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Reducing Brazilian greenhouse gas emissions: scenario simulations of targets and policies

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ABSTRACT

This paper aims to evaluate the economic impacts of greenhouse gas emission reduction on the Brazilian economy. To this end, we developed an integrated input–output linear programming model for 2009 using the Supply and Use Tables and emissions data of the Brazilian Ministry of Science and Technology and Innovation. We simulated emissions targets for various potential scenarios in which the adopted policy design took account of sectoral composition in terms of emissions and available production technology. The results were directly affected by the high level of livestock emissions, counterbalancing this sector's economic importance for Brazil. In the short term, sectoral emissions targets associated with taxation policy or emission permits could be developed in order to create private incentives to mitigate emissions. In this sense, the results also show that different sectoral targets may be able to balance environmental benefits with the possible economic losses incurred by such policies.

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1. Introduction

In the late 1980s, debates about economic growth and its impact on the environment intensified, and the Brundtland Report was produced. In general terms, this report addressed incompatibility between the production and consumption patterns of the time and sustainable development. Concerns about the environment thus began to gain ground, and global warming arising from greenhouse gas (GHG) emissions is now one of the most important environmental issues of our time.

Developing countries are responsible for more GHG emissions than developed countries. Specifically, deforestation in Brazil has been an important source of GHG emissions. Timber exploitation and the conversion of forests into pasture and farmland in the Amazon are the main causes of Brazilian deforestation (Fearnside, 2005; Nepstad et al., 2001; Rivero et al., 2009). For this reason, the agriculture and livestock sectors are the biggest polluters in Brazil. However, it is important to note that, over the last decade, the federal government has adopted a deforestation control policy. The result of this policy has been a

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significant decrease in Brazilian deforestation (Ribeiro et al., 2015) and these authors assert that between 2005 and 2010 emissions fell by half.

Several studies have used varied techniques to measure the economic impact of GHG emission mitigation at regional and sectoral level. The methods most frequently used are input–output (I–O) analysis (Brizga et al., 2014; Carvalho et al., 2013; Freitas et al., 2016; Liu and Wang, 2015; Su et al., 2013), computable general equilibrium (CGE) models (Allan et al., 2014; Chen et al., 2013; Gurgel and Paltsev, 2014; Magalhães and Domingues, 2013; Orlov and Grethe, 2012) and integrating linear programming (LP) with I–O (Cristóbal, 2010; 2012; Hristu-Varsakelis et al., 2009; 2010; 2012).

According to Vogstad (2009), I–O analysis initially influenced LP. As a matter of fact, the I–O model could be considered a special example of an LP formulation, in which there is no other choice to make once the final output vector has been determined (Beutel, 1983; Carter, 1970; Dorfman et al., 1958).

The integration of I–O-LP models is a powerful tool for assessing the economic impact of climate policy. Cristóbal (2010, p. 225) 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 general, I–O models are simpler versions of CGE models, which assume constant returns to scale, implicitly assume perfectly elastic supply and admit fixed coefficients. This means that the effects of price changes or technological advances are not taken into account, while projected changes are derived from exogenous changes in demand (Miller and Blair, 2009). CGE models, for their part, use flexible prices, allowing, for example, alternative specifications between production factors and regional markets. Such flexibility enables the incorporation of agent behavior in the face of changes imposed exogenously. On the other hand, I–O models do not assume behavioral responses, rather technological relations are held constant, which, given the difficulty of predicting agent behavior, may be considered an advantage.

Another common argument in favor of CGE modeling is ease in imposing capacity constraints, particularly in the short-term. According to Harrigan et al. (1991), in cases such as those presented earlier, it is possible to attain different results from the I–O and CGE models. Here we are able to validate one advantage of our approach. When we use an integrated model (LP + I–O), we are explicitly incorporating the constraint side (e.g. economic constraint and environment constraint) into the model and, clearly, we are eliminating some of the weakness of the pure I–O approach. This characteristic, together with the simplicity of the model in terms of data requirement (Rose and Casler, 1995), assumptions and operation resources, may be considered advantages of our approach.

Furthermore, the transparent nature of the I–O model associated with relatively modest data needs facilitates an understanding of how the results are produced. Moreover, in certain situations, more complex models may generate similar results (Cooper et al, 2007; Pleeter, 1980). As an example to verify this statement, Freitas et al. (2016), using an I–O model, and Magalhães and Domingues (2013), using a CGE model, found similar results in relation to climate policy in Brazil. Both studies pointed out the regressive effect of an emission taxation policy.

Following West (1995), different model structures and assumptions, and different applications produce different sets of results. Thus, we do not expect, and it is not our aim, to make a comparison between models. As indicated by Rose and Casler (1995), different approaches such as I–O, Integrated models (I–O plus Econometric; I–O plus LP), Static CGE and Dynamic CGE – are not competitive, but in several cases they are complementary. All approaches have different degrees of restriction, which has to be recognized. Based on the hypothesis that all methods have restrictions and on the idea of the complementarity of the models, the approach adopted in this paper presents certain strengths, which can be summarized as follows: (a) the general interdependence approach is applied to an empirical study of the relationships between different parts of the economy, focusing on aspects related to output and income; (b) it is flexible in terms of the construction of scenarios and policy design; (c) the design of the maximization problems is based on economic theory; (d) the simplicity and transparency of the I–O method and data are strengths rather than weaknesses.

In terms of adherence to the problem discussed, there are two reasons why our approach is defined by the aim of this paper. First, the type of problem under consideration is fundamental to the choice of model Perese (2010) and Labandeira and Labeaga (2002) provide examples of this approach; they deal with similar issues and also use models based on the I–O approach. Second, since each model contains particular characteristics, making it more suitable for a given application than for any other, we may assert that the models must be tailor-made for the problem under analysis. In this case, our approach is in line with the characteristics and availability of data for the Brazilian economy, allowing us to give concrete answers to an issue that is fundamental to the Brazilian economy.

In this context, the aim of this paper is to evaluate the economic and environmental impacts of Brazilian GHG emissions. In other words, reductions in production and emission are measured given a set of constraints. The idea is to make certain simulations, taking emissions targets into account. In other words, what would the economic impact be of the government deciding to adopt a climate policy that imposed a 5% reduction on all Brazilian GHG emissions? Should the government intervene in all economic activities, imposing the same target? Alternatively, is it possible to reduce the adverse effects by selecting specific sectors?

By answering these questions, the exercise can provide important insights for policymakers. It is worth noting that we found no studies of this kind applied to Brazil. Furthermore, given that this is a developing country, should the government not impose controls, it is expected that Brazilian GHG emissions will increase in the near future.

The remainder of this paper is organized into five sections. The next section describes the method and database. The third section presents an exploratory analysis, which is followed by a section containing the main results and discussion. The last section contains the principal findings and policy directions.

2. Method and database

The I-O model represents the entire economy in terms of relationships between industries and final demand. More specifically, according to Leontief (1941, p. 3), it is: “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”.

Mathematically, a traditional I-O analysis is evaluated as a system of linear equations, where each sector $i = (1, \ldots, n)$ combines a set of inputs from the entire economy to produce a given amount of output.

$$\mathbf{x} = \mathbf{Bf} = \mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1},$$

where $\mathbf{x}$ is a $n \times 1$ vector that indicates total production for each sector $j = (1, \ldots n)$; $\mathbf{A}$ is the Technological Matrix with dimension $n \times n$; $\mathbf{f}$ is a $n \times 1$ vector that indicates final demand; and $\mathbf{B}$ is the Leontief Inverse matrix with dimension $n \times n$.

We used 2009 data for the purposes of this paper, since these are the most recent data available for Brazilian IO matrix and GHG emissions. The three main GHGs are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). These can be combined into a measure of CO2-equivalents.

The methodology applied here is an extension of the traditional I–O model, and is based on four previous papers: Cristóbal (2010), Hristu-Varsakelis et al. (2009; 2010) and Hristu-Varsakelis et al. (2012). Formally, in order to include emissions in an I–O framework, information regarding sectoral emissions was used as an emissions coefficient. In this sense, we can define c_j as the total amount of carbon equivalent emissions generated per unit of output in industry j or the direct effect, and the total volume of gas k produced by the entire economy as

$$\mathbf{c} = \mathbf{c}\hat{\mathbf{B}}\mathbf{f} = \hat{\mathbf{c}}\mathbf{x},$$

where $\mathbf{c}$ is a $n \times 1$ vector of emissions coefficients and $\hat{\mathbf{c}}$ is the diagonalized form of $\mathbf{c}$.

For policy-makers, discussions regarding GHG emissions are centered on two conflicting goals: production maximization and emission reduction. These problems can be made explicit as follows:

$$\begin{aligned} \max \quad & \sum_j \mathbf{x}_j \\ s.t. \quad & (\mathbf{I} - \mathbf{A})\mathbf{x} \leq \mathbf{f} \quad \text{(economic constraint)}, \\ & \hat{\mathbf{c}}\mathbf{x} \leq \mathbf{t} \quad \text{(environmental constraint)}, \\ & \mathbf{x} \geq 0, \end{aligned}$$

where $\mathbf{t}$ is a $n \times 1$ vector of sectorial targets for emissions. This target can be defined variously for each sector j, or can be set as a reduction goal for overall Brazilian emissions (in the latter case, the environmental constraint can be reduced to $\sum_j \hat{c}_j x_j \leq t_j \, \forall j$).

The result indicates which sectors need to reduce their emissions (and consequentially their production) to achieve a given emission reduction goal for the country with minimal economic cost. The problem is solved by changing the final demand production for each sector.[1]

As expected, sectors with the highest emission coefficient, i.e. which generate more gas emissions per output unit, require the smallest direct economic cost in order to achieve their target, when economic cost is measured by loss in total output. Accordingly, the optimization process suggests that highly polluting sectors provide the optimal means of

[1] The problem was solved using LP Simplex.

achieving this target. Furthermore, by using an I–O framework, these sectors are linked to others. If their activity levels are reduced, output is triggered in other sectors, also causing them to reduce emissions.

However, when we estimate these models for Brazil, a problem occurs: the concentration of GHG emissions in livestock and fisheries[2] means that this sector alone essentially 'pays' for the entire reduction in emissions. Thus, Hristu-Varsakelis et al. (2010) suggest establishing a maximal bound for changes in production. Formally, we need an additional economic constraint, establishing percentage bound change b for final demand variation in each sector:

$$\begin{aligned} \max \quad & \sum_j \mathbf{x}_j \\ s.t. \quad & (\mathbf{I} - \mathbf{A})\mathbf{x} \leq \mathbf{f} \quad \text{(economic constraint)}, \\ & \hat{\mathbf{c}}\mathbf{x} \leq \mathbf{t} \quad \text{(environmental constraint)}, \\ & \Delta f_j \leq b \, \forall j \quad \text{(economic constraint 2)}, \\ & \mathbf{x} \geq 0. \end{aligned}$$

The intention in the simulations presented here is to reduce total emissions by 1%, with b as a parameter ranging between 1.1% and 5.13%. It is worth mentioning that if the emission reduction goal is set at 1%, and we do not allow final demand to fall below 1% precisely, the solution is meaningless, i.e. all sectors need to reduce by 1%. Here, the upper bound is the percentage change in livestock when the second economic restriction is not imposed.

2.1. Database

The I–O matrix estimate was based on the Supply and Use Tables of the Brazilian Institute of Geography and Statistics (IBGE) for 2009, according to the procedures described in Guilhoto and Sesso Filho (2005) and the hypothesis of 'industry-based' technology (Miller and Blair, 2009). We also used data from the World Input–Output Database (WIOD) to conduct certain exploratory analyses.

To construct the emissions vector, we took the following gases into consideration: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) measured in carbon equivalents. These data comes from annual estimates of GHG emissions in Brazil (MCTI, 2014). Together, these pollutants constitute the so-called GHGs, which directly contribute to global warming.

The next section initially presents an exploratory analysis of GHG emissions in 2009 at global level, a time series of Brazilian GHG emissions and the emission multipliers by sector. The results and discussion are then presented.

[2] It is important to note that the fisheries sector, per se, is not emissions-intensive. However, this activity is commonly classified alongside livestock, and sometimes agricultural, activities. This occurs in both the WIOD and Brazilian data. Even if we were able to breakdown livestock and fisheries into two sectors, we would still encounter a lack of data availability for fisheries emissions. Therefore, we are dealing with an aggregation error. To avoid misinterpretations, from this point, the sector will be mentioned as 'livestock'.

3. Results and discussion

According to the WIOD, in 2009, 34,320 million (t/CO_2 eq.) GHGs were emitted into the atmosphere. China emitted the most gases, accounting for 24.02% of global GHG emissions, followed by USA (14.98%), India (6.75%) and Russia (5.8%). In the same year, Brazil was responsible for 2.39% of emissions. Restricting our analysis to Brazil, Figure 1 shows a time series of GHG emissions and economic performance measured in terms of Gross Value of Production (GVP).

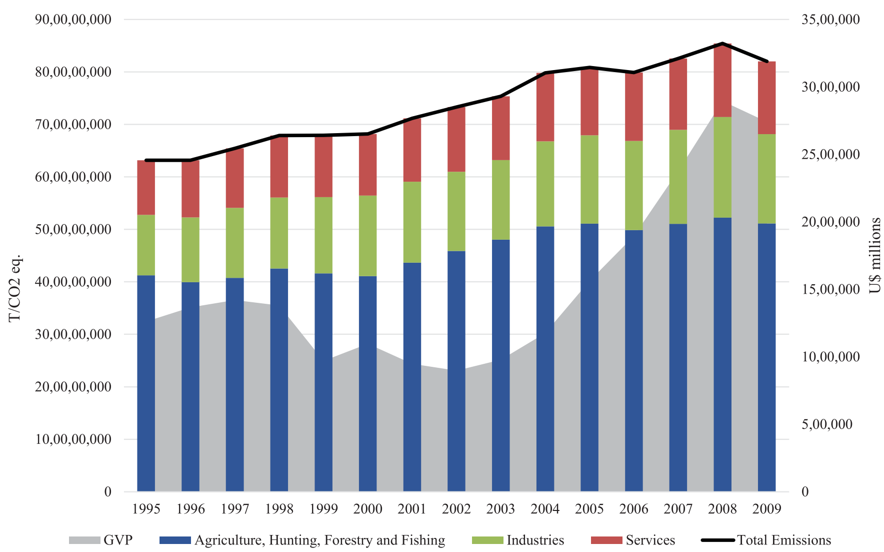
We observe an upward trend in Brazilian GHG emissions until 2008, with a slight drop in 2006. Among other factors, the 2009 reduction may have been caused by the international crisis, which consequently slowed global economic performance, including in Brazil. It is interesting to note that the growth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

The Brazilian economy underwent profound structural changes in the 1990s, which explains the fall in production at the beginning of the series. Among these changes, we note the trade and financial liberalization of the early 1990s, price stabilization in 1994, the privatization of public companies and the new macroeconomic policy regime adopted at the end of the decade, principally due to a currency crisis (Moreira and Ribeiro, 2013).

Other relevant information seen in Figure 1 is the contribution of GHG emissions by economic sector. The agriculture, hunting, forestry and fishing sector is clearly the main generator of GHGs, with a 62.5% average contribution over the period, followed by industries (20.8%) and services (16.8%).

If we take the I–O Brazilian matrix for 2009 into account, we can see varying magnitudes of GHG emissions by sector, although in the same order, i.e. agriculture (53.5%), industries

Figure 1. Brazilian GHG emissions vs. GVP.



Source: Compiled by the author, based on Timmer (2012).

(28.7%) and services (17.8%). We should note that agricultural production accounted for only 5% of total Brazilian production in the same year. Some of the factors that make this industry the largest source of GHG emissions are: burning to create pasture for livestock development, methane gas emitted by cattle and animal waste (Bustamante et al., 2012).

Table 1 provides the 2009 figures for the Brazilian economic sectors, according to GHG emissions, GVP and the direct, indirect and total multiplier effects of emissions in disaggregate form. As we can see, livestock, other mining and quarrying, food and

Table 1. GHG emissions, GVP and emission coefficient – 2009.

			Production multiplier		
Sectors	GHG (t/CO_2 eq.)	GVP (R$ 1.00)	GHG/GVP (direct effect)	Indirect effect	Total effect
Agriculture, forestry and extractive industries	26,082,858	176,093,000	0.15	0.13	0.28
Livestock and fisheries	**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**
Tobacco 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
Clothing – 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, recording materials	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, personal hygiene and cleaning materials	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
Plastic and rubber products	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 non-metallic mineral products	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 – 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
Office and computer machines and equipment	108,056	20,756,000	0.01	0.08	0.08

(*continued*).

Table 1. Continued.

			Production multiplier		
Sectors	GHG (t/CO_2 eq.)	GVP (R$ 1.00)	GHG/GVP (direct effect)	Indirect effect	Total effect
Electrical machinery, equipment and materials	672,814	44,653,000	0.02	0.19	0.21
Electronic materials and communication equipment	132,521	28,788,000	0.00	0.12	0.12
Medical and hospital measurement and optical equipment/instruments	3044	15,268,000	0.00	0.09	0.09
Automobiles, trailers and tow trucks	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
Car parts and accessories	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 waste management	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 – general	2,100,347	493,217,000	0.00	0.06	0.06
Transport, postal and warehousing	**140,911,195**	**270,901,000**	**0.52**	**0.13**	**0.65**
IT services	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
Accommodation and food services	374,390	121,514,000	0.00	0.32	0.32
Services for companies	418,223	231,604,000	0.00	0.03	0.03
Commercial education services	148,235	49,985,000	0.00	0.04	0.05
Commercial health services	200,053	99,267,000	0.00	0.07	0.07
Services provided to families	233,000	123,466,000	0.00	0.12	0.12
Domestic services	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
Average	14,681,588	97,870,375	0.20	0.17	0.37

Source: Compiled by the author, based on the I–O Brazilian matrix – 2009.

beverage, cement, manufacture of steel and derivatives, and transport, postal and warehousing are more intensive in terms of GHG emissions.

Taking livestock as an example, we can see that for each R$ 1000 variation in demand, the entire economy needs to produce 4.61 t/CO_2 eq. in order to meet this demand, of which 4.13 is created directly and 0.48 indirectly. The largest indirect effect, 1.01, comes from the food and beverage industry, since this industry is a major demander of agricultural and livestock commodities.

As we can see, emissions in Brazil are highly concentrated – in 2009 eight (out of a total 56) sectors jointly accounted for 90.2% of total GHG emissions. These sectors are: livestock (50.4%), transport, postal and warehousing (17.1%), manufacture of steel and derivatives (7.1%), oil refining and coke (4%), cement (3.5%), agriculture, forestry and extractive industries (3.2%), other mining and quarrying (2.6%) and oil and natural gas (2.4%).

The first simulation we conducted is the simplest. Our intention was to answer the following question: How much reduction in total Brazilian output is required to achieve an emission target? The problem is therefore to maximize Brazilian production, subject to both an environmental and an economic constraint.

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

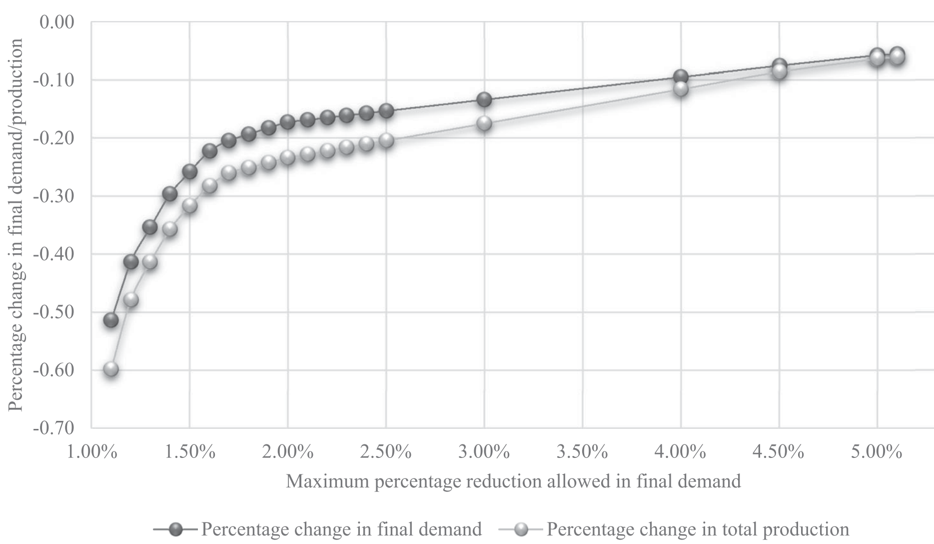
This proportional behavior between production and emissions can be explained by the linearity hypothesis of the I–O model. Without any restrictions to final demand, the largest drop in production (−1.95%) is from livestock, followed by other mining and quarrying (−0.13%), food and beverage, agrochemicals and agriculture, forestry and extractive industries (−0.11%) and chemicals (−0.10%). Most of the sectors that presented a small reduction are related to the service sectors, which have lower emission intensity (see Table 1).

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

The result of this first maximization problem demonstrates that only a reduction in the final demand of livestock is sufficient in order to achieve an emission target of 1% emission reduction. This result was expected because the LP model will first constrain the sector that emitted the most.

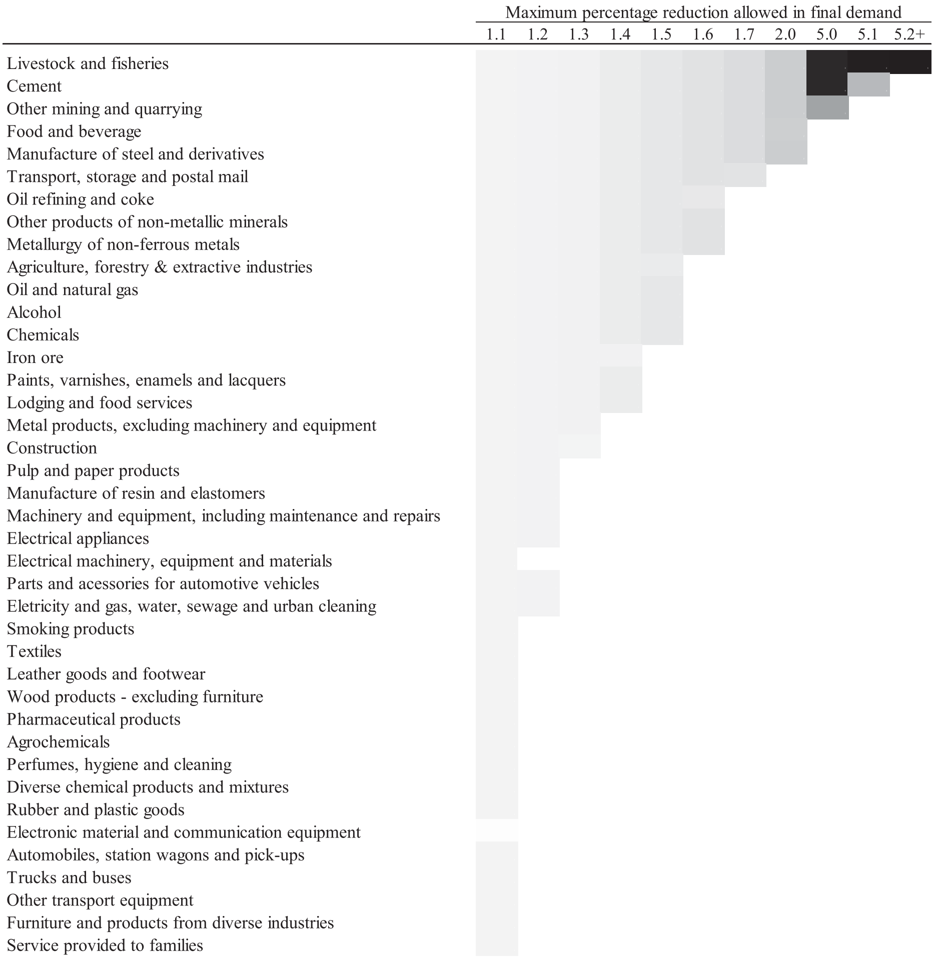
In our first LP problem, a decrease of 5.14% in the livestock final demand achieves the established target. Nonetheless, for several reasons, from a policy perspective this is not a

Figure 2. Percentage change in final demand and production.



Source: Compiled by the author.

Figure 3. Percentage reduction in final demand by sector.



Source: Compiled by the author. Note: darker colors represent greater percentage reductions in sectoral final demand.

feasible result. First, this production is highly concentrated in poor households, who rely on livestock as their main source of income.[3] Second, a policy that controls one sector does not create incentives for others to invest in environmentally cleaner forms of production.

Thus, the second exercise explores the possibility of additional constraints, restricting not only emissions, but also the maximum allowed variation in sectoral final demand. Figure 2 presents the main results. The horizontal axis shows the simulation structure, i.e. the maximum percentage reduction allowed in the final demand. Along the vertical axis, we can see the impact/reaction, that is, the percentage change in final demand and production. We first observe that final demand impact/reaction is consistently higher than production impact/reaction. As we create more degrees of freedom, that is, as we increase the maximum amount of reduction in the final demand, we observe a continuous increase

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

in impact followed by convergence to the same degree of impact. It is interesting to note that the impact on the economy as a whole decreases, even when the emissions target reduction is 1% in all simulations.

It is worth noting that when we allow each sector to reduce no more than 1.1%, the economic impact achieves a maximum of −0.60%. This can be interpreted as representing elasticity between emissions and production reduction when reaching the maximum in terms of economic losses. Several sectors therefore share responsibility for emission

Figure 4. Percentage change in emissions by sector.

Source: Compiled by the author. Note: darker colors represent greater percentage reductions in sectoral final demand.

reduction. It seems that when we allow final demand to vary no more than 1.80%, marginal economic losses decrease, falling to −0.25%.

Figure 3 presents the sectoral results for final demand. There is a high degree of concentration in terms of reduction, which is highly sensitive to the amount of reduction allowed in the final demand. Darker colors represent greater impact. In Figure 3, the color black only occurs in two sectors: (a) livestock and (b) cement. One important point is that this high impact occurred when the maximum final demand variation was around 5%. Impact occurs in most sectors, but the two sectors mentioned above capture the majority of the impact. In all the other simulations, we can see how shared responsibility for GHG reductions understates the individual impact on each sector.

Figure 4 shows the impact on emissions; here, we can observe a heterogeneous structure. For small variations in final demand (between 1% and 1.5%), a number of sectors have low emissions. On the other hand, some sectors are not affected by this kind of restriction. As expected, this is particularly true of the service sectors. The results suggest that, if a mitigation policy were considered, it could focus on a small number of sectors and the cost, in terms of fall in final demand, would not be significant.

4. Conclusions and policy implications

This paper seeks to analyze the economic and environmental impacts of Brazilian GHG emissions. More specifically, it sought to answer the following questions: What is the economic impact? Should the government intervene in all economic activities, imposing the same target? Alternatively, is it possible to reduce adverse effects by selecting specific sectors? We explored these topics using an integrated IO LP model for 2009, examining 55 sectors. The model framework follows a similar approach to those found in the literature. In order to achieve the study goals, we defined an optimization problem with economic and environmental constraints.

The main results indicate that 1% of GHG emission reduction implies a decrease of at least 0.06% in total Brazilian output. Livestock is the major source of GHG emissions in Brazil. This sector alone was responsible for 50.4% of total GHG emissions in 2009. If the final demand of livestock fell by 5.14%, the established target would be achieved.

However, we have seen that this is not a feasible solution from a policy perspective, mainly because it would not create incentives for other industries to reduce emissions. In order to explore other possibilities, we simulated other scenarios in which other sectors shared the responsibility for emission reduction. In these scenarios, it was possible to observe the trade-off between emissions and production, whereby a 1% reduction in emissions could cause a fall of between 0.06% and 0.60% in total Brazilian production. The magnitude depends on the extent to which each sector is individually penalized.

There is no consensus about the best mechanism to reduce emissions as part of climate policy. Noteworthy options include government regulations, taxes, carbon trading, market mechanisms, subsidies, caps, and trade and carbon taxes.

In Brazil, Freitas et al. (2016) have shown that a taxation policy could be effective, since it would reduce total GHG emissions by 9%. However, the authors show the regressive impact of such a policy, whereby the poorest households would suffer the highest impact. Magalhães and Domingues (2013) have shown that if the government created a subsidy to return 5% of the total collected from the carbon tax to households, the fall in GDP would be reduced from −0.91% to −0.82%.

One aspect worth considering is a policy based on structural changes. For instance, given that livestock is the major source of emissions in Brazil, cattle production could be carried out in large-scale facilities where the methane released could be converted into energy.

Structural changes are extremely important in the Brazilian context, since Brazil is a global supplier of meat and there is a trend towards an increase in international demand over the next few years. If Brazil does not change its mode of production, this could mean a significant increase in emissions.

Nonetheless, an important counterbalance to consider is the feasibility of implementing such structural changes in the Brazilian agriculture sector over the short term. These types of public policy could be implemented, but this will take time. Thus, in order to mitigate emissions, it is necessary to implement a combination of incentives both directly, through research support, and indirectly, by raising the cost of emissions through regulations and taxes.

To sum up, the results highlight the importance of livestock for Brazilian emissions counteracting their economic significance. In the short term, sectoral emissions targets could be developed in order to mitigate emissions, but we suggest that in order not to overburden the livestock sector, it is possible to create shared responsibilities by also distributing targets among the less polluting sectors. However, in the long term, it is essential to invest in technological improvements that permanently reduce pollution levels.

Disclosure statement

No potential conflict of interest was reported by the authors.

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