BRAZILIAN GREENHOUSE GAS EMISSION REDUCTIONS AS AN OPTIMIZATION PROBLEM: WHEN THE GOVERNMENT CHOOSES POLICY DESIGN[i]

ABSTRACT

This paper aims to evaluate the economic and environmental impacts of Brazilian greenhouse gas (GHG) emissions. The intention is simulating emissions targets in different possible scenarios for which the adopted policy design should take into account several questions, such as: 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 choosing specific sectors? The results highlight the importance of Livestock and Fisheries for Brazilians emissions counteracting to its economic significance. In the short term, sectoral Emissions targets could be developed in order to mitigate emissions but we suggest that in order to not overcharge the Livestock and Fisheries sector it is possible to create shared responsibilities distributing the targets for less pollutant sectors as well. However, for long term it will be indispensable the investment on technological improvements that permanently reduce pollution levels.

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

Jel-codes: C61; C67; Q52; Q53.

1. Introduction

In the late 1980s, debates about economic growth and its impact on the environment intensified, and the Brundtland Report was drafted. Roughly speaking, this report addressed incompatibility between the production and consumption patterns of the time and sustainable development. A global concern with the environment thus began to develop.

In this context, currently, one of the principal environmental issues relates to air pollutants. According to Genty et al. (2012) and Moll et al. (2006), there are three main types of air pollutants: Greenhouse Gases (GHGs), which contribute to global warming; pollutants which contribute to acidification (ACID); and those with Tropospheric Ozone Forming Potential (TOFP). However, Hristu-Varsakelis et al. (2010) demonstrated that the two latter pollutants have less impact, at least in terms of magnitude, than GHGs. The increase of GHG concentration in the atmosphere is therefore the main cause of climate change.

Developing countries are responsible for more GHG emissions than developed ones. 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 largest 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 huge decrease in Brazilian

[i] This paper is a contribution of the Brazilian Network on Global Climate Change Research funded by CNPq Grant Number 550022/2014-7 and FINEP Grant Number 01.13.0353.00.

deforestation (Ribeiro et al., 2015) and, according to these authors, between 2005 and 2010 emissions fell by half.

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

According to Vogstad (2009), IO analysis initially influenced LP. As a matter of fact, the IO model could be considered a special case of an LP formulation, 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 for assessing the economic impact of 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 aim of this paper is to evaluate the Brazilian economic and environmental impacts of GHG emissions. The idea is make certain simulations taking into account emissions targets. In other words, what would be the economic impact of the government deciding to adopt a climate policy which 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 effect by choosing specific sectors?

By answering these questions, this 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 it 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, 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 input-output 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 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.

$$\boldsymbol{x} = \boldsymbol{B}\boldsymbol{f}$$

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

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

where: $\boldsymbol{x}$ is a vector which indicates total production for each sector j.

$\boldsymbol{A}$ is the Technological Matrix.

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

and $\boldsymbol{B}$ is the Leontief Inverse matrix.

We have used data from 2009 for the purposes of this paper. These are the most recent data available for Brazilian IOM and GHG emissions. The three main greenhouse gases are Carbon Dioxide (CO_2), Nitrous Oxide (N_20), and Methane (CH_4). These can be combined into a measure of Carbon Equivalent Emissions (CEE) as follows:

$$e_j = CO_2 + 310N_20 + 21CH_4$$

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

The methodology applied here is an extension of the traditional IO model, and is based on three previous papers: Cristóbal (2010), Hristu-Varsakelis et al. (2010) and Hristy-Varsakelis (2012). Formally, to include emissions in an input-output framework, the information about sectoral emissions was used as a new coefficient, calculated as:

$$c_j = \frac{e_j}{x_j}$$

where, e_j is the emission in sector j and c_j is the emission coefficient in sector j. In this sense, c_j is the total amount of carbon equivalent emissions generated per unit of output in industry j or the direct effect, and one can define the total volume of gas k produced by the entire economy as:

$$c_j = \hat{c}_j \boldsymbol{Bf} = \hat{c}_j \boldsymbol{X}$$

where $\hat{c}_j$ is the diagonalized form of c_j.

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

$$m_j^p = \sum_{i=1}^{n} e_j^p \cdot b_{ij}$$

The indirect effect (ie_j) was calculated as follows:

$$ie_j = m_j^p - c_j$$

From the policymaker perspective, when we discuss GHG emissions, two conflicting goals need to be achieved: production maximization and emission minimization. These problems can be made explicit as follows:

Problem 1:

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

Problem 2:

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

where t is the target for emissions. This target can be defined differently 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 $\sum_j \hat{c}_j X \leq t$).

Since these problems are complementary (one can reduce emissions only by reducing production, and vice versa), the solutions are symmetrical[1]. Thus, when we solve Problem 1 or Problem 2, the result is exactly the same. This 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.

As we would expect, sectors with the highest emission coefficient, i.e., that generate more gas emissions per unit of output, require the smallest direct economic cost to achieve the target, when economic cost is measured by loss in total output. Accordingly, the optimization process suggests that highly pollutant sectors provide the optimal means of achieving the target. Furthermore, by using an IO framework, these sectors are related to others. If their activity levels are reduced, output is triggered in other sectors, also causing them to reduce emissions.

However, a problem arises when we solve these models for Brazil: the concentration of GHG emissions in Livestock and Fisheries 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:

Problem 1:

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

[1] All problems were solved using LP Simplex.

Problem 2:

$$
\begin{aligned}
& \min eX \\
s.t. \quad & (\boldsymbol{I}-\boldsymbol{A})\boldsymbol{X} \leq \boldsymbol{f} && \text{(economic constraint)} \\
& \hat{c}_j\boldsymbol{X} \leq t \ \forall j && \text{(environmental constraint)} \\
& \Delta\boldsymbol{f}_j \leq \boldsymbol{b} \ \forall j && \text{(economic constraint 2)} \\
& \boldsymbol{X} \geq 0
\end{aligned}
$$

The intention in the simulations presented here is to reduce total emissions by 1%, with $\boldsymbol{b}$ as a parameter ranging between 1.1 and 5.13%. It is worth mentioning that, if the emissions reduction goal is set at 1%, and we do not allow final demand to fall below exactly 1%, the solution is meaningless, i.e., all sectors need to reduce by 1%. Here, 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 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 some exploratory analysis.

To construct the emissions vector, we considered the following gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) measured in carbon equivalents. The data is from the Annual estimates of greenhouse gas emissions in Brazil (MCTI, 2013). Together, these pollutants constitute the so-called greenhouse gases, or GHGs, that directly contribute to global warming.

The next section 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.

3. Exploratory Analysis of Emissions

In 2009, according to the WIOD, 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 the U.S. (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) in 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).

< Figure 1 around here >

Other relevant information seen in < Figure 1 is the contribution of GHG emissions by economic sector. Agriculture, Hunting, Forestry and Fishing 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 IO Brazilian matrix for 2009 into account, we can see varying magnitudes of GHG emissions by sector, although following the same order, i.e. Agriculture (53.5%), Industries (28.7%) and Services (17.8%). It is important to 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 and Fisheries, Other Mining and Quarrying, Food and Beverage, Cement, Manufacture of Steel and Derivatives, and Transport, Postal and Warehousing are more intensive in terms of GHG emissions.

< Table 1 around here >

Taking Livestock and Fisheries as an example, we can see that for each R$ 1,000 variation in demand, the entire economy needs to produce 4.61 tons/CO2 eq. 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.

Emissions in Brazil are highly concentrated, since we can see that in 2009 eight (out of a total 56) sectors jointly accounted for 90.2% of total GHG emissions. These sectors are: Livestock and Fisheries (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%).

4. Results and Discussion

The first simulation we conducted is the simplest. The intention was to answer the following question: How much reduction to 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 IO model. Without any restrictions to final demand, the largest drop in production (-1.95%) is from Livestock and Fisheries, 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 and Fisheries, 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 and Fisheries is sufficient to achieve an emission target of 1% emission reduction. This result was expected, because the linear programming model will first constrain the sector which emitted the most.

In our first linear programming problem, a decrease of 5.14% in the Livestock and Fisheries final demand means that the established target has been achieved. Nonetheless, for several reasons, this is not a feasible result from a policy perspective. First, this production is highly concentrated in poor households, who rely on Livestock and Fisheries as their main source of income[2]. 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 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.

< Figure 2 around here >

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

---

[2] The 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.

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 Fisheries and b) Cement. One important feature is that this high impact occurred when the maximum final demand variation was around 5%. There is an impact on most of the sectors, but the two above-mentioned sectors capture the majority of the impact. For all the others simulations, we see how shared responsibility for greenhouse gas reductions understates the individual impact on each sector.

Figure 4 shows the impact on emissions; here, we observe a heterogeneous structure. For small variations in final demand (between 1% and 1.5%), many 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 we consider implementing a mitigation policy, such a policy could focus on a small number of sectors and the cost, in terms of fall in final demand, is not huge.

< Figure 3 around here >

< Figure 4 around here >

5. Conclusions and Policy Implications

This paper seeks to analyze the economic and environmental impacts of Brazilian GHG emissions. More specifically, we 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 choosing specific sectors? We explored these topics using an integrated input-output linear programming 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 emissions reduction implies a decrease of at least 0.06% in total Brazilian output. Livestock and Fisheries are 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 and Fisheries 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 emissions reduction. In these scenarios, it was possible to observe the trade-off between emissions and production, where 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, Ribeiro et al. (2015) 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 and Fisheries are the major source of emissions in Brazil, cattle production could be carried out in large-scale facilities where the released methane 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 huge increase in emissions.

Nonetheless, an important counterbalance to consider here is the feasibility of implementing such structural changes in the Brazilian agriculture sector over the short term. These kinds of public policies 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 and Fisheries for Brazilians emissions counteracting to its economic significance. In the short term, sectoral Emissions targets could be developed in order to mitigate emissions but we suggest that in order to not overcharge the Livestock and Fisheries sector it is possible to create shared responsibilities distributing the targets for less pollutant sectors as well. However, for long term it will be indispensable the investment on technological improvements that permanently reduce pollution levels.

References

Allan, G.; Lecca, P.; McGregor, P.; Swales, K. The economic and environmental impact of a carbon tax for Scotland: A computable general equilibrium analysis. Ecological Economics, v.100, pp. 40-50, 2014.

Beutel, J., 1983. Input-output analysis and linear programming. The general input-output model. In: M. Grassini and A. Smyshlyaev (eds.) Input-output modeling, Proceedings of the 3rd IIASSA Task Force Meeting, 313-328. Laxenburg: IIASA.

Brizga, J., Feng K. and Hubacek, K., 2014. Drivers of greenhouse gas emissions in the Baltic States: A structural decomposition analysis. Ecological Economics 98, 22-28.

Bustamante, M. C., Nobre, C. A., Smeraldi, R., Aguiar, A. P. D., Barioni, L. G., Ferreira, L. G., Longo, K., May, P., Pinto, A. L. and Ometto, J. P. H. B., 2012. Estimating greenhouse gas emissions from cattle raising in Brazil. Climatic Change 115(3-4), 559-577.

Carter, A. P., 1970. A linear programming system analysing embodied technological change. In: A. P. Carter and A. Brody (eds.) Applications of input-output analysis. Amsterdam, North-Holland, 77-98.

Carvalho, T. S., Santiago, F. S. and Perobelli, F. S., 2013. International trade and emissions: The case of the Minas Gerais state - 2005. Energy Economics 40, 383-395.

Cristóbal, J. R. S., 2010. An environmental/input-output linear programming model to reach the targets for greenhouse gas emissions set by the Kyoto protocol. Economic Systems Research 22(3), 223-236.

Cristóbal, J. R. S., 2012. A goal programming model for environmental policy analysis: Application to Spain. Energy Policy 43, 303-307.

Dorfman, R., Samuelson, P., Solow, 1958. Linear programming and economic analysis. New York, McGraw Hill. Dietzenbacher, E. Los B., Stehrer R., Timmer M. and Vries, G., 2013. The Construction of world input–output tables in the WIOD project. Economic Systems Research, 25 (1), 71-98.

Fearnside, P. M., 2005. Deforestation in Brazilian Amazonia: History, rates and consequences. Conservation Biology 19(3), 680–688.

Genty, A., Arto, I. and Neuwahl, F., 2012. Final database of environmental satellite accounts: technical report on their compilation. WIOD documentation. Available at: http://www.wiod.org/publications/source_docs/Environmental_Sources.pdf.

Guilhoto, J. J. M., Sesso Filho, U. Estimação da matriz insumo-produto a partir de dados preliminares das contas nacionais. Economia Aplicada 9(2): 277-299, 2005.

Gurgel, A. C., Paltsev, S. Costs of reducing GHG emissions in Brazil. Climate Policy 14(2): 209-223, 2014.

Hristu-Varsakelis, D., Karagianni, S., Pempetzoglou, M. and Sfetsos, A, 2010. Optimizing production with energy and GHG emission constraints in Greece: An input-output analysis. Energy Policy, 38, 1566–1577.

Hristu-Varsakelis, D., S. Karagianni, M. Pempetzoglou and A. Sfetsos, 2012. Optimizing production in the Greek economy: Exploring the interaction between greenhouse gas emissions and solid waste via input–output analysis. Economic System Research, 24 (1), 55-75.

Leontief, W. The structure of the American economy, 1919-1939: an empirical application of equilibrium analysis. New York: Oxford University Press, 1941.

Liu, Q.; Wang, Q. Reexamine SO_2 emissions embodied in China's exports using multiregional input–output analysis. Ecological Economics, v. 113 pp. 39-50, 2015.

Magalhães, A. S., Domingues, E. P. Economia de baixo carbono no Brasil: alternativas de políticas e custos de redução de emissões de gases de efeito estufa. Texto para discussão, n. 491, CEDEPLAR/UFMG, Belo Horizonte, agosto de 2013.

Miller, R. E.; Blair, P. D. Input-output analysis: foundations and extensions. New York: Cambridge University Press. Second edition, 2009.

Moll, S., Vrgoc, M., Watson D., Femia, A., Gravgard P. O. and Villanueva, A., 2006. Environmental input-output analysis based on NAMEA data. A comparative European study on environmental pressures arising from consumption and production patterns European topic center on resource and waste management, published by the European Environment Agency.

Moreira, T. M. and Ribeiro, L. C. S., 2013. Mudanças estruturais na economia brasileira entre 2000-2005 e o novo regime macroeconômico: Uma abordagem multissetorial. Revista Economia, 14 (1C), 751-780.

Orlov, A., Grethe, H. Carbon taxation and market structure: a CGE analysis for Russia. Energy Policy 51: 696-707, 2012.

Nepstad, D., Carvalho, G., Barros, A. C., Alencar, A., Capobianco, J. P., Bishop, J., 2001. Road paving, fire regime feedbacks, and the future of Amazon forests. Forest Ecology and Management 154, 395–407.

Ribeiro, L. C. S., Freitas, L. F. S., Souza, K. B., Hewings, G. J. D., 2015. GHG emissions' tax in Brazil using an input-output model. In: Proceedings of the 23rd International Input-Output Conference. Mexico City, Mexico.

Ribeiro, L. C. S., Leão, E. S. A., Freitas, L. F. S., 2015. Trade-off between GHG emissions and economic performance of the Brazilian Agriculture: an environmental input-output analysis. In: Proceedings of the 23rd International Input-Output Conference. Mexico City, Mexico

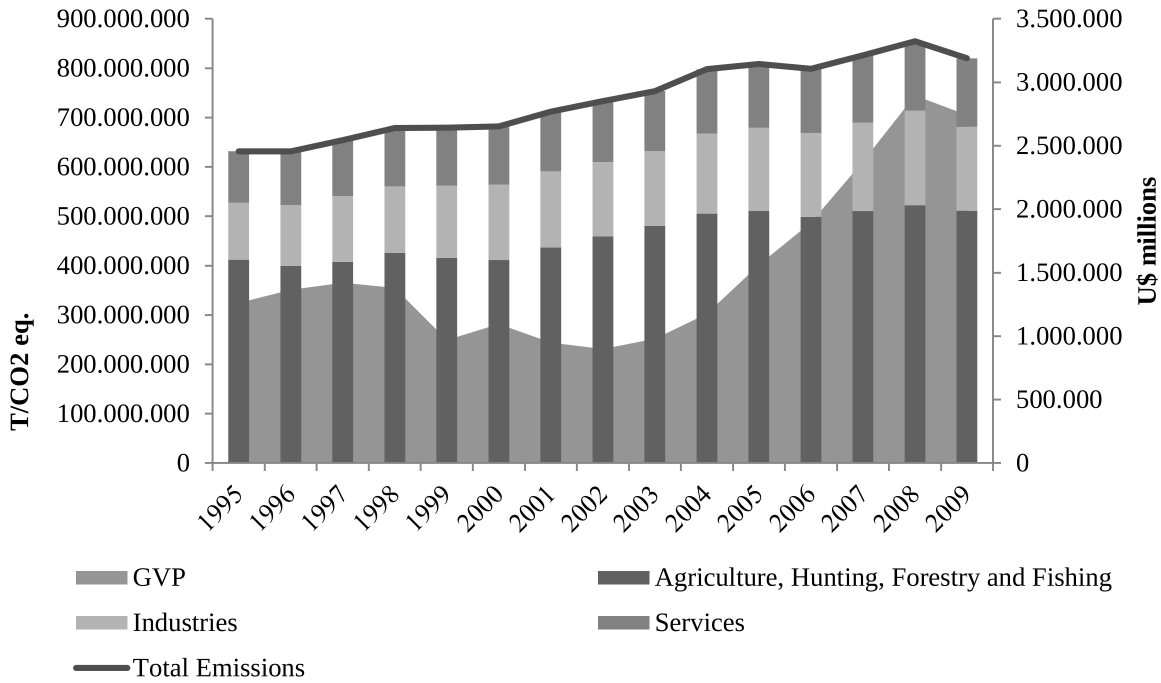
Rivero, S., Oriana, A., Ávila, S., Oliveira, W., 2009, Pecuária e desmatamento: uma análise das principais causas diretas do desmatamento na Amazônia. Nova Economia 19(1), 41-66.

Su, B.; Ang, B. W. Low, M. Input–output analysis of CO_2 emissions embodied in trade and the driving forces: processing and normal exports. Ecological Economics, v.88 pp. 119-125, 2013.

Timmer, M. P. (ed.), 2012. The World Input-Output Database (WIOD): Contents, sources and methods. WIOD Working Paper Number 10. Available at: www.wiod.org.

Tables and Figures:

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



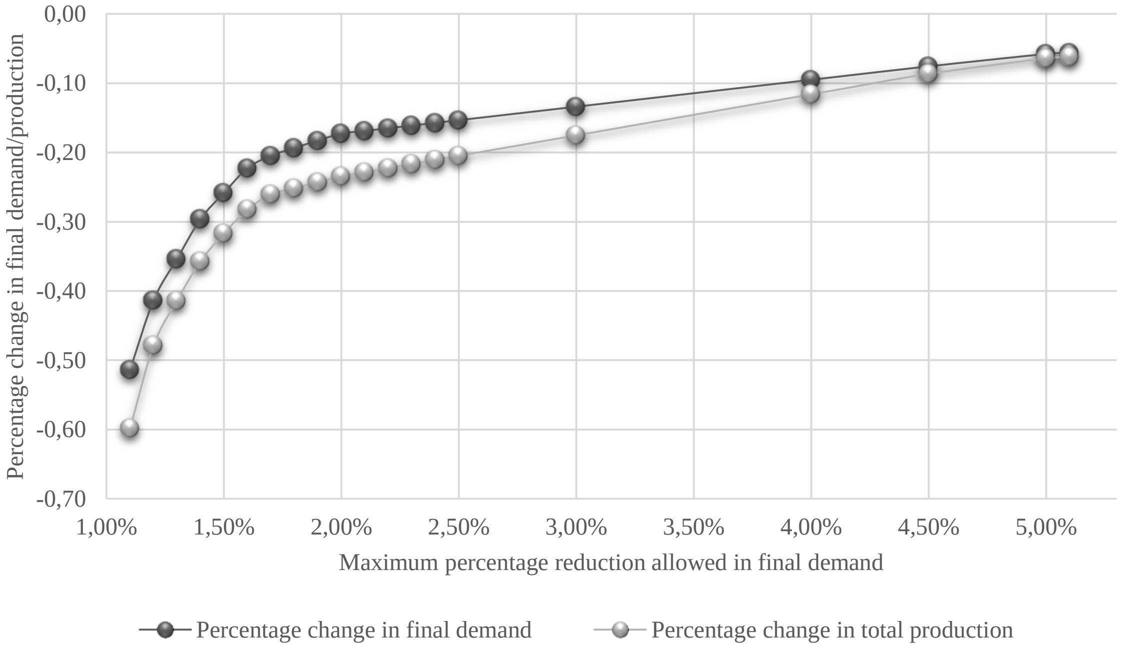
Source: Compiled by the author, based on Timmer (2012).

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

Sectors	GHG (t/CO_2 eq.)	GVP (R$ 1.00)	Production Multiplier		
			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
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	3,044	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**

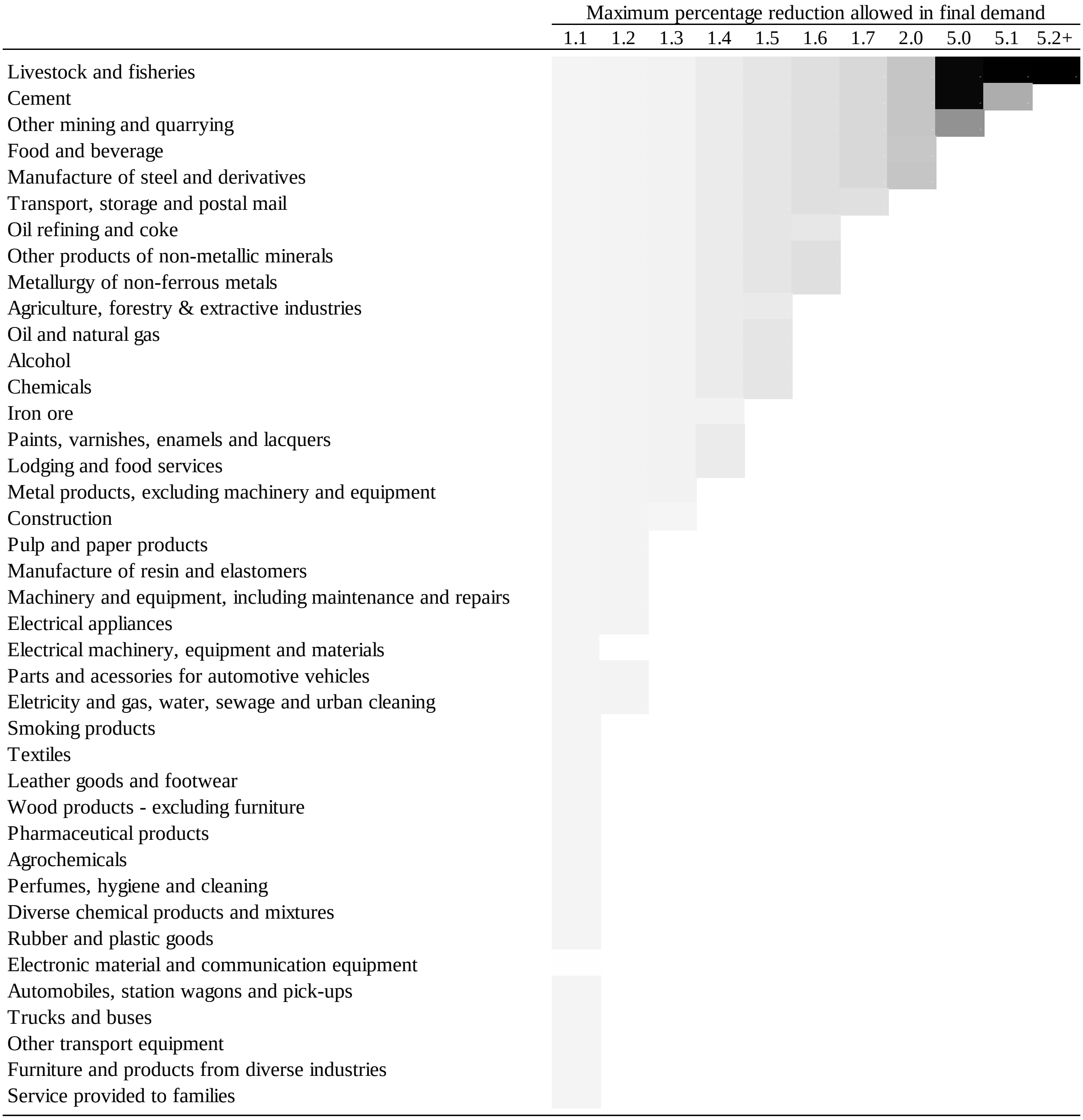
Source: Compiled by the author, based on the IO Brazilian matrix – 2009

Figure 2: Percentage change in final demand and production



Source: Compiled by the author

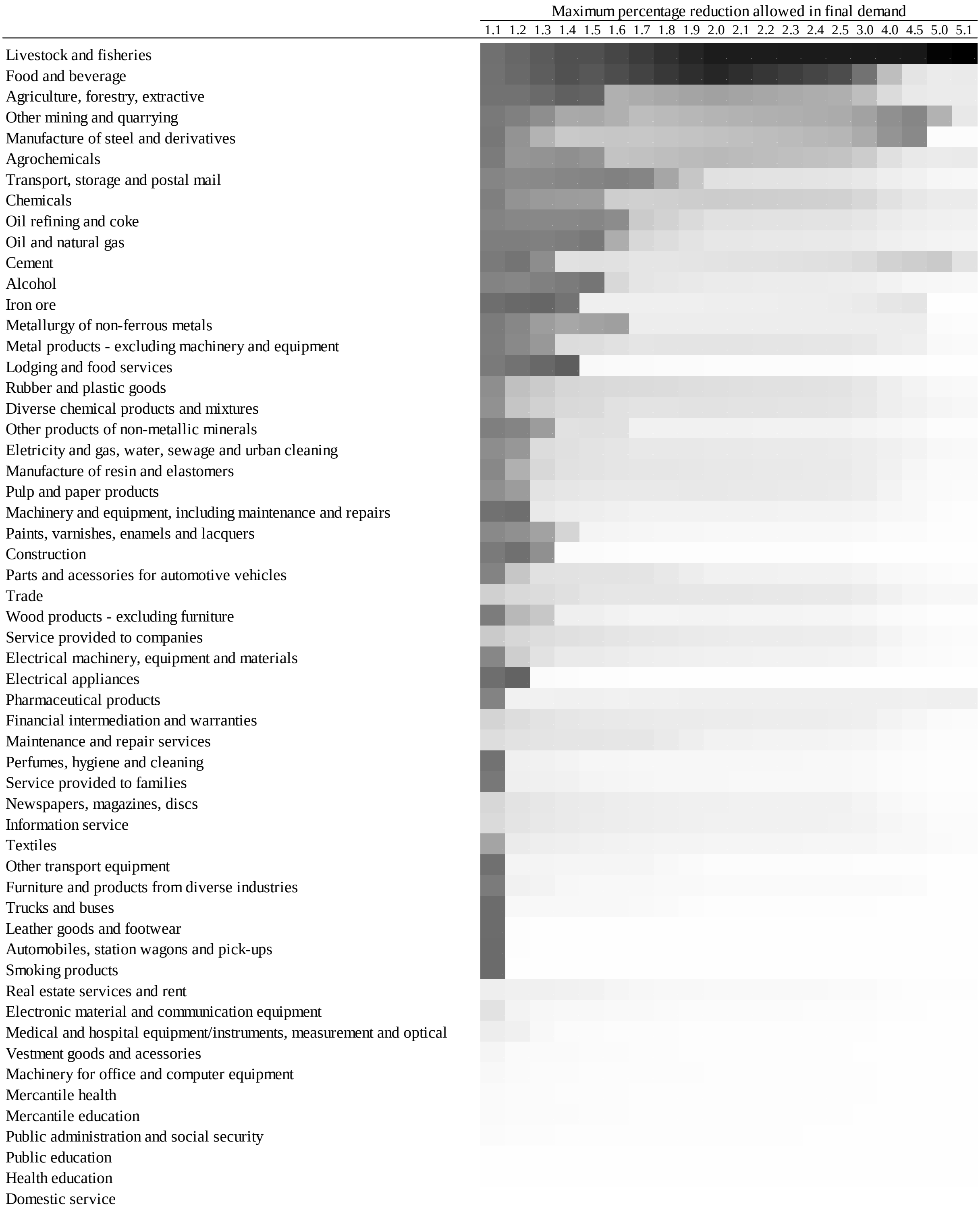
Figure 3: Percentage reduction in final demand by sector



Source: Compiled by the author

Note: darker colors represent greater percentage reductions in sectoral final demand

Figure 4: Percentage change in emissions by sector



Source: Compiled by the author

Note: darker colors represent greater percentage reductions in sectoral final demand