mathbf{g}$, and $\mathbf{A} \equiv \lfloor a_{ij} \rfloor$, the $n \, x \, n$ matrix of technical coefficients, represented as $\mathbf{A} \equiv \mathbf{Z}\hat{\mathbf{x}}^{-1}$, the pollution output ($CO_2$eq emissions) coefficients as a function of final demands can be written as $\mathbf{q}^* \equiv \left[(\mathbf{I} - \mathbf{A})^{-1} \right]^T \mathbf{q}$, where $\mathbf{I}$ is an identity matrix. The elements in $\mathbf{q}^* \equiv \lfloor q_j^* \rfloor$ reflect the amount of pollution output (CO_2eq emissions) associated with delivering a monetary unit worth of industry j's output to final demand directly and indirectly.[12]

5.3 The decomposition of the subsystems

Momigliano and Siniscalco (1982a, 1982b) refer to the concept of a subsystem by constructing a matrix:

$$\mathbf{B} = \hat{\mathbf{x}}^{-1}(\mathbf{I} - \mathbf{A})^{-1}\hat{\mathbf{f}}^*$$

Each row of $\mathbf{B}$ adds up to 1 and shows 'the proportion of the activity of each branch which comes under the various subsystems' (Momigliano and Siniscalco, 1982a, p. 281). $\mathbf{B}$ therefore can be used as an operator to reclassify any variable from a sector base into a subsystem base. On the basis of $\mathbf{B}$, Momigliano and Siniscalco (1982a, 1982b) actually worked out the matrix $\mathbf{N}$, defined as:

$$\mathbf{N} = \hat{\mathbf{g}}\mathbf{B}$$

where $\hat{\mathbf{g}}$ is the diagonalised vector of pollution output (CO_2eq emissions) flows. The generic element n_{ij} of $\mathbf{N}$ is the amount of CO_2eq emissions required, both directly and indirectly, from sector i in order to satisfy the final demand in sector j.

12 The vector is a measure of the content of CO_2eq savings, known as carbon intensity of economy. This is a reference measurement of the degree of economic efficiency on carbon, widely used in the literature as Focacci (2005) and Kooten (2013).

Also of relevance is the matrix $\mathbf{C}$, which is obtained by dividing each of the cells in $\mathbf{N}$ by the total of the corresponding column. Denoting with $\mathbf{i}'$ a row unit vector and $\mathbf{M}$ as $\mathbf{M} \equiv \mathbf{i}'\mathbf{N}$, $\mathbf{C}$ can be written as:

$$\mathbf{C} = \mathbf{N}\hat{\mathbf{M}}^{-1}$$

The generic element of $\mathbf{C}$, c_{ij}, measures the share accounted for by sector i in total CO_2eq emissions required by subsystem j in order to satisfy final demand. It should be noted that, as demonstrated by Rampa (1982), all previous matrices are invariant to relative prices. A comparative analysis of the changes that occur over time in the above defined matrices is useful for disentangling the determinants of structural change. Indeed, while $\mathbf{N}$ works out levels, $\mathbf{B}$ and $\mathbf{C}$ measure shares and do not depend on, respectively, sectoral CO_2eq emissions requirements and the final demand structure. More precisely, $\mathbf{B}$ calculates the shares of each subsystem in each relevant sector, for example in terms of CO_2eq emissions required. Thus, changes in total CO_2eq emissions in a certain sector, with gross production constant, do not affect these shares. On the other hand, assuming constant returns to scale, $\mathbf{C}$ is not affected by changes in the composition of final demand. And the same might hold if all sectors share the same patterns of returns to scale, either increasing or decreasing. If this is not the case and, for example, returns to scale are increasing in the manufacturing sectors only, an increase in industrial demand might lead to a decrease in the manufacturing elements of $\mathbf{C}$.

6. Analytical results

The result from de aggregation procedures of I-O Tables data can see in Annex A for both periods (2000 and 2009). The Tables 1 and 2 represent the basic data from I-O Tables for the 11 sectors of Brazilian economy.[13]

Table 1Total Final Demand, Total Industry Outputs by Sectors in Brazil (2000)

Sectors	Total Final Demands f (R$ 1,000,000)	Total Industry Outputs x (R$ 1,000,000)
Agriculture	33,181	91,394
Forestry	1,585	4,367
Manufacturing	395,292	706,287
Services	661,843	961,014
Energy - Oil and Gas	1,077	20,958
Energy - Refining and Coke	16,710	51,716
Energy - Ethanol	3,248	8,841
Energy - Electricity	17,033	49,528

13 Other vectors and matrices are available from the authors.

Sectors	Total Final Demands	Total Industry Outputs
	f	x
	(R$ 1,000,000)	(R$ 1,000,000)
Energy - Residential and Commercial Gas	1,699	4,939
Water Supply and Waste	4,224	12,282
Transport	42,222	92,245
TOTAL	**1,178,113**	**2,003,571**

Source: prepared by authors from Guilhoto and Sesso Filho (2005, 2010) and MCTI (2013).

In 2000, the most expressive sectors both in Total Final Demands and Total Industry Outputs are "Services" and "Manufacturing".

Table 2Total Final Demand, Total Industry Outputs by Sectors in Brazil (2009)

Sectors	Total Final Demands	Total Industry Outputs
	f	x
	(R$ 1,000,000)	(R$ 1,000,000)
Agriculture	97,009	262,072
Forestry	5,321	14,375
Manufacturing	1,046,633	1,855,542
Services	1,818,572	2,653,019
Energy - Oil and Gas	19,833	81,614
Energy - Refining and Coke	41,413	150,105
Energy - Ethanol	11,061	22,444
Energy - Electricity	42,316	126,636
Energy - Residential and Commercial Gas	4,220	12,630
Water Supply and Waste	10,493	31,403
Transport	114,331	270,901
TOTAL	**3,211,203**	**5,480,741**

Source: prepared by authors from Guilhoto and Sesso Filho (2005, 2010) and MCTI (2013).

Again, in 2009, the most expressive sectors both in Total Final Demands and Total Industry Outputs are "Services" and "Manufacturing".

The Table 3 show the proportion of Sectors in the respective Subsystem (b) and the proportion of Subsystems in the respective Sector in 2000. The "Manufacturing" and "Services" sectors have more than 80% of participation in its respective subsystem, while the others sectors have less than 20% of participation in its respective subsystem. The exception goes to Energy and Oil Gas with 5% of one in your subsystem.

Table 3 Proportion of Sectors and Subsystems in Brazil (2000)

Sectors	The proportion of each Sector in its respective Subsystem	The proportion of each Subsystem in its respective Sector
	b	c
Agriculture	0.40299	0.91968
Forestry	0.37548	0.99586
Manufacturing	0.84026	0.01867
Services	0.87037	0.03743

Sectors	The proportion of each Sector in its respective Subsystem	The proportion of each Subsystem in its respective Sector
	b	c
Energy - Oil and Gas	0.05248	0.23979
Energy - Refining and Coke	0.39224	0.27006
Energy - Ethanol	0.36973	0.28358
Energy - Electricity	0.42064	0.40758
Energy - Residential and Commercial Gas	0.35155	0.96115
Water Supply and Waste	0.36293	0.93282
Transport	0.49866	0.11559

Source: prepared by authors from Guilhoto and Sesso Filho (2005, 2010) and MCTI (2013).

"Forestry", "Agriculture", "Water Supply and Waste" and "Energy - Residential and Commercial Gas" subsystems have more than 80% of participation in its respective sector, while "Services", "Manufacturing" and "Transport" have less than 20% of participation in its respective sector.

The Table 4 show the proportion of Sectors in the respective Subsystem (b) and the proportion of Subsystems in the respective Sector in 2009. The "Manufacturing" and "Services" sectors still have more than 80% of participation in its respective subsystem, while no sector has less than 20% of participation in its respective subsystem. "Forestry", "Agriculture", "Water Supply and Waste", "Energy - Residential and Commercial Gas", and "Transport" subsystems have more than 80% of participation in its respective sector, while "Services" and "Energy - Ethanol" have less than 20% of participation in its respective sector.

Table 4 Proportion of Sectors and Subsystems in Brazil (2009)

Sectors	The proportion of each Sector in its respective Subsystem	The proportion of each Subsystem in its respective Sector
	b	c
Agriculture	0.41089	0.95300
Forestry	0.38260	0.97931
Manufacturing	0.84018	0.25104
Services	0.86492	0.02145
Energy - Oil and Gas	0.25479	0.65473
Energy - Refining and Coke	0.32535	0.27227
Energy - Ethanol	0.49416	0.15168
Energy - Electricity	0.39766	0.61952
Energy - Residential and Commercial Gas	0.34049	0.88299
Water Supply and Waste	0.34990	0.90742
Transport	0.47172	0.84194

Source: prepared by authors from Guilhoto and Sesso Filho (2005, 2010) and MCTI (2013).

In regarding the results for simplifying assumptions about the MCTI data (2013), wich the structure of GHG emission vector require to be reallocated to turn a compatible structure with the I-O Tables (11 sectors) of the economy. The GHG emission vector nowadays represents the total requirements of GHG emissions necessary for the productive sectors to give the society your products.

The Tables 5 and 6 show the total requirements used by each Sector as well as the requirements used by each Subsystem in Brazil for 2000 and 2009, respectively. In the Annex B should see the direct and indirect requirements of Brazilian economy in these periods.

The sectors who generated more GHGs emissions in 2000 are “Forestry”, followed by “Energy - Residential and Commercial Gas” and “Water Supply and Waste”, while the subsystems that generate more pollutants are “Forestry”, followed by “Energy - Residential and Commercial Gas” and “Water Supply and Waste” again. Due to the process of vertical integration, some subsystems are bigger than their respective sector, especially “Services”, “Manufacturing”, “Energy - Ethanol”, and “Energy - Refining and Coke”, while others subsystems are smaller than their respective sector, notably, “Water Supply and Waste”, “Energy - Residential and Commercial Gas”, “Energy - Oil and Gas”, “Forestry”, and “Agriculture”.

Table 5 Total Requirements by Sector, and Requirements by Subsystem in Brazil (2000)

Sectors	**Total Requirements by Sector**	**Requirements by Subsystem**
	g*	**m'**
	(t CO_2eq)	**(t CO_2eq)**
Agriculture	824,999,301	361,505,512
Forestry	858,278,199	323,610,609
Manufacturing	19,933,475	897,359,090
Services	11,534,285	268,197,594
Energy - Oil and Gas	3,684,600	806,376
Energy - Refining and Coke	18,678,600	27,129,186
Energy - Ethanol	28,591,680	37,278,109
Energy - Electricity	38,584,129	39,820,377
Energy - Residential and Commercial Gas	121,124,406	44,302,829
Water Supply and Waste	145,778,230	56,717,482
Transport	4,363,075	18,822,817
TOTAL	**2,075,549,980**	**2,075,549,980**

Source: prepared by authors from Guilhoto and Sesso Filho (2005, 2010) and MCTI (2013).

The sectors that generate more GHGs emissions in 2009 are again “Agriculture”, followed by “Manufacturing” and “Forestry”, while the subsystems that generate more pollutants are “Manufacturing”, followed by “Agriculture” and “Services”.

Due to the process of vertical integration, some subsystems are bigger than their respective sector, especially “Services” (more than 40 times!), “Manufacturing”, “Energy - Ethanol”, and “Energy - Refining and Coke”, while others subsystems are smaller than their respective sector, notably, “Water Supply and Waste”, “Energy - Residential and Commercial Gas”, “Energy - Oil and Gas”, “Forestry”, and “Agriculture”.

Table 6 Total Requirements by Sector, and Requirements by Subsystem in Brazil (2009)

Sectors	Total Requirements by Sector	Requirements by Subsystem
	g*	m'
	(t CO_2eq)	(t CO_2eq)
Agriculture	595,072,992	256,567,626
Forestry	168,487,608	65,825,055
Manufacturing	169,985,660	568,915,813
Services	3,914,055	157,814,525
Energy - Oil and Gas	26,908,103	10,471,439
Energy - Refining and Coke	15,333,147	18,322,259
Energy - Ethanol	6,270,000	20,427,413
Energy - Electricity	30,815,010	19,779,501
Energy - Residential and Commercial Gas	18,379,800	7,087,374
Water Supply and Waste	45,708,280	17,625,050
Transport	140,911,195	78,949,795
TOTAL	**1,221,785,850**	**1,221,785,850**

Source: prepared by authors from Guilhoto and Sesso Filho (2005, 2010) and MCTI (2013).

In both periods prevailed GHG emissions from “Agriculture” and “Forestry” sectors, considering the contribution of these sectors in the change of land use (especially deforestation). A significant change occurred in the “Forestry” sector, whose emissions fell from 858.3 Mt CO_2eq to 168.5 Mt CO_2eq in this period. This behavior was due to the reduction of deforestation in the Amazon.

The “Agriculture” sector was also responsible for reductions of 825 Mt CO_2eq to 595.1 Mt CO_2eq in the same years. In other segments, however, only the “Services” and “Energy - Residential and Commercial Gas” emissions remained at the same level, while all other sectors registered increase in emissions in 2009 compared to 2000. It is noteworthy, including the prominence of the industrial and transport sectors in the generation of GHG in 2009.

However, not all factors are positive. Quantitatively, the overall reduction was large but specific sectors showed worrying signs. Emissions were increased in the industrial, transport and water and waste supply. In addition, virtually all subsectors of the great industry called "energy" (oil and gas, refining and coke, alcohol and electricity) had increases in their emissions, which corroborate the results obtained in La Rovere, Dubeux and Pereira Jr. (2013). With specific regard to the industrial sector, it is clear that this productive segment exceeded the forest, making it the second most polluting of Brazil.

The Tables 7 and 8 show the total requirements coefficients, a measure known as carbon intensity of economy in 2000 and 2009, respectively. These coefficients are measures of efficiency; more efficient sectors/subsystems generate less GHGs emissions.

Table 7 Total Requirements Coefficients by Sector, and Requirements Coefficients by Subsystem in Brazil (2000)

Sectors	Total Requirements Coefficients by Sector	Requirements Coefficients by Subsystem
	q*	r
	(t CO_2eq)/(R$ 1,000,000)	(t CO_2eq)/(R$ 1,000,000)
Agriculture	9.026,81	3.955,45
Forestry	196.550,69	74.108,71
Manufacturing	28,22	1.270,53
Services	12,00	279,08
Energy - Oil and Gas	175,81	38,48
Energy - Refining and Coke	361,18	524,58
Energy - Ethanol	3.233,99	4.216,50
Energy - Electricity	779,04	804,00
Energy - Residential and Commercial Gas	24.521,96	8.969,23
Water Supply and Waste	11.869,44	4.618,00
Transport	47,30	204,05

Source: prepared by authors from Guilhoto and Sesso Filho (2005, 2010) and MCTI (2013).

Thus, from both perspectives, "Forestry" is the less efficient sector/subsystem (followed by "Energy - Residential and Commercial Gas", "Water Supply and Waste" and "Agriculture" in the case of sectors, and by "Energy - Residential and Commercial Gas", "Water Supply and Waste", "Energy - Ethanol" and "Agriculture" in the case of subsystems). The more efficient one is "Services" (followed by "Manufacturing" and "Transport" in the case of sectors), but the more efficient one is "Energy – Oil and Gas" (followed by "Transport" and "Services" in the case of subsystems).

Table 8 Total Requirements Coefficients by Sector, and Requirements Coefficients by Subsystem in Brazil (2009)

Sectors	Total Requirements Coefficients by Sector	Requirements Coefficients by Subsystem
	q*	r
	(t CO_2eq)/(R$ 1,000,000)	(t CO_2eq)/(R$ 1,000,000)
Agriculture	2,270.65	979.00
Forestry	11,720.68	4,579.06
Manufacturing	91.61	306.60
Services	1.48	59.48
Energy - Oil and Gas	329.70	128.30
Energy - Refining and Coke	102.15	122.06
Energy - Ethanol	279.36	910.15
Energy - Electricity	243.33	156.19
Energy - Residential and Commercial Gas	1,455.31	561.18
Water Supply and Waste	1,455.53	561.25

Sectors	Total Requirements Coefficients by Sector	Requirements Coefficients by Subsystem
	q*	**r**
	(t CO_2eq)/(R$ 1,000,000)	**(t CO_2eq)/(R$ 1,000,000)**
Transport	520.16	291.43

Source: prepared by authors from Guilhoto and Sesso Filho (2005, 2010) and MCTI (2013).

Thus, again from both perspectives, “Forestry” is the less efficient sector/subsystem (followed by “Agriculture”, “Water Supply and Waste”, and “Energy - Residential and Commercial Gas” in the case of sectors, and by “Agriculture” and “Energy - Ethanol” in the case of subsystems) and “Services” is the more efficient one (followed by “Manufacturing” and “Energy - Refining and Coke” in the case of sectors, and by “Energy - Refining and Coke” and “Energy - Oil and Gas” in the case of subsystems).

Due to the process of vertical integration, some subsystems have bigger coefficients than their respective coefficient sector, especially “Services” (more than 40 times!), “Manufacturing”, “Energy - Ethanol”, and “Energy - Refining and Coke”, while others subsystems have smaller coefficients than their respective coefficient sector, notably, “Water Supply and Waste”, “Energy - Residential and Commercial Gas”, “Energy - Oil and Gas”, “Forestry”, and “Agriculture”.

7. Conclusions

In this paper the vertically integrated sectors (subsystem) approach is proposed as an alternative to evaluate the emissions of Greenhouse Gases (GHGs) because it shows how much of GHGs are generated to produce commodities. In our application to analyse the impacts of the Brazilian economy on the vectors of GHGs in 2000 and 2009 we discuss the real weight of subsystems of economy and yours relationship with other subsystems.

A significant decline of emissions was observed from 2000 to 2009, especially in the crop/livestock and forestry sectors, which can be attributed to the reduction of the country’s deforestation rate. On the other hand, increased emissions were observed in the majority of other sectors (industry, oil and gas, refining and coke, alcohol, electricity, water supply and waste and transport). Thus, the country’s lower level of pollution consequent upon the decline of deforestation is not due to technological advances or changes in the production process. Therefore, government policies still face a huge challenge in the reduction of GHG emissions.

In this context, notwithstanding the relevance of quantitative gains, qualitative results still cause some concern. The polluting potential of certain specific segments of the Brazilian production matrix is growing, requiring adequate public policies to be curbed. Moreover, since the most carbon emissions were reduced by means of lower deforestation, we cannot conclude that the country’s environmental developments are associated with technological advances or changes in production processes, which would be desirable.

With regard to structural changes and vertically integrated sectors, the analysis focused on services and energy subsystems. The first aspect to be observed is that GHG emissions, measured for sectors and subsystems (vertically integrated sectors), are not equal. This occurs because a subsystem considers all required inputs from all sectors to produce the final product (and the resulting GHG emissions), and disregards what is produced (and generated in GHG emissions) for that particular sector, and all others, to the other economic sectors. It becomes clear that some subsystems generate more greenhouse gas emissions than their respective sectors.

In the final, the sectorial incompatibility in the structure defined by UNFCCC, via IPCC, for the emission inventories (six sectors) with the national accounting structure of the I-O Tables (56 sectors) provoke the challenges for policy makers who need analyse the mitigation and adaptation policies for response the climate change. The procedure to transform a traditional input-output matrix compatible with the structure of inventories of GHG emissions is very hard.

Thereby, the paper emphasizes the need for IPCC to advance the establishment of standards of compatibility and recommendations of best practices for the development of economic models that use I-O matrix data.

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Annex A

Input-Output Matrix of Brazilian Economy in 2000 (R$ billion)

Sectors	Agriculture	Forestry	Manufacturing	Services	Energy - Oil and Gas	Energy - Refining and Coke	Energy - Ethanol	Energy - Electricity	Energy - Residential and Commercial Gas	Water Supply and Waste	Transport	Total Intermediary Consumption	Final Demand	Total Demand
Agriculture	7,389	224	45,250	1,954	6	4	3,384	1	0	0	2	58,214	33,181	91,394
Forestry	224	140	2,162	93	0	0	162	0	0	0	0	2,781	1,585	4,367
Manufacturing	15,423	737	214,590	68,045	2,524	1,083	752	1,949	194	483	5,213	310,995	395,292	706,287
Services	4,700	225	84,218	180,317	3,688	2,334	559	4,859	485	1,205	16,583	299,171	661,843	961,014
Energy - Oil and Gas	5	0	175	56	198	18,849	0	441	44	109	3	19,881	1,077	20,958
Energy - Refining and Coke	1,376	66	11,590	4,267	186	8,445	86	680	68	169	8,074	35,006	16,710	51,716
Energy - Ethanol	54	3	1,499	1,258	0	2,727	33	14	1	3	0	5,593	3,248	8,841
Energy - Electricity	468	22	9,916	9,820	413	281	57	8,344	832	2,069	273	32,495	17,033	49,528
Energy - Residential and Commercial Gas	47	2	989	979	41	28	6	832	83	206	27	3,241	1,699	4,939
Water Supply and Waste	116	6	2,459	2,435	102	70	14	2,069	206	513	68	8,058	4,224	12,282
Transport	1,927	92	21,737	16,579	1,785	793	205	454	45	112	6,294	50,023	42,222	92,245
TOTAL	31,730	1,516	394,583	285,804	8,944	34,613	5,257	19,644	1,959	4,871	36,537	825,458	1,178,113	2,003,571

Source: prepared by authors from Guilhoto and Sesso Filho (2005, 2010)

Input-Output Matrix of Brazilian Economy in 2009 (R$ billion)

Sectors	Agriculture	Forestry	Manufacturing	Services	Energy - Oil and Gas	Energy - Refining and Coke	Energy - Ethanol	Energy - Electricity	Energy - Residential and Commercial Gas	Water Supply and Waste	Transport	Total Intermediary Consumption	Final Demand	Total Product
Agriculture	20,387	711	129,392	4,401	17	12	10,134	4	0	1	4	**165,063**	97,009	**262,072**
Forestry	711	446	7,097	241	1	1	556	0	0	0	0	**9,054**	5,321	**14,375**
Manufacturing	48,411	2,655	548,475	171,597	10,015	3,631	1,484	4,999	499	1,240	15,902	**808,909**	1,046,633	**1,855,542**
Services	14,049	771	241,635	494,437	20,645	5,319	1,113	11,850	1,182	2,938	40,508	**834,447**	1,818,572	**2,653,019**
Energy - Oil and Gas	22	1	143	101	2,612	53,834	0	3,758	375	932	3	**61,781**	19,833	**81,614**
Energy - Refining and Coke	7,293	400	29,474	13,783	662	20,362	236	2,583	258	640	33,000	**108,692**	41,413	**150,105**
Energy - Ethanol	121	7	2,504	3,452	3	4,856	9	60	6	15	350	**11,383**	11,061	**22,444**
Energy - Electricity	888	49	25,308	28,693	1,307	595	162	18,669	1,862	4,630	2,159	**84,320**	42,316	**126,636**
Energy - Residential and Commercial Gas	89	5	2,524	2,862	130	59	16	1,862	186	462	215	**8,409**	4,220	**12,630**
Water Supply and Waste	220	12	6,276	7,115	324	147	40	4,630	462	1,148	535	**20,910**	10,493	**31,403**
Transport	4,936	271	65,403	47,514	8,454	2,285	444	2,537	253	629	23,845	**156,570**	114,331	**270,901**
TOTAL	**97,128**	**5,328**	**1,058,230**	**774,196**	**44,171**	**91,101**	**14,193**	**50,951**	**5,081**	**12,635**	**116,523**	**2,269,538**	**3,211,203**	**5,480,741**

Source: prepared by authors from Guilhoto and Sesso Filho (2005, 2010)

Annex B

Direct and Indirect Requirements by Sectors in Brazilian Economy (2000 e 2009).

Sectors	Direct Requirements (2000)	Indirect Requirements (2000)	Direct Requirements (2009)	Direct Requirements (2009)
	g*	g	g*	g
	(t CO_2eq)	(t CO_2eq)	(t CO_2eq)	(t CO_2eq)
Agriculture	299.5	525.5	220.3	374.8
Forestry	311.6	546.7	62.4	106.1
Manufacturing	81.6	64.2	95.9	74.1
Services	3.0	1.4	2.7	1.2
Energy - Oil and Gas	1.0	18.9	6.5	20.4
Energy - Refining and Coke	3.7	7.8	4.2	11.1
Energy - Ethanol	1.4	2.3	3.1	3.2
Energy - Electricity	9.8	18.8	10.3	20.5
Energy - Residential and Commercial Gas	6.4	12.3	6.1	12.2
Water Supply and Waste	13.3	25.3	15.3	30.4
Transport	55.4	65.7	59.5	81.4
TOTAL	**786,8**	**1,288.8**	**486,2**	**735.5**

Source: prepared by authors from MCTI (2013).