

HALTING DEFORESTATION IN THE BRAZILIAN AMAZON REGION: ECONOMIC IMPACTS AND GREENHOUSE GAS EMISSIONS

Abstract

This paper analyzes the economic impacts of freezing deforestation in the Brazilian Amazon, through the use of a dynamic computable general equilibrium (CGE) model extended for handling land-use changes and its GHG emissions. This model uses observed data to represent emissions and land use through transition matrices, calibrated with satellite imagery provided by the Brazilian National Institute for Space Research. The policy considers halting new land supply, which is justified by the international efforts to control deforestation around the world, as established by the New York Declaration on Forests, issued in the United Nations Climate Summit 2014. Furthermore, the implemented policy goes beyond the current domestic goals, which established reducing deforestation in the Legal Amazon region by 80% by 2020, in relation to the average recorded in 1996-2005. The extreme policy deals with a very restricted scenario, considering the high costs and limitations involved for the agents, which may facilitate the design and implementation of intermediate policy scenarios. Besides, zero deforestation although extreme, is feasible, since the clearing of new areas has been successfully curbed in Brazil over the past few years. The main results show that deforestation control focused on the Amazon Biome can effectively reduce domestic GHG emissions, although some sinks may occur as a result of the displacement of deforestation to other regions and biomes. Such movement has another major implication, namely, that of enhancing regional inequalities. Therefore, the asymmetries between the southeast and mid-west regions were intensified, especially in the latter, where negative impacts on the regional GDP, consumption levels, employment, and other macroeconomic variables were quite pronounced, as expected. Finally, a promising approach to be evaluated in future research was identified, that of productivity gains in agriculture, as alternative for deforestation control.

Keywords: deforestation, greenhouse gases, CGE model.

JEL codes: C68, D58, Q24, Q28, Q54

1. INTRODUCTION

Global agriculture faces the challenge of meeting an increasing demand for food resulting from fast urbanization rates, population growth, and rising incomes, especially in the developing world.

New arable land areas are being made available to meet the demand for agricultural products. As a result, over the past 50 years 67 million hectares (Mha) of arable land were set apart for agriculture, as a result of opposite trends, an increase of 107 Mha in developing countries and a decrease of 40 Mha in developed countries (FAO, 2013).

Brazil follows the trend for developing countries, as the supply of land for agriculture increased. Between the agricultural censuses carried out in 1995/96 and in 2006, cropland areas grew by 19.4%, from 50 Mha to just over 60 Mha, while pastureland areas grew by only 1.79%, from 100 Mha to almost 101 Mha (IBGE, 2014a).

Regionally, the expansion of Brazilian agriculture has been concentrated in the mid-west and north regions, where land is still available. However, most of these regions are covered by savannas and forests. Thus, agricultural expansion has incorporated new land and, consequently, led to the deforestation of a vast area of native vegetation, especially in the Amazon and Cerrado Biomes, which stretch over more than half of the Brazilian territory.

Recent estimates show that, in 1980, around 300,000 km² of native vegetation were deforested in the Amazon, accounting for 6 percent of this biome. In the 1980s and 1990s, a further 280,000 km² of forests were occupied to give way to other activities. The situation got worse in the early 2000s, when the (cumulated) deforested area rose to 670,000 km² - a deforestation peak in the Amazon region (BRASIL, 2013).

An important underlying issue must be considered in connection with the conversion of forests into other uses, namely, the issue of GHG emissions. In Brazil, they grew sharply in the Amazon region due to its high carbon content as compared to other biomes. In 2010, for example, 52.2 percent of all GHG emissions associated with land use change and forests were generated in the Amazon Biome (BRASIL, 2013).

Furthermore, 77 percent of all domestic GHG emissions came from land use change and forests. Thus, the Brazilian government assumed the commitment to reduce the domestic GHG emissions by creating a national plan on climate change – *Plano Nacional sobre Mudança do Clima*. Such plan lists actions designed to reduce GHG emissions, highlighting the role of deforestation control to achieve this goal, as land use changes account for the greatest part of all domestic emissions.

However, a policy that could reduce the domestic supply of new land should be evaluated in detail by, for example, considering its effects on land allocation, GHG emissions, and on the domestic economy. For this reason, this essay analyzes the economic impacts of zero deforestation in the Amazon Biome, i.e. of halting new land supply.

This policy is justified by the international efforts to halt deforestation around the world, as established by the New York Declaration on Forests, issued in the United Nations Climate Summit 2014¹. Furthermore, an extreme policy deals with a very restricted scenario, considering the high costs and limitations involved for the agents, which may facilitate the design and implementation of intermediate policy scenarios.

Silva (2010), Diniz (2012), Ferreira Filho and Horridge (2012), and Cabral (2013) made progress in analyzing the curbing of deforestation and its impacts on land allocation, food security, prices, the farming sector, and the economy as a whole. In this essay, we take a step further in that analysis by linking land use change to its GHG emissions in a regional CGE model disaggregated by biomes, which captures land and emission heterogeneity across the country.

Finally, this essay is divided into five sections, besides this introduction. The first section sets out the main features of the deforestation under way in the Brazilian Amazon region. The second and the third sections are devoted, respectively, to presenting the methodology and the scenarios considered. The fourth section discusses results, and the last one presents the final remarks.

¹ In September, the United Nations promoted the UN Climate Summit 2014, a forum to discuss alternatives to reduce GHG emissions and mitigate the effects of the climate change. Policies to eliminate the deforestation was one of issues addressed in this meeting.

2 DEFORESTATION IN BRAZIL

Productive and economic growth and increasing population growth rates are some of the elements leading to intense changes in land use and forests. In Brazil, deforestation is one of the consequences of this process, triggered by the substitution of large areas of native vegetation for roads, cities, crop fields, pastureland or simply by their use as a source of raw materials, such as timber.

However, after years of increasing and almost continuous deforestation (1997-2004), the pace of forest clearing slowed down in the mid-2000s, particularly in the Amazon region. Since then, deforestation rates in almost all states in that region have been lower than before 2004, as shown in Figure 1.

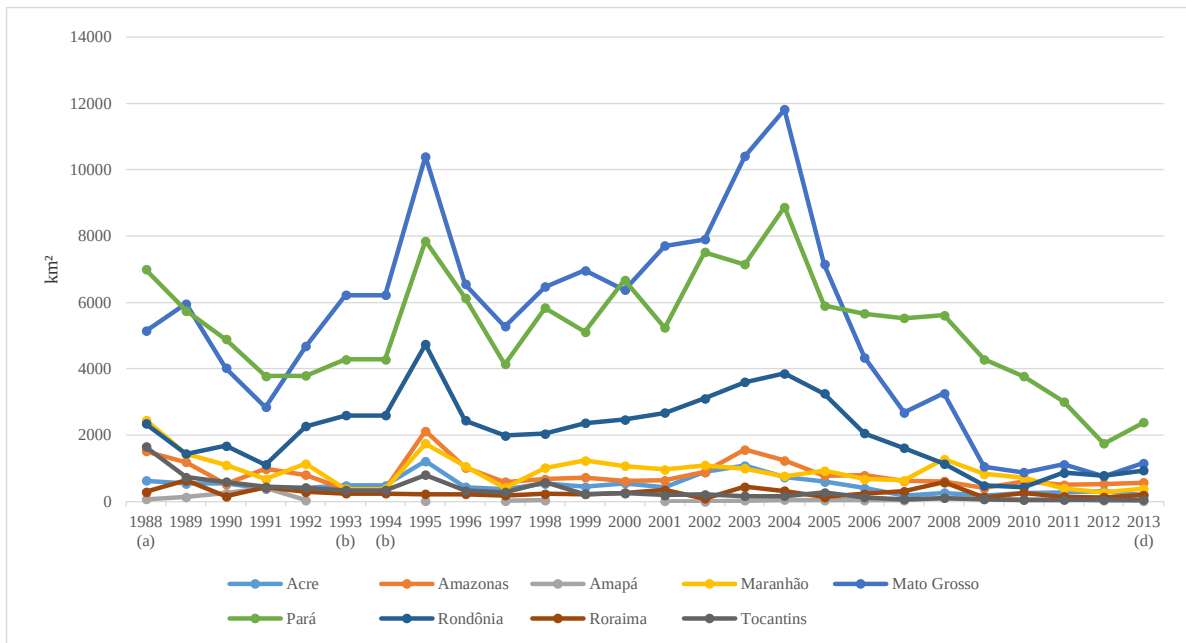


Figure 1 - Annual deforestation rates in the Legal Amazon region between 1988 and 2013, in km²/year.

Source: INPE (2014). Prepared by the author.

(a) Average between 1977-1988

(b) Average between 1993-1994

(c) Estimated rate.

Deforestation in the Legal Amazon region between 1988 and 2013 resulted in the clearing of 402.615 km², especially in the states of Mato Grosso (137.251 km²), Pará (136.127 km²), Rondônia (54.772 km²), and Maranhão (23.917 km²). Notwithstanding, the

reduction observed in deforestation rates in these states was also pronounced and, as a result, Mato Grosso dropped from the first to the second position in the ranking of deforesters, second to the state of Pará (INPE, 2014).

Contrasting with these high deforestation rates, the Amazon and Pantanal regions were classified as the most preserved Brazilian biomes, especially as compared to the Atlantic Forest, which in 2010 had lost 88.4% of its original vegetation. In the remaining biomes the situation was similar, such as, for example, in the Caatinga, Pampa, and Cerrado regions, which lost 44.6%, 54.2%, and 49.1% of their native vegetation, respectively. In the Cerrado Biome, the most deforested area is to be found in the states of São Paulo and Mato Grosso do Sul, with percentages of 90.2% and 76.1%, respectively, while the lowest percentage of deforestation was recorded in the state of Rondônia, only 3.1% (IBGE, 2012).

Thus, the efforts being made to reduce deforestation in the Legal Amazon² region are concentrated in the states of Maranhão (MA), Pará (PA), Mato Grosso (MT), and Rondônia (RO), which form a strip of land known as the “Deforestation Arch,” as shown in Figure 2. This area concentrates some of the municipalities with the highest rates of deforestation, such as Açailândia and Santa Luzia in the state of Maranhão and Vila Rica in the state of Mato Grosso, which in 2010 deforested 90.47%, 91.34%, and 61.83% of their natural vegetation areas, respectively (INPE, 2010).

² Legal Amazon is a region that comprises nine Brazilian states, namely, Acre, Amazonas, Roraima, Rondônia, Pará, Amapá, Tocantins, and part of Mato Grosso and Maranhão. It covers 59% of the national territory, and despite the name, has three different biomes, all the Amazon, 37% of the Cerrado biome, and 40% of the Pantanal biome (INSTITUTO SOCIOAMBIENTAL, 2009).

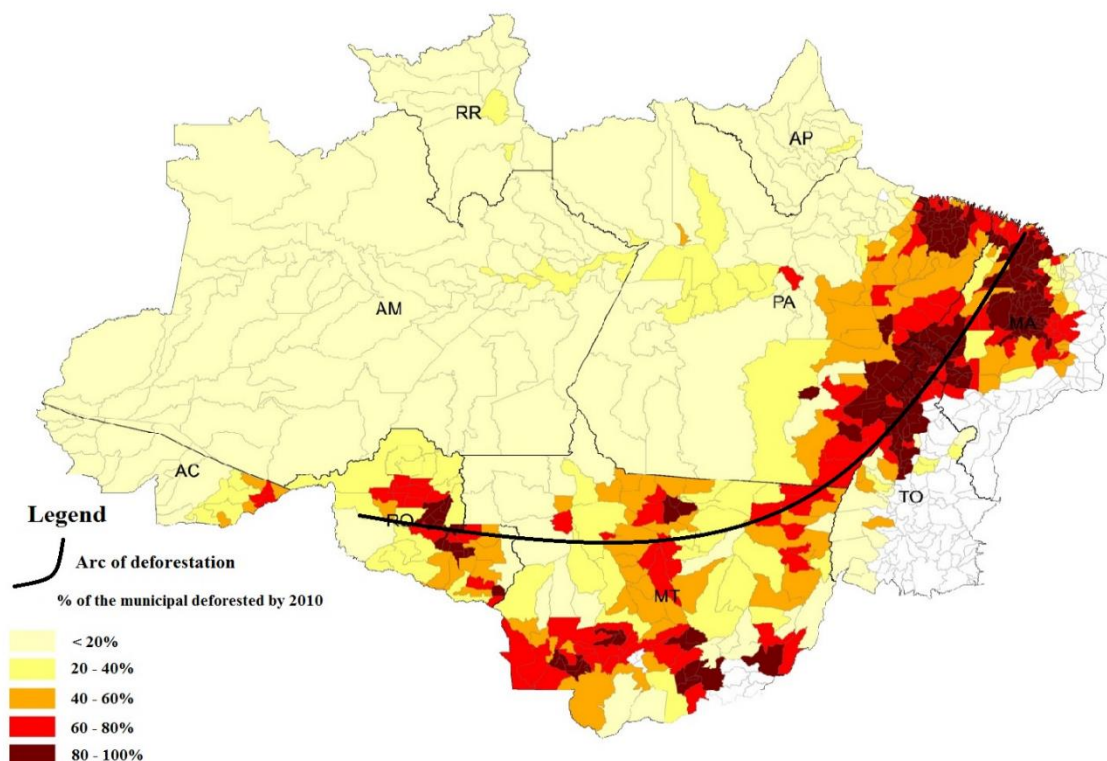


Figure 2 - Share of deforested areas in the Legal Amazon region by municipality in 2010.

Source: Adapted from IPAM (2013).

Identifying the *locus* of deforestation can support the design of actions to curb it, as was done through the post-2004 policies that triggered a slowdown in forest clearings. Among other actions carried out, the following ones deserve special mention: creation of monitoring systems³, repression of logging and land grabbing, credit constraints imposed on offenders of environmental laws, and establishment of a list of priority municipalities for deforestation control purposes⁴ (BRASIL, 2013).

The actions to reduce the deforestation in the Brazilian Amazon region are listed in the *Plano de Ação para a Prevenção e Controle do Desmatamento na Amazônia Legal* - PPCDAm (Action Plan to Prevent and Control Deforestation in the Brazilian Legal Amazon

³ *Sistema de Detecção do Desmatamento em Tempo Real* (DETER) is a system designed to detect and monitor deforestation in real time and it was created by the National Institute for Space Research in 2004.

⁴ It is worthwhile stressing that all measures adopted by the Brazilian government benefited from a drop in the prices of agricultural commodities and from the 2008 financial crisis, which slowed down international trade.

Region)⁵. This plan was launched in 2004 by the federal government and was structured around three thematic axes: territorial and property organization, environmental monitoring and control, and actions to boost sustainable productive activities.

Figure 3 shows that the policies adopted so far were efficient in reducing deforestation rates from an average of about 1,996 thousand hectares in 1995-2006 to 476 thousand hectares in 2012, the lowest rate in the time series. Nonetheless, the target set by the National Policy on Climate Change is to reduce the annual deforestation rate by 80% by 2020 in relation to the average rate observed in 1995-2006 (BRASIL, 2013).

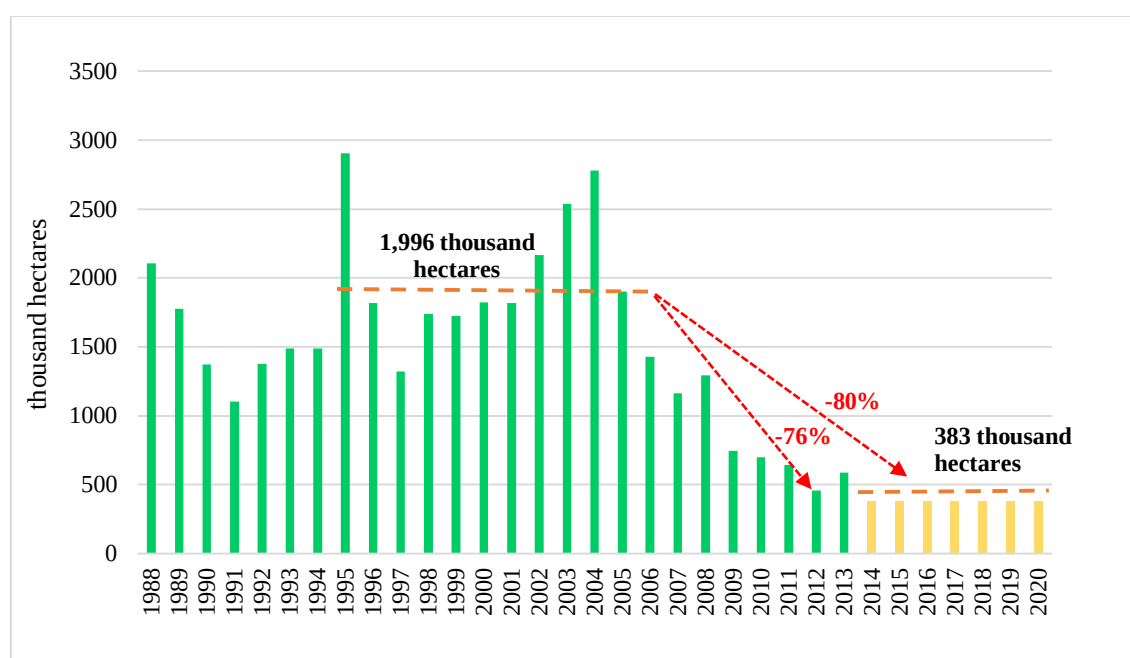


Figure 3 - Brazil's target to reduce deforestation rates in the Legal Amazon region by 2020: observed (green) and target (yellow) rates, in thousand hectares.

Source: INPE (2014). Prepared by the author.

It is worth noticing that despite the gains achieved in terms of avoiding the clearing of new areas, which in 2012 led to a reduction of 76% in the deforestation rate in the Amazon region, the annual target rate was not achieved. On the contrary, the rate rose to 28.9% in 2012-2013. For this reason, all the actions described before should be followed strictly to

⁵ For more details, see Brasil (2013).

prevent the beginning of a new cycle of rising deforestation, since it is a dynamic phenomenon and, therefore, one that is difficult to control.

3 METHODOLOGY

This essay uses TERM-BR, an inter-regional, multi-period, general equilibrium model of Brazil, tailored for climatic analysis. As a bottom-up model, it may be thought as several CGE models, linked by trade and labor movements between regions. In other words, national results are driven by regional results, which allow modelling multiple regions within a single country.

TERM-BR is a typical CGE model, whereby each industry minimizes production costs to a specific output level by optimizing labor, capital, and material inputs. Production levels are chosen to meet the demand from their users, namely, several domestic industries, households, the government, and other countries.

The model captures supply and demand for commodities, as well as the movement of such goods from producers to consumers, considering several transportation modalities. In addition, TERM-BR evaluates demand and supply shocks and their effects on prices and quantities in a specific region, following its bottom-up structure, while its capacity to respond to exogenous shocks depends on three basic elements:

- The database (regional input-output tables);
- Behavioral parameters (how agents minimize their costs) and;
- Closure (which variables will be exogenous or endogenous in the model).

TERM-BR is a multi-period, as noted before, and has a recursive-dynamic structure⁶, which consists of: (i) a stock-flow relation between investment and capital stock, which assumes a one year gestation lag; (ii) a positive relation between investment and the rate of profit; and (iii) a relation between wage growth and regional employment, i.e. long-run labor market adjustment occurs as a combination of inter-regional labor migration and changes in regional real-wage differentials, as stated by Horridge (2012).

⁶ More details in Appendix B.

The model's dynamics allows the construction of a base forecast (baseline) for the future of the economy. The policy scenarios in turn, differ from the base only via shocks on policy variables. Thus, the deviations between base and policy scenarios can be interpreted as the effect of the policy change.

TERM-BR handles a large number of regions and sectors. However, in this essay the model has 15 regions, 36 commodities and industries, 10 labor grades, and two margins (trade and transportation). Finally, the model is solved using the GEMPACK system (Harrison and Pearson, 1996).

3.1 The TERM-BR data structure

Following Horridge (2012), the database of the model consists of flow matrices organized by commodity, industry, and region. The dimensions of the matrices are indicated by indices (s, c, m, i, o, d, r, p, f, u), as shown in Table 1.

Table 1 - Main sets of the TERM-BR model.

Index	Set	Description	Size
s	SRC	Source (dom., imp.)	2
c	COM	Commodities	110
m	MAR	Margins (transport and trade)	2
i	IND	Industries	110
o	OCC	Skills	10
d	DST	Regions of use (destination)	15
r	ORG	Region of origin	15
p	PRD	Regions of margin production	15
f	FINDEM	Final demanders (HOU, INV, GOV, EXP)	4
u	USER	Users = IND + FINDEM	114

Source: Horridge (2012).

Figure 4 shows the schematic representation of the model's input-output database. It represents the model's core in bold and flow values (rectangles) as follows:

- i. Basic values = output prices (for domestic goods) or CIF prices (for imported goods);
- ii. Delivered values = basic values + margins;
- iii. Purchasers' values = basic values + margins + tax = Delivered + Tax

The matrices on the left-hand side of Figure 4 are similar (for each region) to a standard single-region, input-output database. For example, the USE matrix at the top shows

the delivered price of demand for every good (c in COM), whether domestic or imported (s in SRC) in every region of destination (DST) for each user (USER), considering each industry (IND) and individual demanders (households, investment, government and exports).

The matrices can usually be represented as follows:

- USE (“rice”, “imp”, “HOU”, “Bahia”): imported rice used by households in Bahia state;
- USE (“beef”, “dom”, “EXP”, “Sao Paulo”): beef produced domestically but exported through a port in São Paulo state.

The values of the USE matrix are at delivered prices and do not consider regional information on the origin of the goods. The TAX matrix, in turn, which represents tax revenues, contains an element that matches every element of the USE matrix. Such matrices, together with those of primary factor costs and production taxes, add production costs (or production value) for each regional industry.

The MAKE matrix, at the bottom of Figure 4, shows the production cost of each industry in each region. Moreover, a subtotal of the MAKE matrix, MAKE_I, represents the total production of each good (c in COM) in each “d” region. It is worth mentioning that, in principle, every industry is capable of producing any good.

The regional sourcing mechanism is represented on the right side of Figure 4. TRADE is the key matrix that shows the interregional trade value by origin (r in ORG) and destination (d in DST) for each good (c in COM), whether domestic or imported (s in SRC). The diagonal of that matrix (r = d) shows the use value for goods of domestic origin. Imported goods (s = “imp”) in turn, are represented by the origin subscript “r” (in ORG), which denotes the entrance port.

The TRADMAR matrix shows, for each cell of the TRADE matrix, the margin value of each good (m in MAR) which is required to facilitate that flow. Adding the TRADE and TRADMAR matrices, the DELIVRD matrix is generated, which represents the delivered value (basic prices + margins) of all intra and interregional flows of goods. It should be mentioned that there is no information in the TRADMAR matrix about where the margins are produced (the r subscript is related to the basic underlying flow).

It is the SUPPMAR matrix that shows where margins are produced (p in PRD). This matrix doesn’t have a specific subscript for goods c (COM) and s (SRC), indicating that the same proportion of m is produced in that region for all margins on the goods used to transport any other good from region r to region d.

TERM-BR assumes that all users of a specific good (c, s) in a given region (d) have the same origin mix. Actually, for each good (c, s) and region of use (d) there is an agent that decides, for every user in d, where the supply will come from. Furthermore, the equilibrium conditions of the model’s database establish that the sum over users of USE, USE_U will be equivalent to the sum of regional origins of the DELIVRD matrix, i.e. DELIVRD_R.

Finally, the equilibrium between supply and demand for domestic goods remains, which is represented by the line connecting MAKE_I to the TRADE and SUPPMAR matrices. Goods with no margins, the domestic part of the TRADE matrix, will be added (over de in DST) to the matched element of the good supply matrix, MAKE_I.

3.2 The TERM-BR equation system

The equations of the TERM model are also similar to those of other CGE models. Producers choose a cost-minimizing combination of intermediate and primary factor inputs, subject to production functions, which are structured by a series of CES “nesting” assumptions.

Figure 5 shows TERM-BR’s production structure for a representative industry and region. At the top level, inputs of a goods composite and a primary factor composite are demanded in proportion to output (Leontief assumption). The primary factor aggregate is a CES composite of capital, land, and a labor aggregate – the latter being itself a CES composite of different labor types. The composite goods are a CES combination of imported and domestic goods, according to Armington assumption, which establishes that goods from different sources are considered imperfect substitutes.

Again, total demand of each region are a CES combination of goods from different regions. The final demand is represented by government, households, firms, rest of the world, and has similar nesting assumptions. Land supply showed in Figure 5 will be detailed further.

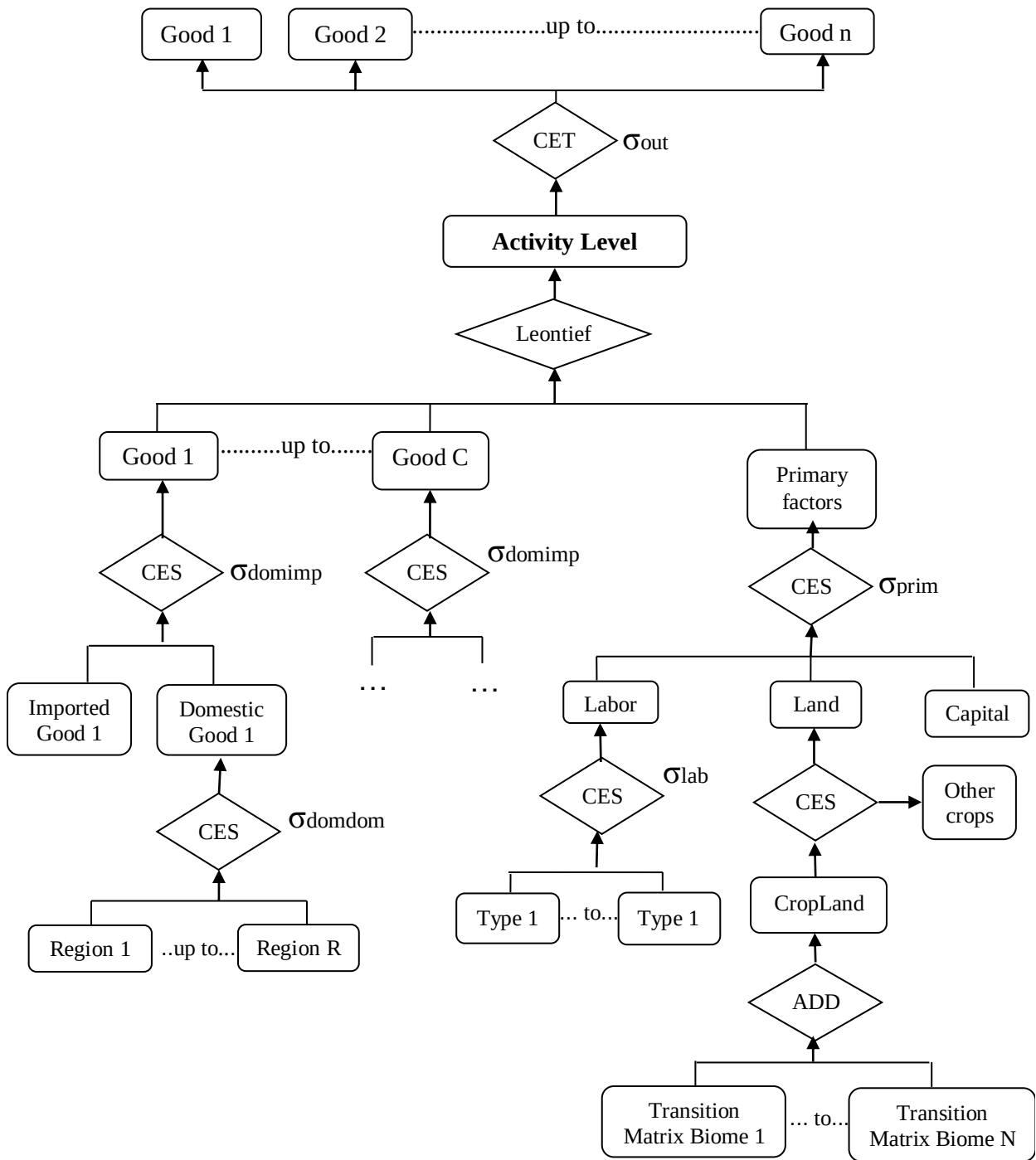


Figure 5 - TERM-BR production nesting structure.

Source: Adapted from Horridge (2012).

3.3 TERM-BR sourcing mechanisms

Figure 6 describes several nests representing all substitution possibilities permitted by the model. The dashed rectangles, on the left-hand side, show (in lowercase) the value of the flows associated with each level of the nested system. In addition, in the same dashed rectangles the lowercase represents price variables ($p_{...}$) and quantity ($q_{...}$) associated with each flow. The dimensions of those variables are indicated by subscripts c, s, m, r, and d, as shown in Table 1.

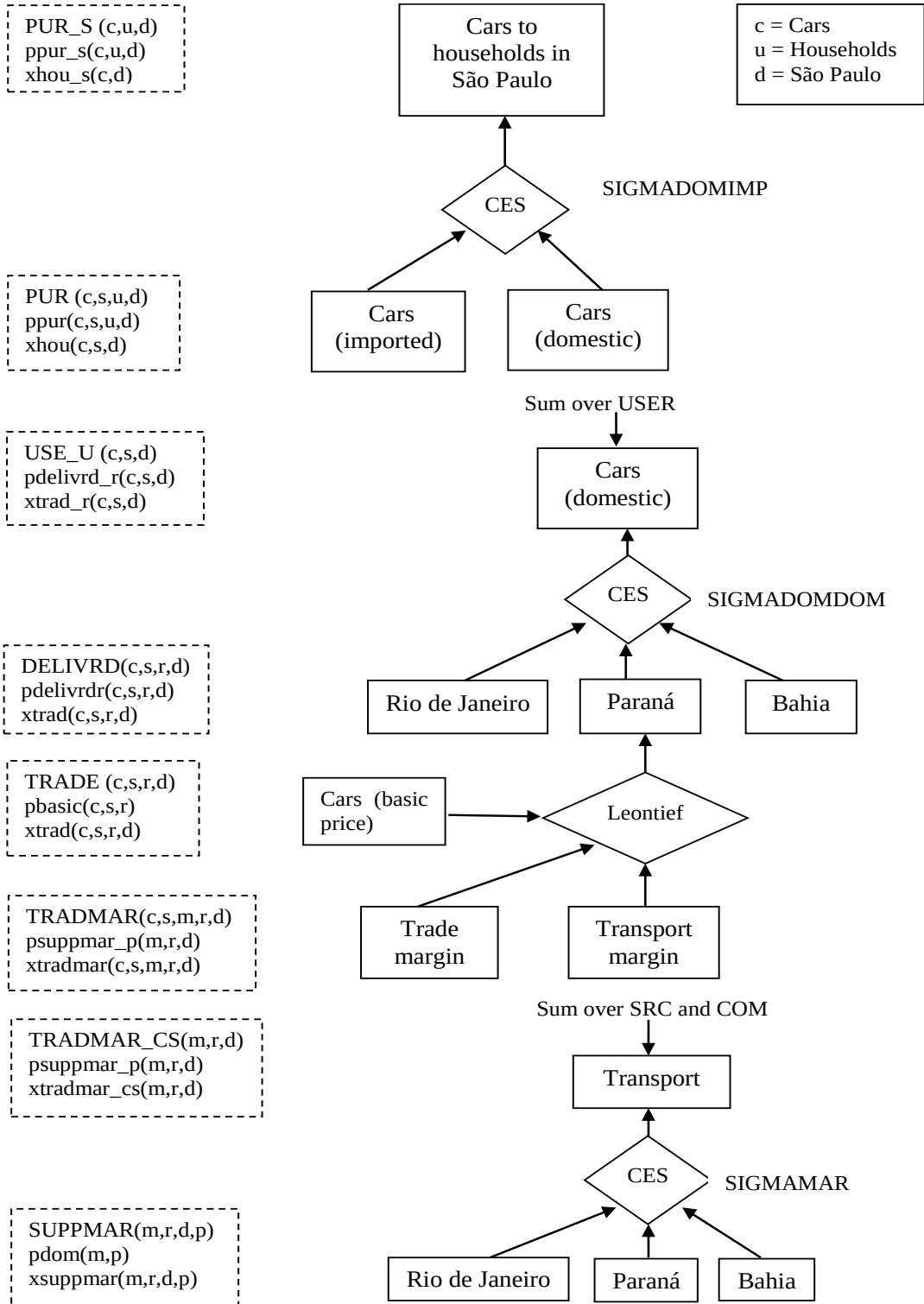


Figure 6 - TERM-BR sourcing mechanisms

Source: Adapted from Horridge (2012).

At the first level, at the top of the structure, households choose between imported or domestic cars, which is a choice described by a CES specification, with an Armington elasticity that governs the substitution between domestic and imported cars. At this level of the demand structure, flows can be obtained through the PUR_S (c, u, d), which is expressed in terms of purchaser prices. Its values are obtained adding the PUR matrix over (s), which in turn results from the sum between the USE and TAX matrices.

Domestic cars are in turn a composite of the output from the region of origin, in this case Rio de Janeiro, Paraná, and Bahia. Such production is governed by a CES function, which allows the substitution of goods with high relative costs (basic value + margins) for goods (cars) from the region of origin, but with a lower relative cost. Therefore, variations in basic values or margins change the share of the region of origin (supplier) in the market under consideration.

At the third level, cars demanded by Paraná state are an aggregation of the output at basic prices (TRADE matrix) and margins (TRADMAR matrix). Therefore, the Leontief function combines those elements, so that the transportation cost has a higher weight for remote regions (FACHINELLO, 2008).

The last level of the structure shows that trade margins are produced in the region of origin, while transportation margins can be produced in both origin and destination regions. As a result, possibilities of substituting margins is represented by a CES function, which allows for changes in margins according to the region under consideration.

3.4 Land-use change and GHG emissions module

Land-use changes and forests are treated endogenously through a transition matrix approach, which was calibrated with data from the Brazilian Agricultural Censuses carried out in 1995/96 and 2006. The transition matrix shows the land use dynamic in a specific region (r) at two points in time – initial (i) and final (f). In Table 2, there are four land use categories: crop (cr), pasture (pt), plantforest (pt), and unused land (un). The latter represents all areas not being used for agricultural purposes, such as forests, grasslands, urban areas, rivers, lakes, and reservoirs, among others. In other words, the “unused” category represents areas of native vegetation and works as a proxy for evaluating deforestation.

Table 2 - Transition matrix for region r.

<i>LAND USE</i> (p, q)	<i>CROP</i> _{f}	<i>PASTURE</i> _{f}	<i>PLANTFOREST</i> _{f}	<i>UNUSED</i> _{f}	<i>TOTAL</i> _{f}
<i>CROP</i> _{i}	$(cr, cr)_{i,f}$	...	...	$(cr, un)_{i,f}$	$\sum_f (p, cr)_i$
<i>PASTURE</i> _{i}	...	$(pt, pt)_{i,f}$	...	...	...
<i>PLANTFOREST</i> _{i}	...	...	$(pf, pf)_{i,f}$	...	...
<i>UNUSED</i> _{i}	$(un, cr)_{i,f}$	...	...	$(un, un)_{i,f}$	...
<i>TOTAL</i> _{i}	$\sum_i (cr, q)_{i,f}$	...	...	...	$\sum_i \sum_f (p, q)$

Source: Prepared by the author.

The elements of the main diagonal represent land use that remains in the same category, while the off-diagonal elements represent land conversion between the four land categories under consideration. For example, $(pt, cr)_{i,f}$ corresponds to the amount of pastures (pt) in the initial period (i) converted into crops (cr) in the final period (f). Moreover, summing over the column (total) shows the total for each category in the initial period, whilst summing over lines ($TOTAL_i$) shows the total in the final period. The transition matrix can be expressed in share form, as in Ferreira Filho and Horridge (2012, 2014). This was done employing Markov probabilities, which are modeled as a function of land rent values, as shown by Equation 1.

$$S_{pqr} = \mu_{pr} \cdot L_{pqr} \cdot P_{qr}^\alpha \cdot M_{qr} \quad (1)$$

where:

S_{pqr} = share of land type p that becomes type q in region “r”;

μ_{pq} = a slack variable, adjusting to ensure that $\sum_q S_{pqr} = 1$;

L_{pqr} = a constant of calibration = initial value of S_{pqr} ;

P_{qr}^α = average unit rent earned by land type q;

α = a sensitivity parameter, with value is set to 0.28;

M_{qr} = a shift variable, initial value 1.

The parameter of sensibility “ α ” was set at 0.28 in order to approach a Normal representation. Therefore, if land rents of crop areas increase, the rate of conversion of pastures into crops will also increase. Furthermore, for representing the rate of conversion of the “Unused” category into other uses, a fictitious rent was employed that is based on a regional CPI (FERREIRA FILHO AND HORRIDGE, 2014).

In this version of TERM-BR, land-use changes and forests, as well as their GHG emissions, are based on observed data. Such representation also employs transition matrices, but calibrated with satellite imagery provided by the Brazilian National Institute for Space Research.

The new transition matrices also made progress, as compared to the former version, in incorporating a new dimension in the TERM-BR model, that of the Brazilian biomes, namely, the Amazon (rainforest), Cerrado (savannah), Atlantic Forest (tropical forest), Pantanal (wetlands), Caatinga (semi-arid), and Pampa (grasslands) regions, as show in Figure 7.



Figure 7 - Brazilian biomes.

Source: Adapted from IBGE (2014b).

The biomes capture the heterogeneity associated with different types of soil, weather and carbon content, resembling the idea of the AEZs developed by the GTAP⁷. Besides, those differentials of soil, vegetation and weather are represented accurately by biomes, as compared to the counterpart structures widely used for studying physical aspects related to land-use changes.

In the new production structure of TERM-BR, land supply are driven by transition matrices, which are summed over biomes, to determine in each state and year the total area of each land use category, namely, Crop, Pasture, PlantForest, and Unused. Then, the resulting total area is allocated among crops, livestock activities according to the CET-like rule:

$$A_{jr} = \lambda_r \cdot K_{jr} \cdot R_{jr}^{0.5}$$

where A_{jr} is the area of crop land in region r used for industry j , and $R_{jr}^{0.5}$ is the unit of land rent earned by industry j . K_{jr} is a constant of calibration, while a slack variable λ_r adjusts so that:

$$\sum_j A_{jr} = A_r = \text{pre-determined area of cropland.}$$

Such strategy is also used to distribute Pasture areas between Beef and Dairy uses, while Forestry has only one use. Besides, the model considers a land use category, called Unused, which represents all areas not used in agriculture, like native forests, urban areas, grasslands, reservoirs, lakes and roads. Thus, changes in Unused are considered as a proxy for deforestation.

Finally, the resulting model captures differentials of GHG emissions associated with the same land use category, but in distinct biomes. For example, the conversion of unused areas into pastures, which releases more carbon dioxide in the Amazon than in the Cerrado biome.

3.4.1 Data strategy

The new version of the TERM-BR model with a module based on new information about land use and emissions was developed in two steps. First, it was built from transition

⁷ More details in Lee (2004).

matrices by Brazilian biome and state. At this stage, it used satellite images, as noted before, which were disaggregated into polygons, biomes, municipalities, and GHG emissions for the whole country⁸.

The first version of the transition matrices follows the format shown in the Second Brazilian Inventory of Anthropogenic Emissions by Sources and Removals by Sinks of Greenhouse Gases (Brasil, 2010), with the exception of the regional dimension⁹. However, initially the Brazilian states were explicitly represented to meet the CGE model demands and research concerns related to the implementation of regional policies.

At the second stage, the transition matrices built by state and biome were aggregated again under the set CAT, which considers 15 land use categories (Non-managed forests, Managed forests, Secondary forests, Forests with selective timber extraction, Reforestation, Non-managed fields, Managed fields, Field with secondary vegetation, Planted pastures, Crops, Urban areas, Rivers and lakes, Reservoirs, Other uses, and Non classified areas). These 15 land use categories were aggregated into 4 broader categories (Crop, Pasture, Plantforest and Unused) under a new set, the ALNDTYPE set.

The number of land use categories of the former model remains, but as noted before a new dimension biome was created to capture the heterogeneity of land use and GHG emissions between different regions (r) of the country. Besides, land-use change was traced to its GHG emissions and the transition matrices can be interpreted as a hypothetical example:

- TRANS0 (“Non-managed forest”, “Pasture”, “MtGrosso”, “Amazon”) = 100 hectares of non-managed forests in the initial period converted into pasture in the final period in the Amazon Biome in Mato Grosso state;
- EMIS0 (“Non-managed forest”, “Pasture”, “MtGrosso”, “Amazon”) = 100 hectares of Non-managed forest converted into Pastures in the state of Mato Grosso in the Amazon Biome emit 100 gigagrams of carbon dioxide equivalent (CO₂ eq.);
- YTRANS2 (“Unused”, “Crop”, “Bahia”, “Cerrado”) = 50 hectares of Unused areas in the initial period converted into crops in the Cerrado Biome of Bahia state.

⁸ For more details see Brasil (2010).

⁹ The initial transition matrix is shown in Table 20, in the Appendix A.

Figure 8 shows the procedure adopted for building the module of land-use change and GHG emissions. The initial area matrix (TRANS0), after being aggregated into 4 broad categories, was annualized (YTRAN) following the model's temporal structure.

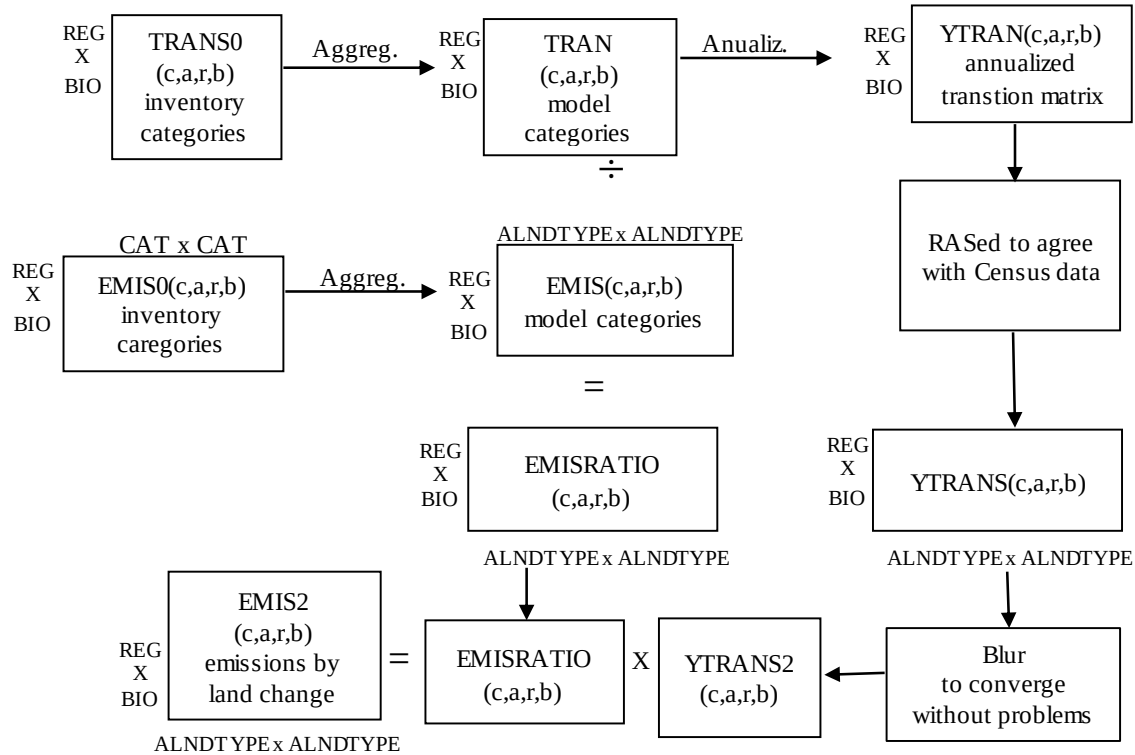


Figure 8- Treatment of data on land-use change and emissions.

Source: Prepared by the author.

The RAS¹⁰ mathematical method was then applied to the resulting transition matrix to ensure that the totals matched the data from the Brazilian Agricultural Census. Thus, any area discrepancies between different data sources were solved. As a result, the new transition matrices were assigned to GHG emissions, considering each land use category. Then, the emissions by hectare ratio (EMISRATIO) was applied to area data (YTRANS2) and the amount of GHG was obtained for each land use category, according to the biome and region under consideration.

¹⁰ For more details about RAS method, see United Nations (1999).

At the end of the stages described above, a new model suitable for handling land use and its GHG emissions endogenously emerged. Consequently, land (re)allocation was promoted through the four broad categories and transition matrices according to the biome and region, governed by a constant elasticity of transformation (CET) function.

Table 3 shows GHG emissions distributed by biome and land use category. In the initial database, cattle farming is the main emitter of GHG in Brazil, especially in the Amazon and Cerrado regions, which is a major indication of the locus of domestic emissions and of key activities for curbing the ongoing deforestation process in Brazil.

Table 3 - Emissions of converting Unused lands in other uses, by Biome, in gigagrams of carbon dioxide (initial database).

Land use	Amazon	Cerrado	Caatinga	MAatlantica	Pampa	Pantanal	Total
1 Crop	118799	146693	23509	4481	0.0	1383	294866
2 Pasture	891264	165451	27913	91285	1.0	11829	1187743
3 PlantForest	1337	2076	-25	289	0.0	0.0	3678
4 UNUSED	-173462	-14652	-4770	2427	-122	-366	-190945
Total	837939	299569	46627	98481	-121	12847	1295342

Source: Model's database.

Therefore, the TERM-BR model can analyze patterns of occupation of the Brazilian territory considering the main economic activities in each sub-region and the expansion of the agricultural frontier, associating them to GHG emissions. Furthermore, the model can indicate alternatives for the Brazilian agriculture in terms of reallocating economic activities with the aim of increasing agricultural production and reducing deforestation and GHG emissions.

4 SCENARIOS

This essay evaluates the economic impacts of halting deforestation in the Amazon Biome and its consequences in terms of GHG emissions in Brazil in the 2005-2035 period. This policy goes beyond the targets of the PPCDAm, which established reducing deforestation in the Legal Amazon region by 80% by 2020, in relation to the average recorded in 1996-2005, as noted before. Such policy, although extreme, is feasible, since the clearing

of new areas has been successfully curbed in Brazil over the past few years. Furthermore, it matches the goals of the New York Declaration on Forests, agreed in the United Nations Climate Summit 2014.

In summary, the simulations have the following structure:

- **Baseline:** 2005 is the starting point, and year of the most recent Brazilian Input-Output table. However, model's database was updated up to 2012, with observed data (historical simulation) to capture macroeconomic changes during 2005-2012. For 2013-2035, base simulation assumes moderate economic growth, around 3% per year, and follows population growth rates from the IBGE. For land allocation, after the historical period, the model was calibrated according to the rate of deforestation observed for 2009-2013 by the PRODES monitoring project. Besides, land-augmenting technical change was set to 1 p.a. Thus, the transition matrix will lead the land allocation, considering the recent rates of deforestation.
- **Policy:** simulations follow the previous scenario up to 2014. For 2015-2035, a zero percent variation was imposed on the "Unused" category (which represents native vegetation areas) in the agricultural frontier of the Amazon Biome. Therefore, a scenario was considered wherein the supply of new land in that biome is suspended, with crops, pastures, and reforestation activities continuing to grow across the country.

4.1 Model closure

The main features of the model's closure are:

- Real wage change drives the movement of labor between regions and activities (but not between labor categories). Total labor supply increases, according to official projections from IBGE.
- Capital accumulates between periods following the dynamic investment rule. Furthermore, the capital stock is updated based on the new capital price, i.e. the start-of-period price.

- Regional consumption is linked to regional wage income and to national household consumption. Moreover, regional real government spending demand follows regional real household demand.
- The national GDP price index is chosen as the fixed *numeraire* price. Other prices should thus be interpreted as relative to the GDP price index.
- The national balance of trade is a percentage of real GDP. Thus, in the long run that account is close to zero.
- The regions of the model were divided into two groups: Land-constrained (LndUsed, where agricultural land is consolidated) and Frontier (region where there is land available for expanding agriculture), as shown in Figure 9. Thus, the regions where deforestation is growing will be easily identified, so that specific policies can be applied to just those regions.



Figure 9 - Frontier (green) and Land-constrained (yellow) regions of the model.

Source: Prepared by the author.

5 RESULTS

The policy of zero deforestation in the Amazon Biome means imposing a constraint on the land supply for the Brazilian economy. Hence, major macroeconomic variables such as consumption, investment, and government spending follow the performance of GDP, which decreased in relation to the baseline, as shown in Figure 10.

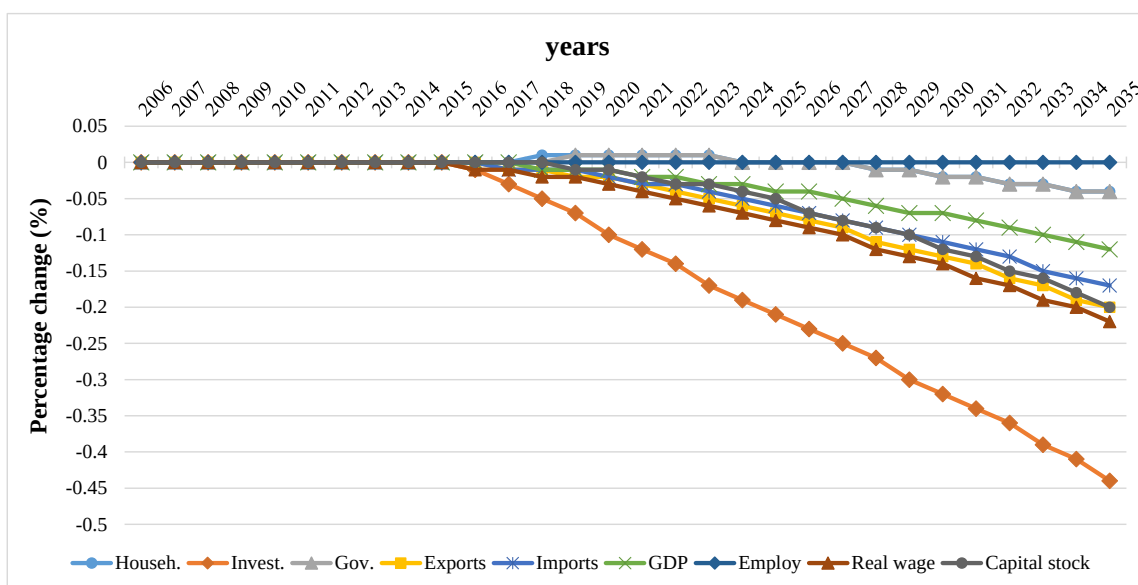


Figure 10 - Annual growth rates of major macro variables in real values in 2005-2035 (cumulative % growth).

Source: Model results.

In 2005-2035, GDP grew by 0.06% in relation to the reference scenario, while consumption, investment, and capital stock grew by -0.05%, -0.07%, and -0.1%, respectively, over the same period. The shock applied imposed a land restriction, as noted before, which increased production costs and reduced the rate of return and investment. The impact on capital stock was in turn sluggish, since this variable is somewhat rigid in the short run, but over time it incorporates the effects of reductions in investment.

Furthermore, it is worth mentioning that despite a worse macroeconomic scenario, the negative impact of zero deforestation in the Amazon Biome on GDP, consumption, and investment levels was relatively modest, which is a major result of this policy.

In regional terms, the effects of the policy, as expected, enhanced inequalities between Brazil's mid-west and north regions due to the high costs imposed on the latter, which is located within the Amazon Biome, as shown in Figure 11.

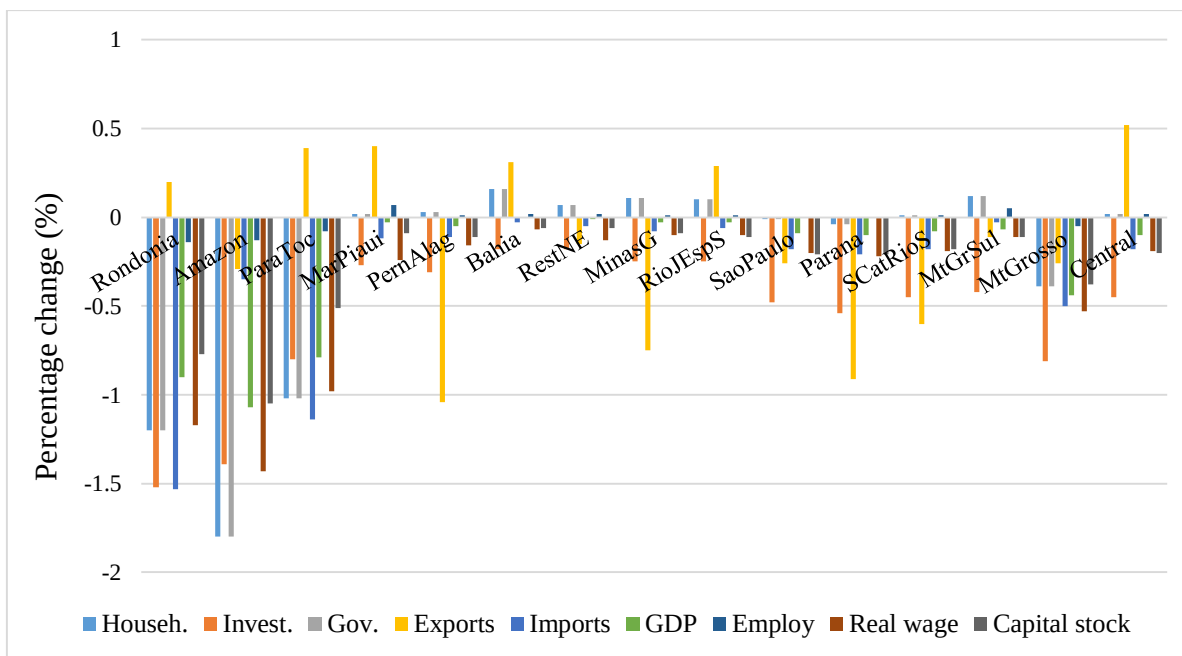


Figure 11 - Policy deviations: growth rates of the main macro variables by region in real values cumulated in 2035 (percentage change).

Source: Model results.

In Rondônia, ParaToc (Pará and Tocantins), and MtGrosso (Mato Grosso) states, regional GDP dropped by -0.35%, -0.25%, and -0.28%, respectively, over the 2005-2035 period. In other regions, such as in RestNE (rest of the Northeast), MinasG (Minas Gerais), and Paraná, GDP dropped less, as expected. However, MarPiaui (Maranhão and Piauí) and Bahia state benefited from the policy, as these states still have land available for expanding agriculture, especially in the Cerrado Biome.

Economic performance in terms of production also highlights the negative effects of the policy in the agricultural frontier in the Amazon Biome, as shown in Table 4. In Mato Grosso, for example, the cumulative production growth of soybean, maize, and beef cattle in 2005-2035 amounted to -0.98%, -0.69%, and -1.80%, respectively. Similarly, in Pará and

Tocantins, the production of agricultural commodities decreased as a result of the constraints imposed on land supply.

Table 4 - Agricultural output, cumulative ordinary change in 2035 (deviations from the baseline).

agricxtot	Frontier-regions					
	Amazon	Rondonia	ParaToc	MarPiaui	Bahia	MtGrosso
Rice	-43.15	-9.02	-10.48	-0.43	0.87	-0.93
Corn	-27.41	-5.6	-4.9	-0.03	0.22	-1.23
Wheat	-23.71	-4.85	-4.08	-0.67	-0.42	-0.88
Sugarcane	-14.83	-2.1	-1.06	-0.33	-0.6	-0.09
Soybean	-36.15	-6.33	-8.12	-1.03	-0.19	-1.23
Other agric	-22.46	-0.11	-2.55	0.28	0.01	-0.34
Cassava	-29.56	-0.85	-2.91	3.29	2.52	2.29
Tobacco	-26.95	-5.15	-6.67	-0.94	-0.2	-0.91
Cotton	-26.11	-3.49	-4.63	-0.39	-0.08	-0.61
Citrus fruits	-29.82	-1.53	-4.95	0.57	0.15	-0.36
Coffee	-32.7	-5.5	-6.78	-0.91	-0.33	-0.91
Forestry	-19.66	-0.06	-6.09	-1.19	0.47	-0.62
Meat cattle	-42.61	-3.17	-7.3	1.36	2.25	-0.74
Milk cattle	-41.65	-3.22	-8.33	-0.73	-0.36	-1.49

Source: Model results.

In the states of Bahia, Maranhão, and Piauí, production decreased less due to the characteristics of those frontier regions. Bahia, for example, is not located in the Amazon Biome and therefore it is not directly affected by the impacts of deforestation control, meaning that agriculture can expand into Cerrado areas. In the latter two regions, the drop in production was balanced by production growth in land located in other biomes, especially in the Cerrado Biome.

In the rest of the country, there was a reduction in traditional crops, such as in coffee, wheat, and sugar cane crops, at the same time that rice, soybean (in São Paulo and Paraná), and beef cattle production grew in other regions, as shown in Table 5.

Table 5 - Agricultural output, cumulative ordinary change in 2035 (deviations from the baseline).

Agricxtot	Land-constrained regions								
	Central	Pern Alag	RestNE	MtGr Sul	MinasG	RioJ EspS	Sao Paulo	Parana	SCat RioS
Rice	0.59	0.87	0.64	0.44	0.71	0.29	1.11	0.95	0.33
Corn	-0.32	-0.1	-0.08	-0.08	-0.21	-0.57	-0.19	-0.11	-0.3
Wheat	-0.12	-0.17	-0.42	-0.32	-0.24	-0.49	0.15	0.01	-0.23
Sugarcane	-0.14	-0.45	-0.36	-0.44	-0.28	-0.59	-0.18	-0.35	-0.52
Soybean	-0.23	-0.16	-0.35	-0.35	-0.09	-0.52	0.19	0.04	-0.23
Other agric	0.19	-0.03	-0.04	0.16	-0.03	-0.39	0.17	0.11	0.03
Cassava	5	1.63	1.89	5.32	3.46	2.4	3.2	2.65	3.14
Tobacco	-0.01	-0.19	-0.27	-0.12	-0.17	-0.39	0.3	0.22	-0.05
Cotton	0.26	0.06	-0.06	0.15	0.12	-0.16	0.47	0.58	0.27
Citrus fruits	0.56	0.16	0.12	0.42	0.01	-0.43	0	0.15	-0.15
Coffee	-0.13	-0.28	-0.38	-0.18	-0.2	-0.5	0.16	0.12	-0.21
Forestry	0.18	0.57	0.29	0.44	0.24	0.22	0.45	0.31	0.21
Meat cattle	1.81	1.7	1.59	1.69	2.39	3.26	2.61	3.19	2.69
Milk cattle	-0.11	0.37	0.28	0.1	0.32	-0.12	-0.45	-0.5	-0.38

Source: Model results.

Therefore, it is worth highlighting the performance of the forestry sector, as well as the boost in agriculture in São Paulo and Paraná. These states were benefited from constraints imposed on the agricultural frontier and stepped up their production, except in their citrus and sugar cane crops. The former was substituted by other cultures, while the latter are being displaced to the mid-west region (Central, Mato Grosso do Sul, and Mato Grosso), particularly to Cerrado areas.

The constraints imposed on land supply, as well as the resulting production drop in some of the most important Brazilian crops, adversely affected the prices paid by households, as shown in Figure 12. More specifically, low-income households (POF1-POF5) were forced to pay higher prices, while prices decreased for most medium- and high-income households (POF6-POF10)¹¹. In other words, the policy tends to worsen income distribution. Nonetheless, the magnitude of these price variations was small, since the policy shock was only applied to the Amazon Biome.

¹¹ POF1 ranges from 0 to 2 minimum wages, POF2 from 2+ to 3, POF3 from 3+ to 5, POF4 from 5+ to 6, POF5 from 6-8, POF6 from 8-10, POF7 from 10-15, POF8 from 15-20, POF9 from 20-30, and POF10 above 30 minimum wages. The minimum wage in Brazil in 2005 was around US\$150.00, considering US\$1.00 = R\$ 2.00

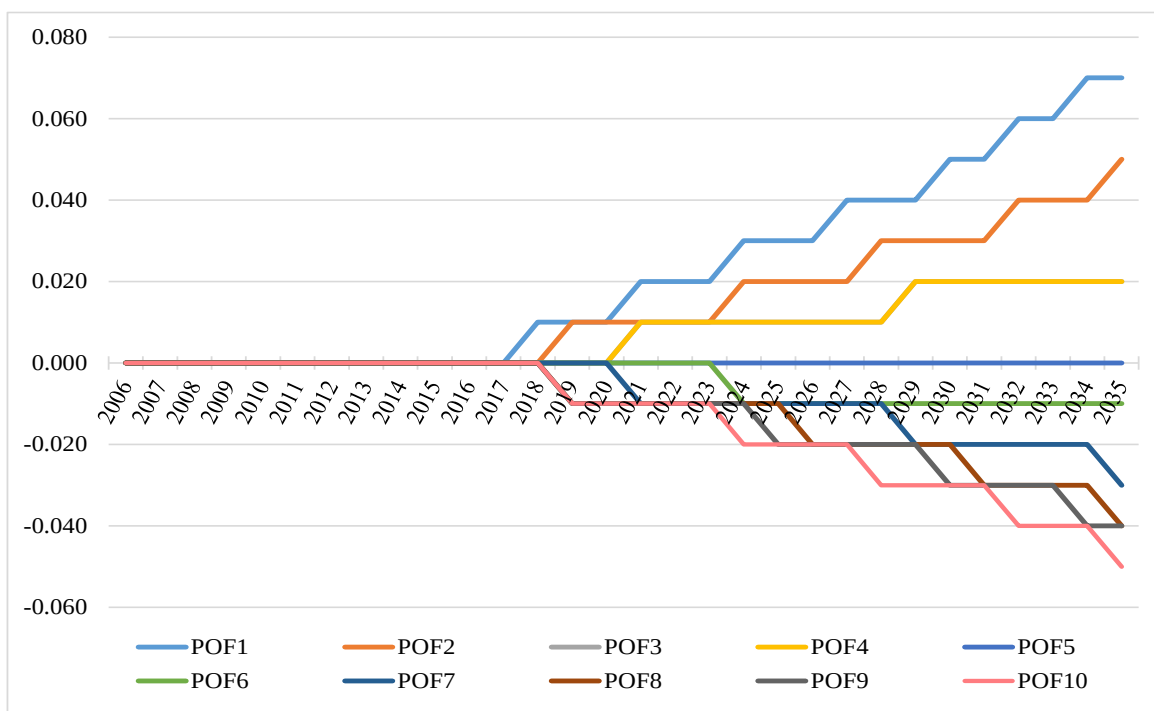


Figure 12 - National CPI by household income, policy deviations, cumulated values in 2005-2035 (in percentage change).

Source: Model results.

Thus, halting land supply in the Amazon Biome tends to shift agricultural production to other Brazilian biomes, as well as deforestation. This process would be important in the Cerrado, Caatinga, and Pantanal biomes, where areas of native vegetation (Unused) may decrease in 2035 by -0.49%, -0.24%, and -0.51%, respectively, as shown in Figure 13.

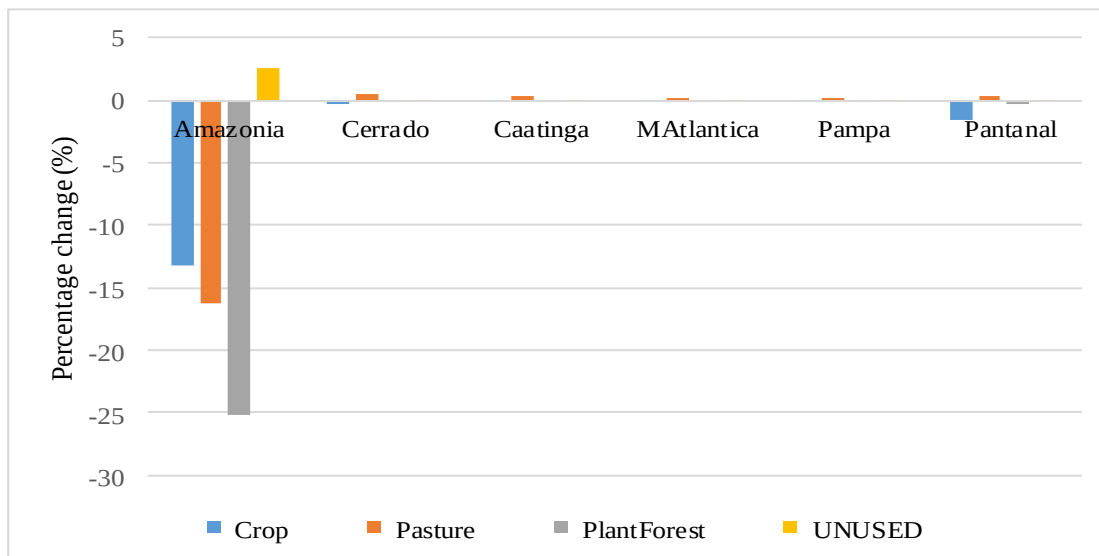


Figure 13 - Policy deviations of land-use change, by categories in the Brazilian biomes, cumulated values in 2035 (percentage change).

Source: Model results.

Deforestation can also be noticed by observing the growth of pasturelands, the predominant land use category in Brazil after clearing of forests. In the Amazon region (Frontier), the slowdown observed in the growth of crops, pastures, and forestry, by assumption, results of freezing land supply.

The role of livestock, as the main agent of deforestation, is highlighted by the simultaneous reduction in pasturelands and the increase in “Unused” areas, as shown in Figure 14. Therefore, the constraints to convert areas of native vegetation into other uses in the Amazon region would cause a reduction in areas occupied by crops, pastures, and forestry by -1.28 million of hectares (Mha), -7.3 Mha, and -0.05 Mha, respectively, cumulatively in 2005-2035. When aggregated, these results correspond to the total “Unused” area preserved by the policy.

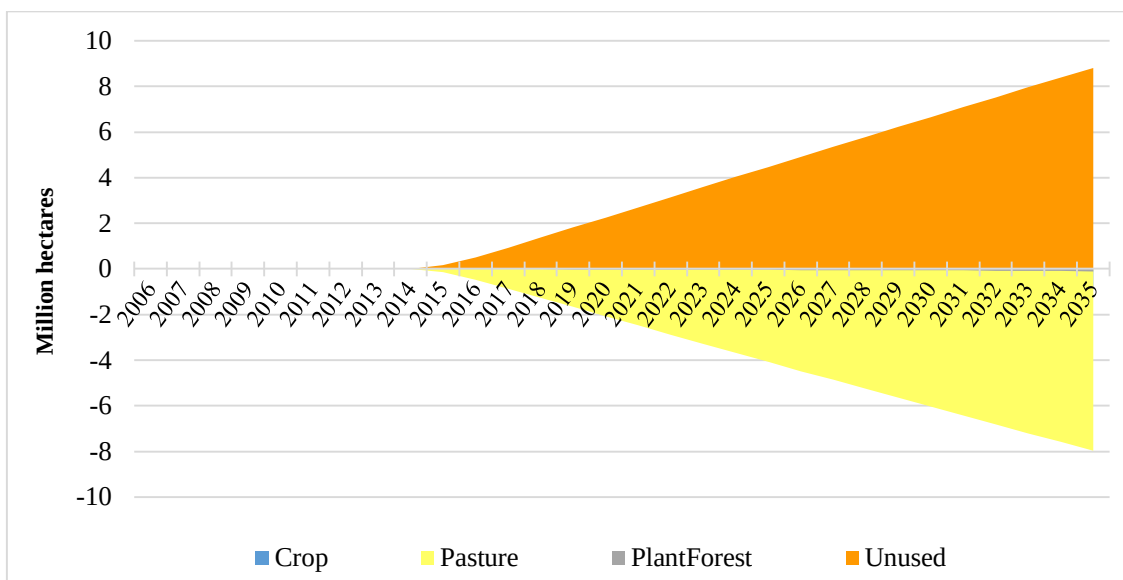


Figure 14 - Policy deviations: land areas, cumulative ordinary change during 2005-2035 (Million hectares).

Source: Model results.

Furthermore, land conversion into pastures constitutes the main source of GHG emissions among all land use categories in Brazil, as noted before. Such emissions have been higher in the Amazon Biome, because of its greater concentration of carbon above and below the soil. These emissions are followed by those from the Cerrado Biome, released from agriculture, which grew throughout this region over the last decades (Table 6).

Table 6 - Emissions by Brazilian biome, policy deviation cumulated in 2035 (Net gigagrams of CO₂e).

delucemit_d	Amazon	Cerrado	Caatinga	Atlantic Forest	Pampa	Pantanal	Total
Crop	-9,195.99	-106.96	-14.59	-27.82	-0.04	-14.27	-9,359.67
Pasture	-148,207.03	1,173.41	153.32	280.53	-0.01	94.47	-146,505.31
PlantForest	-11.38	4.92	0.09	9.46	0.02	0	3.11
UNUSED	5,220.41	-443.19	-3.18	-82.24	-0.37	-23.81	4,667.62
Total	-152,193.99	628.18	135.64	179.93	-0.4	56.39	-151,194.25

Source: Model results.

Table 6 shows how important designing specific policies for the Amazon Biome can be, since in the simulation, even after a net reduction of 152,193.99 gigagrams of carbon dioxide equivalent (Gg. of CO₂e) cumulated in 2035, such biome still accounts for 68.9% of all domestic emissions from land-use change. In other words, this percentage means 299,379.22 Gg. of CO₂e in the final period, 2035. The Cerrado region, in turn, after its net emissions rose by 628.18 Gg. of CO₂e, (cumulated value in 2035), accounts for 19.6% of all domestic emissions or for 85,133.34 Gg. of CO₂ eq. in 2035.

The shift in emissions from the Amazon to other biomes is an expected result of halting deforestation in the former. The policy triggers this shift in emissions from the Amazon to the Cerrado region as a result of the shift in land use change from the former to the latter, and in response to the land constraints imposed on the Amazon region. Among the factors explaining those shifts, a major one is the proximity between these biomes, which facilitates the spillover of productive activities between them.

Figure 15 shows the effectiveness of a zero deforestation policy in the Amazon Biome in reducing domestic GHG emissions, especially those from the conversion of land into crops and pasture. Emissions from such converted land would amount to -419,066.8 Gg. of CO₂e and 3,097,291 Gg. of CO₂e cumulatively in the 2005-2035 period, respectively.

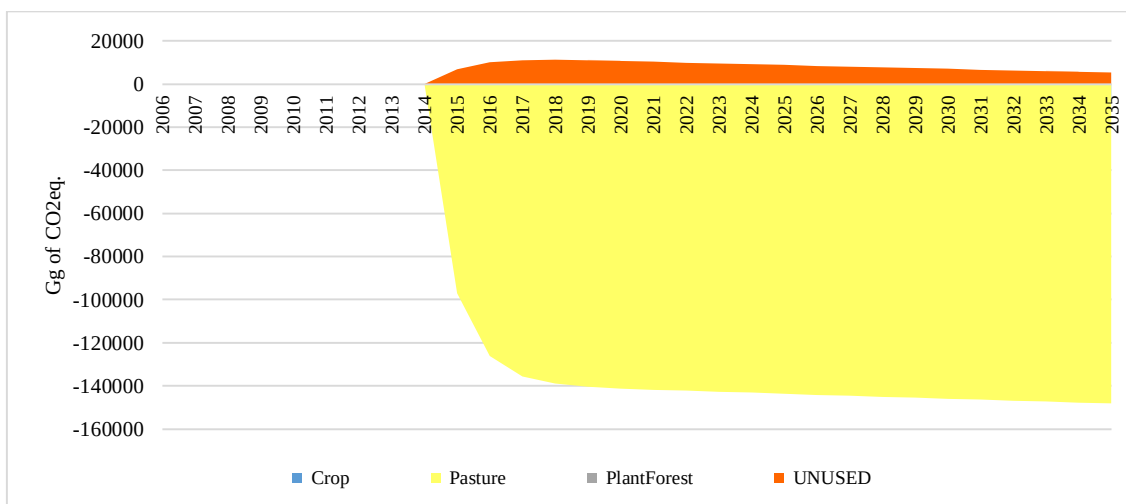


Figure 15 - Policy deviations of emissions from land use categories in the Amazon Biome, during 2005-2035 (net gigagrams of CO₂e. - cumulative).

Source: Model results.

Figure 16 shows in turn the evolution of GHG emissions in the Cerrado Biome. In the 2005-2035 period, the amount emitted as a result of land being converted into crops and pastures can increase by 10,831.38 Gg. of CO₂ eq. and 82,811.63 Gg. of CO₂ eq., respectively. This growth indicates the shifting of livestock toward Cerrado areas, as a result of the constraints imposed on the Amazon Biome, as noted before. However, it is worth noticing that the growth in cattle farming observed in the Cerrado region occurred at the expense of crops and unused areas/emissions.

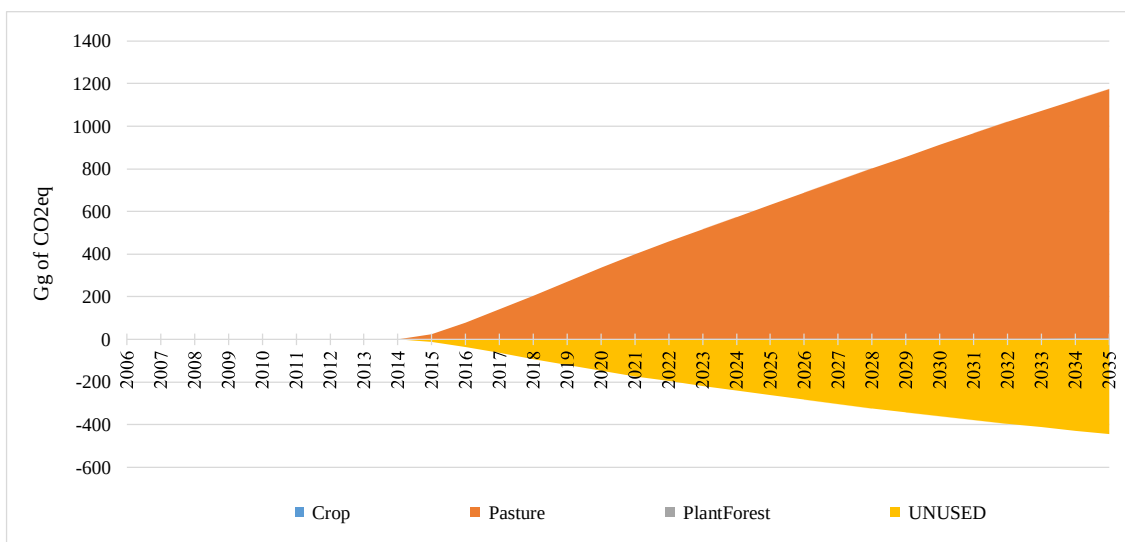


Figure 16 - Emissions from land use categories in the Cerrado Biome, policy deviations during 2005-2035 (net gigagrams of CO₂e - cumulative).

Source: Model results.

The growth in emissions in the Cerrado region did not undermine gains in terms of GHG reductions achieved in the Amazon Biome. However, the other Brazilian biomes must be contemplated by the same policies as an alternative to controlling possible leaks of emissions and the spillover of deforestation agents such as livestock.

Table 7 shows the effectiveness of the policy to curb domestic GHG emissions. The amount of gases related to land-use change (LUC) released from Brazil was reduced by almost half, from 1,329.081 Gg. of CO₂ eq. to 987,647 Gg. of CO₂ eq. in 2035, the last year under consideration. In other words, the share of LUC emissions would drop from 62.7% in 2005 to 12.9 % in 2035.

Table 7 - Total emissions and their shares, by source in the initial and final periods.

EMIT	2005		2035	
	Gg. CO2 eq.	Share	Gg. CO2 eq.	Share
Mining	113,664.96	0.054	316,008.56	0.144
Gasoline	32,705.03	0.015	105,256.84	0.048
Gasohol	9,448.62	0.004	28,070.30	0.013
Combustible oil	139,590.80	0.066	311,670.69	0.142
Petrochemicals	15,363.88	0.007	34,627.34	0.016
Activity	479,532.75	0.226	1,116,393.50	0.509
LUC	1,329,081.13	0.627	282,877.31	0.129
TOTAL	2,119,387.15	1.000	2,194,904.54	1.000

Source: Model database (2005) and results (2035).

When the main target is reduce GHG emissions, the deforestation in other Brazilian biomes should not be neglected, especially emissions from cattle farming. Notwithstanding the effectiveness of zero deforestation in the Amazon in reducing domestic emissions, these gains would be amplified by, for example, including the Cerrado Biome, which was affected by the policy's spillover effect.

In addition, reduction in emissions from land-use change were partially offset by those from fuels and other activities. The increase in the latter is due to the reallocation of factors in the economy, which adapted itself to the constraints. Besides, non-land intensive sectors may increase their production and, consequently, GHG emissions, such as the fuel, mining, and transportation industries, among others.

Finally, the balance of freezing deforestation in the Amazon Biome, albeit positive in respect of deforestation and emission reduction, failed to produce positive results for the economy. Besides, the zero deforestation policy designed for the Amazon region alone was not capable of fully halting deforestation and its GHG emissions and neither of protecting the economy from its adverse consequences. Alternative policies should therefore be considered in connection with, for example, productivity gains in agriculture, which can generate a land saving effect combining environmental preservation and production, with positive implications for food security and the economy as a whole.

FINAL REMARKS

This study analyzed the economic consequences of zero deforestation in the Amazon Biome in Brazil. Albeit this is an extreme case, the Brazilian government has ambitious targets to reduce deforestation and has made progress in achieving them. The step forward taken through an extreme case in this essay provides important insights into the dynamic of deforestation and, consequently, of its GHG emissions, which were displaced to other Brazilian regions and biomes, which

Deforestation control in the Amazon Biome can effectively reduce domestic GHG emissions; however, leaks of deforestation and emissions to other regions and biomes can compromise the gains achieved. Such leaks or movements have another important implication, namely, that of increasing regional inequalities. The policy applied intensified asymmetries between Brazilian regions, especially between the mid-west and all the other regions, since in the former the negative impacts on the regional GDP, consumption levels, and employment, among other variables, were more pronounced, as expected.

The gains of halting deforestation in the Amazon Biome would be amplified by, for example, including the Cerrado Biome, which was affected by the policy's spillover effect triggered by available lands close to the former (border) region. The increase of fuels and activities emissions also would offset policy gains, in terms of emissions. Such increase, would be caused by factors reallocation in the economy, which adapted itself to the constraints. Besides, non-land intensive sectors would increase their production and, consequently, GHG emissions, such as the fuel, mining, and transportation industries, among others.

In addition, this essay draws attention to the importance of specific policies for the different Brazilian regions, as the costs and benefits of these policies vary considerably and, as a result, they can impose more constraints on less developed regions and on important sectors such as agriculture, but with no effects on deforestation and GHG emissions.

The specialized literature considered productivity gains in agriculture as an important alternative for reducing the demand for new land for farming and, consequently, for reducing deforestation. However, the consequences of productivity gains in agriculture

for the Brazilian economy, land allocation, and GHG emissions are still not accurately known and, therefore, constitute an important field for future research.

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