

AN INPUT-OUTPUT LINEAR PROGRAMMING MODEL TO ASSESS BRAZILIAN GREENHOUSE GAS EMISSIONS¹

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ABSTRACT

This paper aims to evaluate the Brazilian economic and environmental impacts caused by the Brazilian greenhouse gases (GHG) emissions. The idea is make simulations taking into account emissions targets. In other words, if the government, for instance, decide to adopt a climate policy which impose a reduction of 5% of the whole Brazilian GHG emissions, what would will be the economic impact? In the attempt of answer this question, we used the Brazilian input-output matrix for 2009 and emissions data from the Ministry of Science, Technology and Innovation. The main results indicate that for each 1% of GHG emissions' reduction leads a decrease of at least 0.06% in the total output. Without any restrictions for final demand downsizing, production major decrease (-1.95%) is from the Livestock and fishing production, followed by Other mining and quarrying (-0.13%), Food and beverage, Agrochemicals, Agriculture, forestry, extractive (-0.11%) and Chemicals (-0.10%).

Keywords: GHG emissions; input-output; linear programming.

RESUMO

Este artigo objetiva avaliar os impactos econômicos e ambientais causados pela emissão brasileira de gases de efeito estufa (GEE). A ideia é realizar simulações considerando metas de emissões. Em outras palavras, se o governo, por exemplo, decide adotar uma política de mitigação que impõe uma redução de 5% no total de emissões brasileiras de GEE, qual seria o impacto econômico? Na tentativa de responder esta pergunta, a matriz de insumo-produto brasileira para o ano de 2009 foi usada e utilizou-se dados de emissões do Ministério da Ciência, Tecnologia e Inovação. Os principais resultados indicam que cada 1% de redução na emissão de GEE implica queda de 0,06% na produção total. Na ausência de restrições para a demanda final, as maiores quedas na produção setorial são da Agropecuária e pesca (-1,95%), seguida por Outras atividades extrativas (-0,13%), Alimentos e bebidas, Agroquímicos, Agricultura, sicultura e exploração florestal (-0,11%) e Químicos (-0,10%).

Palavras-chave: Emissões de GEE; insumo-produto; programação linear.

Jel-codes: C61; C67; Q52

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1. Introduction

One of the main environmental issue nowadays is regarding to air pollutants. According to Genty et al. (2012) and Moll et al. (2006), there are three main sets of air pollutants, which are Greenhouse Gases (GHG) contributing to global warming, pollutants contributing to acidification (ACID) and Tropospheric Ozone Forming Potential (TOFP). However, Hristu-Varsakelis et al. (2010) demonstrated that impact caused by the last two is smaller at least in magnitude than the GHG. In this regard, the increase of GHG concentration in the atmosphere is the main cause of climate change.

Several studies in the literature are using different kind of techniques to measure the economic and environmental impacts caused by the increase of GHG emissions. The most used methods are: input-output (IO) analysis (Brizga et al., 2014; Freitas et al., 2014; Carvalho et al., 2013), computable general equilibrium models (Gurgel and Paltsev, 2014; Magalhães and Domingues, 2013; Orlov and Grethe, 2012) and the integration of linear programming (LP) with IO (Hristu-Varsakelis et al., 2010; 2012; Cristóbal, 2010; 2012).

According to Vogstad (2009), IO analysis have influenced LP in the beginning. As a matter of fact, IO model can be thought as a special case of LP problems in which there is no choice to make once the final output vector has been determined (Dorfman et al., 1958; Carter, 1970; Beutel, 1983).

The integration of IO-LP models is a powerful tool to assess the economic impact of a climate policy. Cristóbal (p. 225, 2010) argues that: "A balanced combination of environmental and economic considerations may provide the best basis for identifying the opportunities to reduce pressures on the environment as well as for designing and implementing successful environmental policies".

In this context, the objective of this paper is evaluate the Brazilian economic and environmental impacts caused by the GHG emissions. The idea is make some simulations taking into account emissions targets. In other words, if the government, for instance, decide to adopt a climate policy which impose a reduction of 5% of the whole Brazilian GHG emissions, what would will be the economic impact?

This exercise can provide important insights for the policymakers. It is also relevant to highlight there is no findings of this kind of study applied to the Brazilian case. Besides, as a developing country, if there is no kind of government control it is expected that Brazilian GHG emission increase in the near future.

The next section describes the method and database. The third section presents an exploratory analysis, followed by the main results and discussion. The last section presents the main findings and policy directions.

2. Method and Database

The input-output model represent the whole economy among the relations between industries and the final demand. More specifically, according to Leontief (1941, p.3): "An attempt to

apply the economic theory of general equilibrium - or better, general interdependence - to an empirical study of inter-relations among the different parts of a national economy as revealed through covariations of prices, outputs, investments, and incomes".

In order words, the traditional input-output analysis is evaluated as a system of linear equations, where each sector combines a set of inputs from all over the economy to produce a given amount of output.

$$X = Bf$$

$$A = a_{ij} = \frac{z_{ij}}{x_j}$$

$$B = (I - A)^{-1}$$

X is a vector which indicates the total production for each sector j ;

$A = [a_{ij}]$ is the Technological matrix;

z_{ij} is the intermediate trade between sectors i and j ;

B is the Leontief Inverse matrix;

The methodology applied here was based on three previous papers: Cristóbal (2010), Hristu-Varsakelis *et al.* (2010) and Hristy-Varsakelis (2012). To include the emissions in an input-output framework, the information about sectorial emissions was used as a new coefficient, calculated as:

$$E_{kj} = \frac{e_{kj}}{x_j} \quad \forall k$$

Where, e_{kj} is the emission for gas k in sector j and E_k is the emission coefficient for gas k . In this regard, E_k is the total amount of gas k generated per unit of output in industry k or direct effect, and one can define the total volume of gas k produced by the whole economy as:

$$E_k = \hat{E}_k Bf = \hat{E}_{kj} X$$

Where \hat{E}_{kj} is the diagonalized form of E_{kj} .

Furthermore, we can also calculate the simple output multiplier of sector j (M_j^p). This multiplier can be defined as the total required emissions (total effect) from all sectors, to meet the variation in a monetary unit of the total demand of sector j (Miller and Blair, 2009), and can be expressed by:

$$M_j^p = \sum_{i=1}^n e_{kj}^p \cdot b_{ij}$$

The indirect effect (IE) was calculated as follow:

$$IE = M_j^p - E_k$$

In this regard, for the purpose of this article was chosen the data of 2009, these being the most recent available both for Brazilian IOM and for the GHG emissions. The three main

greenhouse gases are Carbon Dioxide (CO_2), Nitrous Oxide (N_2O), and Methane (CH_4). They can be combined in a measure of Carbon Equivalent Emissions (CEE) as:

$$e_j = CO_2 + 310N_2O + 21CH_4$$

e_j is the the Global Warming Potential (GWP) in terms of Greenhouse Gases (GHG) for sector j

When talking about GHG emissions, from the perspective of a policymaker, there are two conflicting goals to be solved: production maximization and emissions minimization. These problems can be explicit in the following:

Problem 1:

$$\begin{aligned} & \max X \\ \text{s. t. } & (I - A)X \leq f \quad (\text{economic constraint}) \\ & E_k X \leq t \quad \forall k \quad (\text{environmental constraint}) \\ & X \geq 0 \end{aligned}$$

Problem 2:

$$\begin{aligned} & \min eX \\ \text{s. t. } & (I - A)X \geq f \quad (\text{economic constraint}) \\ & E_k X \leq t \quad \forall k \quad (\text{environmental constraint}) \\ & X \geq 0 \end{aligned}$$

t is the target for emissions. This target can be defined differently for each sector k , or it can be set as a reduction goal for Brazilian overall emissions (in the last case, the environmental constraint can be reduced to $\sum_k E_k X \leq t$).

As both problems are complementary (one can reduce emissions only by reducing production, and contrariwise), the solutions are symmetric. Therefore, when solving Problem 1 or Problem 2, the result is absolutely the same, and indicates which sectors are the ones that should reduce their emissions (and consequentially their production) to active a certain emissions reduction goal for the country with the minimal economic cost. The problem is solved by changing final demand production for each sector.

As one can expect, sectors with the highest emissions coefficient, i.e., generating more gas emissions per unit of output, are the ones with the smallest direct economic cost to active the target, if economic cost is measured by lost in total output. Accordingly, the optimization process indicates highly pollutant sectors as the optimal way of activating the target. Furthermore, with the use of an Input-Output framework, those sectors are related to others, and so, if their activity levels are reduced, this triggers the output in other sectors, causing then to reduce emissions as well.

When we first solve those models for Brazil a problem arises: the concentration of GHG emissions in livestock and fisheries leads to results where only this sector basically “pays” for the whole reduction in emissions. One of the options found in literature (Hristu-Varsakelis *et al.*, 2010), suggests to establish a maximal bound for changes in production. Formally, we need to have an additional economic constraint, establishing a percentage change bound b , for final demand variation in each sector:

Problem 1:

$$\begin{aligned}
& \max X \\
s. t. & \quad (I - A)X \leq f \quad (\text{economic constraint 1}) \\
& \quad E_k X \leq t \quad \forall k \quad (\text{environmental constraint}) \\
& \quad \Delta f_i \leq b \quad \forall i \quad (\text{economic constraint 2}) \\
& \quad X \geq 0
\end{aligned}$$

Problem 2:

$$\begin{aligned}
& \min eX \\
s. t. & \quad (I - A)X \geq f \quad (\text{economic constraint 1}) \\
& \quad E_k X \leq t \quad \forall k \quad (\text{environmental constraint}) \\
& \quad \Delta f_i \leq b \quad \forall i \quad (\text{economic constraint 2}) \\
& \quad X \geq 0
\end{aligned}$$

For the simulations presented here, the exercise is to reduce 1% of total emissions, and b is a parameter that ranges between 1.1 and 5.13%. It's worth nothing, that if emissions reduction goal is set as 1% reduction, and we do not allow final demand falls more than exactly 1%, the solution is meaningless, i.e., all sectors needs to be reduce by 1%. By its turn, the upper bound is the percentage change in livestock and fisheries when the second economic restriction is not imposed.

2.1. Database

The input-output matrix was estimated based on the Tables of Resources and Uses of Brazilian Institute of Geography and Statistics (IBGE) for the year 2009, according to the procedures described in Guilhoto and Sesso Filho (2005) and hypothesis of "industry-based" technology (Miller and Blair, 2009). We also use data from the World Input-Output Database (WIOD) to do some exploratory analysis.

To construct the emissions vector, the follow gases were taken into account: carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) measured in carbon equivalents. The data was from *Estimativas anuais de emissões de gases do efeito estufa no Brasil*² (MCTI, 2013). These pollutants together constitute the so-called greenhouse gases or GHG, which contribute directly to global warming.

The next section presents an exploratory analysis of the GHG emission in 2009, at global level, a time-series of Brazilian GHG emissions and the emissions multipliers by sector.

3. Exploratory Analysis of the Emissions

In 2009, according to the WIOD, it was emitted to atmosphere 34,320 millions of GHG (t/CO₂ eq.) The major contribution of this emissions was made by China, which responded for 24.02% of GHG global emissions, followed by the U.S. (14.98%), India (6.75%) and Russia (5.8%). Brazil, at the same year, was responsible for 2.39%. Restricting our analysis to

²Annual estimates of greenhouse gases emissions in Brazil (own translation). The steps to reconcile the surveyed sectors and the sectors in the input-output matrix are described on Annex 1.

Brazil, Figure 11 shows a time series of GHG emissions and economic performance measured in terms of Gross Value of Production (GVP).

It is easy to see an upward trend of Brazilian GHG emissions until 2008, with a slight drop in 2006. The reduction in 2009 may have been caused, among other factors, by the international crisis that consequently slowed the global economic performance, including Brazil as well. It is interesting to note that the GHG emissions growth in almost all the analyzed period (1995-2009) is not necessarily reflection of increased Brazilian production, which only shows an increasing trend from the early 2000s. Thus, Figure 1 only shows a clear correlation between the two curves (GHG emissions and GVP) in 2008 and 2009.

The Brazilian economy has undergone profound structural changes in the 1990s, which explains this production drop in the beginning of the series. Among these changes, we can highlight the trade and financial liberalization in the early 1990s, prices stabilization in 1994, privatization of public companies and the new macroeconomic policy regime adopted at the end of the decade, mainly due to a currency crisis (Moreira and Ribeiro, 2013).

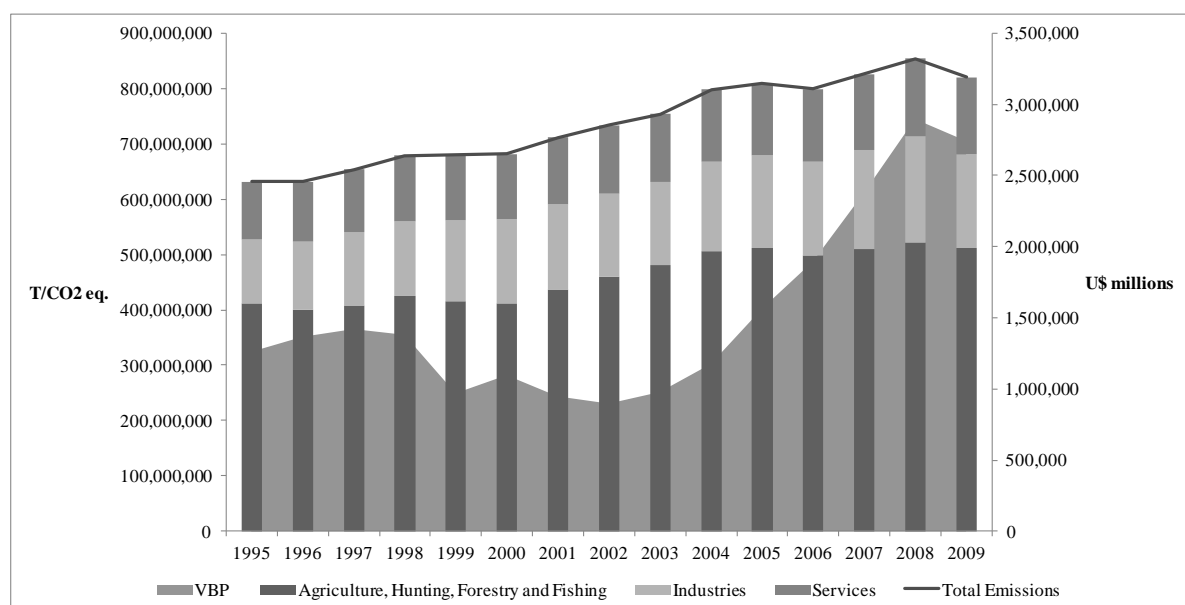


Figure 1: Brazilian greenhouse emissions vs. gross value of production

Source: Own elaboration based on Timmer (2012).

Another relevant information brought by Figure 11 is the contribution of GHG emissions according to the economic sector. We note clearly that Agriculture, Hunting, Forestry and Fishing is the main generator of GHG, with 62.5% average contribution in the period, followed by Industries (20.8%) and Services (16.8%).

If we take in account the IO Brazilian matrix for the 2009 we have different magnitudes of GHG emissions by sector, but the same structure, i.e.: Agriculture (53.5%), Industries (28.7%) and Services (17.8%). It is important to highlight that the Agriculture's production responded per only 5% of the total Brazilian production in the same year. The burnt to create pasture for livestock development, methane gas emitted by the cattle's physiological process and animal waste, are among the factors leading to this industry as the largest source of GHG emissions (Bustamante et al., 2012).

Table 1 shows on a disaggregate form, from the Brazilian economic sectors in 2009, GHG emissions, GVP and the direct, indirect and total multiplier effects of emissions. The sectors

Livestock and fishing, Other mining and quarrying, Food and beverage, Cement, Manufacture of steel and derivatives and Transport, storage and mail, as we can see, are more intensives in GHG emissions.

Table 1: GHG emissions, GVP and emissions coefficient - 2009

Sectors	GHG (t/CO ₂ eq.)	GVP (R\$ 1.00)	Production Multiplier		
			GHG/GVP (direct effect)	Indirect effect	Total effect
Agriculture, forestry, extractive	26,082,858	176,093,000	0.15	0.13	0.28
Livestock and fishing	413,971,696	100,354,000	4.13	0.48	4.61
Oil and natural gas	19,362,452	81,614,000	0.24	0.15	0.38
Iron ore	3,530,316	29,516,000	0.12	0.14	0.26
Other mining and quarrying	21,581,181	19,494,000	1.11	0.21	1.32
Food and beverage	5,404,611	358,919,000	0.02	1.01	1.02
Smoking products	10,909	11,408,000	0.00	0.19	0.19
Textiles	1,311,124	40,363,000	0.03	0.14	0.17
Vestment goods and accessories	45,742	41,550,000	0.00	0.08	0.08
Leather goods and footwear	38,422	24,239,000	0.00	0.17	0.17
Wood products - excluding furniture	166,161	19,285,000	0.01	0.12	0.13
Pulp and paper products	4,488,480	45,049,000	0.10	0.17	0.27
Newspapers, magazines, discs	27,108	38,675,000	0.00	0.08	0.08
Oil refining and coke	32,650,376	150,105,000	0.22	0.23	0.45
Alcohol	2,918,339	22,444,000	0.13	0.23	0.36
Chemicals	12,671,257	64,447,000	0.20	0.24	0.44
Manufacture of resin and elastomers	1,006,111	21,566,000	0.05	0.19	0.24
Pharmaceutical products	700,775	39,496,000	0.02	0.10	0.12
Agrochemicals	277,844	16,735,000	0.02	0.15	0.17
Perfumes, hygiene and cleaning	21,390	26,960,000	0.00	0.19	0.19
Paints, varnishes, enamels and lacquers	1,859,994	12,358,000	0.15	0.17	0.32
Diverse chemical products and mixtures	129,116	14,787,000	0.01	0.14	0.15
Rubber and plastic goods	569,606	60,196,000	0.01	0.13	0.14
Cement	28,402,670	11,889,000	2.39	0.27	2.66
Other products of non-metallic minerals	12,084,047	40,368,000	0.30	0.32	0.62
Manufacture of steel and derivatives	58,654,911	70,506,000	0.83	0.24	1.08
Metallurgy of non-ferrous metals	6,281,449	32,401,000	0.19	0.31	0.50
Metal products - excluding machinery and equipment	122,035	66,683,000	0.00	0.25	0.25
Machinery and equipment, including maintenance and repairs	397,770	84,648,000	0.00	0.24	0.24
Electrical appliances	88,770	14,845,000	0.01	0.25	0.26
Machinery for office and computer equipment	108,056	20,756,000	0.01	0.08	0.08
Electrical machinery, equipment and materials	672,814	44,653,000	0.02	0.19	0.21
Electronic material and communication equipment	132,521	28,788,000	0.00	0.12	0.12
Medical and hospital equipment/instruments, measurement and	3,044	15,268,000	0.00	0.09	0.09
Automobiles, station wagons and pick-ups	121,448	88,419,000	0.00	0.19	0.19
Trucks and buses	28,088	22,163,000	0.00	0.18	0.18
Parts and accessories for automotive vehicles	603,566	65,741,000	0.01	0.22	0.23
Other transport equipment	331,448	33,685,000	0.01	0.16	0.17
Furniture and products from diverse industries	131,138	44,393,000	0.00	0.14	0.14
Electricity and gas, water, sewage and urban cleaning	17,120,645	170,669,000	0.10	0.09	0.19
Construction	1,533,022	285,293,000	0.01	0.22	0.23
Trade	2,100,347	493,217,000	0.00	0.06	0.06
Transport, storage and postal mail	140,911,195	270,901,000	0.52	0.13	0.65
Information service	109,408	206,566,000	0.00	0.04	0.04
Financial intermediation and warranties	113,535	310,934,000	0.00	0.02	0.02
Real estate services and rent	59,663	253,718,000	0.00	0.01	0.01
Maintenance and repair services	32,527	39,237,000	0.00	0.04	0.04
Lodging and food services	374,390	121,514,000	0.00	0.32	0.32
Service provided to companies	418,223	231,604,000	0.00	0.03	0.03
Mercantile education	148,235	49,985,000	0.00	0.04	0.05
Mercantile health	200,053	99,267,000	0.00	0.07	0.07
Service provided to families	233,000	123,466,000	0.00	0.12	0.12
Domestic service	0	37,701,000	0.00	0.00	0.00
Public education	83,517	147,125,000	0.00	0.05	0.05
Health education	154,687	97,398,000	0.00	0.05	0.05
Public administration and social security	1,586,841	441,287,000	0.00	0.04	0.04

Source: Own elaboration based on IO Brazilian matrix - 2009.

Livestock and fishing, for instance, for each US\$ 1,000 variation of their demand, the whole economy needs to produce 4.61 tons/CO₂ eq. for meet this demand, which 4.13 is created directly and 0.48 indirectly. The largest indirect effect, 1.01, is from the Food and beverage industry, justified because this industry is a major demanders of agricultural and livestock commodities.

The emissions are very concentrated in Brazil, once eight (in a total of 56) sectors together accounted for 90.2% of total GHG emissions in 2009. These sectors are: Livestock and fishing (50.4%), Transport, storage and mail (17.1%), Manufacture of steel and derivatives (7.1%), Oil refining and coke (4%), Cement (3.5%), Agriculture, forestry, extractive (3.2%), Other mining and quarrying (2.6%) and Oil and natural gas (2.4%).

4. Results and Discussion

The first simulation held here is the simplest one. The main idea is answer the following question: Which is the necessary reduction on the total Brazilian output to achieve an emission target? In this regard, the problem is to maximize the Brazilian production subject to an environmental constraint and an economic constraint.

According to the solution of the model, in a general perspective, for each 1% of GHG emissions' reduction leads a decrease of 0.06% in the total output. A reduction of 5% in the Brazilian GHG emissions means a drop of 0.31% on total output and so on.

This proportional behavior between production and emissions can be explained because of the linearity hypothesis of the IO model. Without any restrictions for final demand, production major decrease (-1.95%) is from the Livestock and fishing production, followed by Other mining and quarrying (-0.13%), Food and beverage, Agrochemicals and Agriculture, forestry, extractive (-0.11%) and Chemicals (-0.10%). Most of the sectors, which had a small reduction, are related to the service segment, which are low emission intensive (see Table 1).

On the other hand, the sectors, which presented the highest output reduction, are the same sectors that most produce GHG emission (see Table 1). Livestock and fishing, for instance, was responsible for 50.4% of the total Brazilian GHG emission in 2009, as we could see in the exploratory analysis.

The result of this first maximization problem shows that only a reduction on the Livestock and fishing's final demand is enough to achieve the emission target of 1% emissions reduction. This is an expected result because the linear programming model will constraint first the sector which most emitted.

In our first linear programming problem, if the final demand of the Livestock and fishing decrease 5.14% means achieve the established target. Nonetheless, from a policy perspective, this is not a feasible result for several reasons. First, this production is very concentrated in poor households, who relies on Livestock and fishing as main source of income³. Second, a policy that acts over one sector does not create incentives for other activities to invest in environmentally cleaner ways of production.

³ The sector accounts for around 12% of total income for households in the first decile of income per capita according to Brazilian National Household Survey for 2009 data, provided by IBGE.

In this sense, the second exercise explores the possibility of additional constraints, restricting not only emissions, but also the maximum allowed variation on sectorial final demand. The main results are summarized in Figure 3 which shows on the horizontal axis the structure of simulation, i.e., the maximum percentage reduction allowed in final demand and on vertical axis we have the impact/reaction, that is the percentage change in final demand and in production. We first observe that the impact/reaction upon final demand is consistently above the impact/reaction of production. As far as we create degrees of freedom, that is increase the maximum amount of the reduction in final demand, we observe a continuous increase in the impact and a convergence to the same degree of impact. It is interesting to note that the impact in the economy as a whole decreases, even if in all simulations emissions target reduction is reached at 1% reduction.

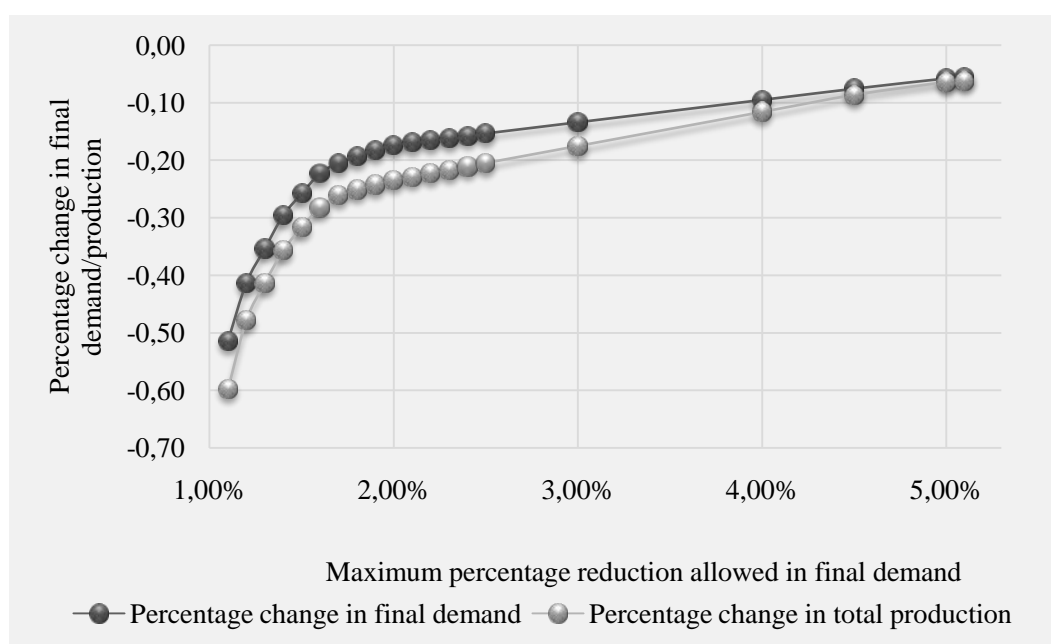


Figure 1: Percentage change in final demand and production

Source: Own elaboration

It is worth noticing when we allow each sector to reduce no more than 1.1% the economic impact activates the maximum of -0.60%. This value can be interpreted as an elasticity between emissions and production reduction when reaches the maximum in terms of economic losses, and several sectors share the responsibility for emissions reduction. Turns out, when we allow final demand to vary no more than 1.80% marginal economic losses grow smaller, reaching -0.25%.

Figures 4 present the sectorial results for final demand. We observe that there is a high degree of concentration in terms of the reduction and it is highly sensitive to the amount of reduction allowed in the final demand. The darker colors means a high impact. At Figure 4, we observe that the black color occurred only in two sectors: a) Livestock and fishing and b) Cement. One important feature is that this high impact occurred when the maximum variation of final demand is around 5%. We observe that there is impact upon the majority of the sector, but the two sectors mentioned earlier captures the majority of the impact. For all the others simulations, we show how the shared responsibility for greenhouse gases reduction understate the impact for each sector individually.

The picture presented on Figure 5 shows the impact upon emissions. We observe that there is a heterogeneous structure of emissions. For small variations on final demand (between 1% and 1.5%) we observe that there is a great number of sectors that emits less. On the other hand, there are sectors that are not affected by this kind of restriction. This occurs mainly on service sectors, which is expected. If we are thinking about a mitigation policy and we look for the results the message is that, the policy can be focused in a small number of sectors and the costs in terms of decrease in final demand is not huge.



Figure 2: Percentage reduction in final demand by sector

Source: Own elaboration

Note: darkest colors implies greater percentage reductions in sectorial final demand



Figure 3: Percentage change in emissions by sector

Source: Own elaboration

Note: darkest colors implies greater percentage reductions in sectorial final demand

5. Final Remarks

This article seeks to analyze the economic and environmental impacts of the Brazilian GHG emissions. It was considered 55 sectors in Brazil in an input-output linear programming model for 2009. The model framework follows similar approaches in the literature. To achieve the goals of the study, we define an optimization problem with economic and environmental constraints.

This paper finds that 1% of GHG emissions reduction implies a decrease of at least 0.06% in the Brazilian total output. Livestock and fishing are the major source of GHG emissions in Brazil. This sector alone was responsible for 50.4% of the total GHG emission in 2009. Therefore, if the final demand of Livestock and fishing decrease by 5.14% the established target is achieved.

However, we could see that, in terms of a policy perspective this is not a feasible solution, mainly because it would not create incentives for other industries to reduce emissions. Moreover, to explore more possibilities we simulate other scenarios where other sectors share responsibilities in emissions reduction. Through these scenarios, it is possible to see the trade-off between emissions and production, where 1% reduction in emissions could cause a drop on total Brazilian production from 0.06% to 0.60%, depending on how much we penalize each sector individually.

There is no consensus about the best mechanism to reduce emissions as part of a climate policy. Among others mechanisms, we can highlight government regulations, taxes, carbon trade, market mechanisms, subsidies, cap and trade and carbon tax.

For Brazil, Ribeiro *et al.* (2015) have shown that a taxation policy would be efficient once it would reduce 9% of total GHG emissions. However, these authors show a regressive impact of this policy, which means that the poorest households would suffer the highest impacts. Magalhães and Domingues (2013) have shown that if the government create a subsidy returning to the households 5% of the total collected from the carbon tax, the drop in GDP would be reduced from -0.91% to -0.82%.

An interesting aspect to taking into account is a policy based on structural changes. For instance, as we could see that Livestock and fishing are the major source of emissions in Brazil. In this case, the cattle production could be made in large facilities where the methane released by the animals could be converted into energy.

Structural changes are extremely necessary in the Brazilian context. This country is an important global supplier of meat, for which the trend is an increase of the international demand in the next years. If Brazil does not change the way of production, this means a huge increase in the emissions.

Nonetheless, one important point that has to be balanced here is the feasibility of the implementation of these structural changes in the Brazilian agriculture sector in the short run. Public policies in this direction can be implemented but it will take time. In this regard, in order to mitigate emissions, it is necessary to have a combination of incentives directly through research support, but also indirectly by means of raising emissions cost using regulations and taxes.

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