

Ethics and Sustainability: An Alternative Approach to Evaluate the Emissions of Greenhouse Gases in Brazil*

Leopoldo COSTA Junior[†]
Centro Universitário UniEuro
Ministry of Planning
Brasília, DF, Brazil

Fernando A. R. SOARES[‡]
Ministry of Planning
Brasília, DF, Brazil

Alexandre C. G. de SOUZA[§]
Central Bank of Brazil
Curitiba, PR, Brazil

Edson R. TOLEDO Neto^{**}
Ministry of Finance
Brasília, DF, Brazil

Abstract

The recent increase in worldwide concern over global warming has raised questions about the factors responsible for this weather phenomenon. Climate change will affect everyone, but the people who will suffer most are those who have done the least to bring it about. Many people do not see climate change as an urgent moral problem because it is not a matter of a clearly identifiable individual acting intentionally. As the vertically integrated sectors (subsystem) approach shows how much of pollutants are generated to produce a commodity, it is proposed as an alternative to evaluate the emissions of Greenhouse Gases (GHGs). It is applied in this paper to analyse the impacts of the Brazilian economy on the vector of GHGs in 2009.

Key words: Greenhouse Gases (GHGs) - Climate Change - Input-Output Matrix - Vertically Integrated Sectors – Environment and Development

JEL Classification: O13, O44, Q54, Q56

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[†] Corresponding author. E-mail: lcostajr@gmail.com

[‡] E-mail: fernando.a.r.soares@gmail.com

[§] E-mail: alexandre.souza@bcb.gov.br

^{**} E-mail: edson.toledoneto@gmail.com

1. Introduction

In recent years the interest in the weather has intensified. Climates always change over long periods. Today, though, there are fears that the climate may be changing faster than it has done for thousands of years and that the gases released into the air from cars, factories, domestic fires, power stations, farming, and forest clearance may be accelerating that change.

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 principally carbon dioxide from the burning of fossil fuels. Many scientists believe human activities that release GHGs may be increasing the natural greenhouse effect and that the resulting enhanced greenhouse effect contributes significantly to the observed global warming. Depending on the extent of that contribution, the amount of future global warming will be related to the calculated value for the natural greenhouse effect.

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.²

When seen in this way, it seems clear that climate change is a dramatic challenge to the moral consciousness of humankind. It not only challenges people to act in a morally responsible way but it also challenges the very idea of moral responsibility. Many people do not see climate change as an urgent moral problem because it is not a matter of a clearly identifiable individual acting intentionally in a way that inflicts an identifiable harm on another identifiable individual who is closely related in time and space. Otherwise, it is a matter of a diffuse group of people who are setting in motion forces that will harm a diffuse group of future people (Jamieson, 2009). The core challenge of climate change is the structural impact on the fragile and vulnerable sections of the society which have limited or the least capacity at both social and individual levels to cope with climate catastrophes.

Environmental ethics and philosophy are central to understanding the likely cost or gain of modifying the economy to make it ecologically sustainable. Central to this issue is the question of what incremental changes in material consumption contribute to well-being and what elements are important for the good life (Power, 2009).

Value in conventional economics is 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

¹ The principal Greenhouse Gases (GHGs) are water vapour (H₂O), carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), ozone (O₃), CFCs (chloro-fluorocarbons), and hydro-fluorocarbons.

² The primary source of environmental damage is the population's production, use, and disposal of material goods. The only source of the material used in production is the natural environment, which is also the only place where the waste products associated with production and use can be disposed of. Consequently, higher levels of production and use of material goods cause higher levels of environmental stress and degradation.

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 purpose of this paper is to argue in favour of an alternative approach to elaborate a system of indicators that synthesize the GHGs embodied in commodities using the notion of vertically integrated sector, or subsystem, proposed by Pasinetti (1973). After this introduction, the next section presents the environmental issue in Brazil. The third section presents the post-Keynesian ecological approach and section 4 outlines the concept of vertical integration. A methodological discussion and presentation of analytical results and thoughts on sectoral policy is made in the next section. The last section makes some concluding remarks.

2. The environmental issue in Brazil

The Intergovernmental Panel on Climate Change (IPCC)³ - the world's foremost collection of experts on climate change - has shown that knowledge gaps still exist about the Earth's climate. However, after initial uncertainties about which factors were responsible for climate changes, a strong international pressure led to the signing of multilateral agreements for the mitigation of GHGs 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)⁴ 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, 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,⁵ 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

³ 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.

⁴ A United Nations agreement that was reached at the United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil, in June 1992 (and sometimes called the Rio Summit or the Earth Summit). The Framework Convention aims to address the issue of global warming by seeking the agreement of national governments to promote relevant research and to reduce emissions of GHGs.

⁵ 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).

of emissions projected by 2020.⁶ This reduction ensures a comfortable position for Brazil in target negotiations that will replace the Kyoto protocol from 2020 (La Rovere, Dubeux and Pereira Jr., 2013).

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), 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.⁷ 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).⁸

⁶ The National Policy on Climate Change (NPCC) estimated the GHGs emission projections for 2020 at 3,236 million tons of CO₂eq (Mt CO₂eq). Applying the voluntary targets, the reduction in GHG emissions should be between 1,168 and 1,259 million tons of CO₂eq (Mt CO₂eq) (Brasil, 2009, 2010).

⁷ Ecology is that branch of biology dealing with the interrelationships between living organisms and between organisms and their environment. 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 evident in ecological economics, bio-economics and the debate surrounding sustainability and sustainable development (O'Hara, 1999).

⁸ 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. Mainstream economics 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).

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).

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,⁹ 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.¹⁰ 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 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

⁹ 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).

¹⁰ 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).

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.¹¹ 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, analytical results and thoughts on sectoral policy

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).

To assess the effects of the Brazilian economy in 2009 on the GHG emission vector, it was required to reconcile the structure of sectors defined by UNFCCC (2008; MCTI, 2013) for the Emission Inventories (six sectors) with the national accounting structure of the 2009 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 (Annex A).¹² Some basic data of these sectors are shown below:

¹¹ Empirical studies in several areas were conducted using the concept of vertical integration, with applications ranging from international trade (Elmslie, 1988; Milberg, 1987) to labour productivity (Montessor 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; Sánchez-Chóliz and Duarte, 2005, 2003).

¹² It is noteworthy that the sectorial structure of emission sources and sinks of CO₂eq was only possible from rules established in 2006 and still spend several methodological changes not technically completed

The most expressive sectors both in Total Final Demands and Total Industry Outputs are “Services” and “Manufacturing”.

Table 1. Proportion of Sectors and Subsystems in Brazil (2009)

	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).

“Manufacturing” and “Services” sectors 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 2. Total Requirements by Sector, and Requirements by Subsystem in Brazil (2009)

	Total Requirements by Sector	Requirements by Subsystem
	g*	m'
	(t CO₂eq)	(t CO₂eq)
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

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.

	Total Requirements by Sector	Requirements by Subsystem
	g*	m'
	(t CO₂eq)	(t CO₂eq)
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).

The sectors that generate more GHGs emissions are “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 3. Total Requirements Coefficients by Sector, and Requirements Coefficients by Subsystem in Brazil (2009)

	Total Requirements Coefficients by Sector	Requirements Coefficients by Subsystem
	q*	r
	(t CO₂eq)/(R\$ 1,000,000)	(t CO₂eq)/(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
Transport	520.16	291.43

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

These coefficients are measures of efficiency; more efficient sectors/subsystems generate less GHGs emissions. Thus, 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”.

6. Concluding remarks

The recent increase in worldwide concern over global warming has raised questions about the factors responsible for this weather phenomenon. Climate change is affecting everyone, but the people who will suffer most are those who have done the least to bring it about. Many people do not see climate change as an urgent moral problem because it is not a matter of a clearly identifiable individual acting intentionally.

Methodology limits mainstream economics ability to deal with many of the complexities associated with the cost or gain of modifying the economy to make it ecologically sustainable. These restrictions can lead to appalling public policy. Post Keynesian economics - with its focus on the role of institutions, radical uncertainty, historical time and its criticism of gross substitution - seems more appropriate do deal with environmental issues and sustainable development.

In this paper the vertically integrated sectors (subsystems) were proposed as an alternative to reformulate a definition of value since it shows how much of GHGs are generated to produce commodities. This alternative approach was applied to evaluate the impacts of the Brazilian economy on the emissions of GHGs.

The empirical results have shown that service subsystem is much more pollutant than its respective sector. The progressive deindustrialisation of world economy has a small impact on the emissions of GHGs than would be estimated by the traditional approach. Further thoughts and actions are required to design proper public policy to deal with this subject.

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Appendix

A. 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, 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.

B. The CO₂eq 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).¹⁸

From the inventories and GHGs emission estimates (MCTI, 2013) for Brazil are calculated emissions associated sectors treated in the proposed model in 2009. 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 (CO₂eq). Therefore, it is necessary to establish the following simplifying assumptions about the MCTI data (2013):

(i) the emissions of CO₂eq 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 2009 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 2009 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 2009 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 their interest in the production value 2009 I-O Matrix.

¹⁸ 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).

In order to determine the CO₂eq emissions vector, we define a set of the organic products (pollution), that is, the CO₂eq emissions by productive sector. The corresponding vector of pollution output (CO₂eq emissions) flows is $\mathbf{g} \equiv [g_j]$, an element of which specifies the amount of pollution output (CO₂eq emissions) directly associated with the output of sector j .

Defining $\mathbf{q} \equiv [q_j]$, the vector of pollution output (CO₂eq emissions) coefficients, as $\mathbf{q} \equiv \hat{\mathbf{x}}^{-1} \mathbf{g}$, and $\mathbf{A} \equiv [a_{ij}]$, the $n \times n$ matrix of technical coefficients, represented as $\mathbf{A} \equiv \mathbf{Z} \hat{\mathbf{x}}^{-1}$, the pollution output (CO₂eq emissions) coefficients as a function of final demands can be written as $\mathbf{q}^* \equiv [(\mathbf{I} - \mathbf{A})^{-1}]^T \mathbf{q}$, where \mathbf{I} is an identity matrix. The elements in $\mathbf{q}^* \equiv [q_j^*]$ reflect the amount of pollution output (CO₂eq emissions) associated with delivering a monetary unit worth of industry j 's output to final demand directly and indirectly.¹⁹

C. 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 (CO₂eq emissions) flows. The generic element n_{ij} of \mathbf{N} is the amount of CO₂eq emissions required, both directly and indirectly, from sector i in order to satisfy the final demand in sector j .

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 CO₂eq 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 CO₂eq 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 CO₂eq emissions required. Thus, changes in total CO₂eq emissions

¹⁹ The vector \mathbf{q} is a measure of the content of CO₂eq 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).

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} .