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Economic analysis of deforestation reduction in Brazil

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Brazil has committed itself to reduce its greenhouse gas (GHG) emissions by 36.1% and 38.9% compared to projected emissions for 2020. In order to accomplish this, the deforestation in the Amazon will have to be reduced by 80% and in the savannah region (Cerrado) by 40% by that year. Concurrently, Brazil is the country with the greatest potential to increase its agricultural production and contribute to the challenge of feeding an increasing world population. Moreover, agribusiness is a key sector of the Brazilian economy for income generation and promotion of foreign exchange. This article discusses the economic impact of a restrictive policy of deforestation on the agricultural and livestock sector and the national economy using a computable general equilibrium model. The results point to low losses in GDP from the limited deforestation scenario as compared with the baseline, but non negligible impacts in the agricultural, livestock and food sector.

Keywords: Deforestation, Land use changes, Agriculture and livestock, General equilibrium.

JEL codes: Q15, O13, D58.

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1. Introduction

The global warming is one of the most alarming phenomena of environmental degradation. Increasing greenhouse gases (GHGs) concentration raises atmospheric and oceanic temperatures and changes the circulation of wind and weather patterns. Estimates of the Intergovernmental Panel on Climate Change (IPCC) point to an increase in average atmospheric temperature between 1.1°C and 6.4°C between 1990 and 2100, but the maximum level reached in the last million years was 1ºC (IPCC 2007a; 2007b, 2007c). The activities that most increase the concentration of these gases in the atmosphere is the burning of fossil fuels, deforestation, use of fertilizers with high nitrogen concentration in agriculture, use of refrigerant gases and large amounts of methane produced by cows.

Due to the current scenario, countries that are large GHG emitters are being pressured by international communities to reduce their emissions. In Brazil, much attention is given to the issue of deforestation, a leading cause of carbon dioxide (CO^2). According to the latest Brazilian Emissions Inventory, 77% of CO^2 in 2005 was caused by land use change, which grew 64% compared with 1990 (BRASIL, 2010b). This was due to a high deforestation rate in the Amazon and savannah (*Cerrado*) regions in the past decade. Estimates of the National Space Research Institute (INPE – acronym in Portuguese) of the Program to Calculate Deforestation in the Amazon (Prodes – acronym in Portuguese) indicate that more than 700,000 km^2 have been cleared in the Amazon, which corresponds to 17% of the original forest. Of this total, 183,500 km^2 (about 26%) have been deforested in the last decade. In the *Cerrado*, data from the Monitoring of the *Cerrado* biome program of the Environmental Ministry show that the annual deforestation rate reached 14.18 million km^2 between 2002 and 2008 and 7.63 million km^2 in 2009. Remaining natural areas have decreased from 55.73 % of biome in 2002 to 51.54 % in 2008.

Considering the need to adopt effective measures to mitigate emissions of greenhouse gases and reduce deforestation, the Brazilian government submitted two bills of law, establishing a policy and a national fund for climate change, to Congress. Approved by Law no. 12,187 of December 2009, the National Policy on Climate Change (PNMC – acronym in Portuguese) sets forth the standards for the development of the National Plan on Climate Change, the state plans and other plans such as the Action Plan for Prevention and Control of Deforestation in the Legal Amazon (PPCDAm – acronym in Portuguese) and the Action Plan for the Prevention and Control of Slash-and-Burn in the *Cerrado* (PPCerrado – acronym in Portuguese), all related to climate change (BRASIL , 2009a). Moreover, the country is committed to reducing its emissions between 36.1% and 38.9% as compared with the emissions forecast for 2020. In order to accomplish this, Law no. 12,187 was enacted and regulates that deforestation in the Amazon must be reduced by 80% and in the *Cerrado* by 40% by 2020.

Concurrently, the production of food is one of the world's biggest challenges. According to estimates of the Organization for Economic Cooperation and Development (OECD) and the UN Food and Agriculture Organization (FAO), income growth in developing countries and the process of urbanization in countries, like China and India, which still have the majority of their population living in rural areas, is expected to increase the demand for food by 70% by 2050 (OECD and FAO, 2011). Furthermore, according to these organizations, Brazil is the country with the greatest potential to increase agricultural production, around 40% by 2019.

In addition, the importance of food production in Brazil is enhanced by the fact that agribusiness is a key sector of the Brazilian economy in terms of its contribution to both income and foreign exchange generation. According to Brazil's IBGE statistics institute, the sector accounted for over 22% of GDP in 2011. The agriculture and livestock sector was responsible for 28.8% of the total agribusiness GDP, while the food and processing industry and the distribution chain accounted for 59.4% and the agricultural machinery, equipment and input sector contributed with 11.8%. Agribusiness exports made up 36.9% of overall exports in 2011, generating US$ 94.6 million for the trade balance.

In the event of restricting deforestation in Brazil, probably the most affected sector would be the area which requires the most use of deforested areas, namely agriculture. According to a survey of the Brazilian Agricultural Research Corporation (Embrapa – acronym in Portuguese) and INPE, cattle breeding is the driving force for deforestation in the Amazon, accounting for more than 62% of the deforested area (EMBRAPA and INPE, 2011). Cattle raising is the leading factor of land usage in all states of the Amazon region, which have registered an overall growth in this area, making cattle breeding the economic activity with the greatest impact in the region (Rivero et al. 2009). In the *Cerrado*, the expansion of farming areas is encroaching on the remaining areas of native vegetation. Considered to be the last agricultural frontier on the planet, the *Cerrado* occupies 21% of the country's area, and about half of the original two million square kilometers are being used to develop pastures, plant annual crops and for other reasons (KLINK and MACHADO, 2005).

Aanalyzing the economic impact of such measures, however, is also quite relevant in ensuring economic and social development. Since this discussion is recent, Brazilian economic literature is still limited and is focused mainly at the regional, municipal or state level. As an example, Costa (2009) evaluated the impact of policies to contain deforestation in a southeast mesoregion in Pará using a model of the input-output matrix. Padilla Jr. (2004) studied the major impact on agricultural activity before the development of the Legal Reserve in Paraná State.

On the other hand, Ferreira Filho and Horridge (2012) analyze how limiting the Brazilian agricultural frontier could affect domestic food prices and exports of agriculture, using the model of computable general equilibrium, TERM-BR. The results obtained show that stopping deforestation would increase food prices by 2% by 2025, relative to the baseline, due to a drop in agricultural yield and rising prices, but the Brazilian GDP would decrease by only 0.5% by 2025, and real exports and real wages would fall by 1%.

In short, there is a discussion underway about deforestation in Brazil and the resulting GHG emissions, from the standpoint of the Forest Code, as well as from the implementation of programs to reduce deforestation in the Amazon and the *Cerrado* region, based on the commitments made at COP15. What will be the possible economic impact of policies aimed at restricting deforestation in Brazil, which will, in turn, restrict land use? One hypothesis is that it would lead to lower agricultural production, higher agricultural product and food prices and lower income.

Thus, the aim of this paper is to estimate the economic impact of deforestation restricting policies on the agricultural sector and the national economy. In other words, how these restrictions will affect the aggregate income, the level of business and trade flow of agricultural products and food and changes in land use, more specifically, in relation to pastures, crops and natural areas. For this purpose, a general equilibrium model, able to consider the relationships between the different sectors of the economy and a broad range of policy distortions, was used. Thereby, the study aims to guide the preparation of coordinated environmental and economic policies, as well as point out a few consequences of such policies, since the economic consequences of reducing deforestation are not yet well known.

2. Methods and Data

2.1. Features and data

The analysis method used in this study is the computable general equilibrium (CGE) model. This approach takes into account all interactions between markets and, consequently, all interrelationships between sectors are explicitly considered, as well as the interdependency among economic agents, different sectors, countries and regions. Unlike partial equilibrium analysis, whereby all prices of goods except the object of study are fixed, in general equilibrium models, prices vary. Moreover, these models allow the directions and magnitudes of exogenous shocks to be obtained, which makes them very suitable for the present study, where policies to reduce deforestation are evaluated.

The CGE model used is known as the Emissions Prediction and Policy Analysis (EPPA) developed by the MIT Joint Program on the Science and Policy of Global Change as described in Paltsev et al. (2005). The EPPA consists of a multi-sector, dynamic-recursive, multi-regional model designed to simulate scenarios of anthropogenic emissions of greenhouse gases and to estimate the economic impact of policies to mitigate climate change, according to Reilly and Paltsev (2007) Paltsev et al. (2008, 2009, 2012) and Gurgel, Reilly and Paltsev (2007) and Jacoby et al. (2009). The version of the model being utilized is the fifth version of EPPA, calibrated for the base year 2004, being solved endogenously for the year 2005 and thereafter, at intervals of five years, between 2005 and 2100, providing projections for sixteen countries and regions. Countries and regions, as well as the sectors and factors considered in EPPA for this work, are presented in Table 1.

[Table 1]

The EPPA model is solved numerically using the General Algebraic Modeling System (GAMS) (BROOKE et al., 1998), which is a modeling system for mathematical programming and optimization software, developed for large-scale modeling and it allows building models that are easily adaptable to new situations or proposals. The syntax of the algorithm used is a Modeling System Programming program for General Equilibrium (MPSGE), which was developed by Rutherford (1999). The MPSGE builds algebraic equations that characterize the conditions for zero economic profit for production, balance between income and consumer spending and balance between supply and demand in goods and factor markets.

In each period, production functions for each sector of the economy describe the combinations of capital, labor, land, energy and intermediate inputs to produce goods and services. The choices among different inputs reflect the technology used, in other words, the possibility of replacing various production factors and intermediate inputs in the production process. Consumption is modeled by assuming the decisions of a representative consumer, who seeks the maximization of utility through the consumption of goods and services. The substitution between goods and services illustrates the preferences of the representative consumer. The ability of consumers and firms to make choices between different inputs and goods are determined by elasticities of substitution in production functions and utility consumers.

The optimization problems are addressed in the model as a mixed complementarity problem due to the large amount of economic agents and distortions. This approach requires zero economic profit, market equilibrium and balance of income. For these conditions to be met, prices, quantities and income cannot be negative.

The condition of zero economic profit means that any industry that produces a positive amount of a product must have an income equal to zero. In other words, the value of inputs of any activity must be equal to or greater than the value of production. The condition of market equilibrium requires that there be a positive price for any good whose supply equals demand and that, along with any excess, supply must have a zero price. The equilibrium condition requires that income for each agent, including government entities, the amount of income must be equal to the value of factor endowments and tax revenues.

In each region and sector, a representative firm chooses a level of output, from the combination of quantities of primary factors and the amount of intermediate inputs deriving from other sectors in order to maximize profit. The optimizing behavior of the firm implies the equilibrium condition that price equals marginal cost. A representative agent for each region presents initial allocations for the supply of production factors that will be sold or rented to firms, choosing the consumption and saving level of each period to maximize the utility function subject to the budget constraint, given the income level. Lastly, the system of equations is closed, and the market clearance conditions determine the prices in different markets for goods and factors of production.

The EPPA model assumes that production functions and utility functions are represented by constant elasticity of nested substitution (CES). This provides flexibility in determining the substitution between different groups of input and factors, and the elasticities of substitution, particularly with regard to fuel and electricity and other sensitive issues and processes for mitigation costs. However, these structures in the EPPA model are very complex because they have various offshoots.

The temporal evolution of the model is based on scenarios of economic growth resulting from the behavior of consumption, savings, investment and capital accrual, as well as exogenous assumptions about an increase in labor productivity, energy and land. Structural changes occur in the demand for goods and services produced by each sector, including food and fuel, as the product and income increase. Inventories of limited resources, such as fossil fuels, decrease as they are depleted, causing an increase in the cost of extraction and processing. Sectors that use renewable resources such as land compete for the availability of services provided by them. The development or decline of a particular technology is endogenously determined according to its relative competitiveness. All these phenomena, coupled with simulated policies, such as taxes and subsidies for energy use, control pollutant emissions and fuel mandates, determine the growth of economies and alter the competitiveness and participation of different technologies over time and in alternative scenarios.

Since savings and investments are based on variables of the current period, the savings in each period are equal to investments and contribute to the formation of capital for the next period, considering depreciation. Therefore, the investment sector will be represented by a specific production sector, equaling the level of savings determined by the utility function of the representative agent. The marginal propensity to save is kept constant over time, thus avoiding shocks related to economic cycles.

In order to represent the rigidness of the capital stock, it is divided into two components, a malleable and a non-malleable one. It is assumed that the soft portion of the capital stock in each sector is described by CES functions. This means that capital can replace and be replaced by other inputs in the production function. The share of non-malleable capital is treated through a Leontief function, which does not allow substitution among inputs. The share of non-malleable capital and other inputs in the production function are defined at the time that such capital is formed, reflecting the technology being used at the time of employment of that capital. This formulation allows the model to display answers short and long term from changes in relative prices. Over time, the non-malleable capital generated in a given period will depreciate and be replaced by new installments of non-malleable capital, reflecting the technologies in use in recent times, arising from changes in relative prices.

The growth of the workforce is set exogenously and is composed of the separate effects of population growth and labor productivity. Population growth is based on the long-term trend data of the United Nations (UN, 2000 and 2001). Labor productivity is specified to allow playback levels of gross domestic product in the regions of the model as provided by the International Monetary Fund (IMF, 2000).

The macroeconomic closure of the model considers the total supply of each production factor to be constant (except for the different categories of land use, which are convertible into others) in a single period. Factors are mobile across sectors within a same region, with the exception of the non-malleable portion of the capital, and there is no movement of factors from one region to another. The land factor is specific to the agricultural sectors while natural resources are specific to the sectors that extract them for the production of energy.

There is no unemployment in the model, so factor prices are flexible. On the demand side, the marginal propensity to save is constant and specific to each region according to its share in total consumption and aggregate savings in the initial database. International capital flows that offset imbalance in trade in goods and services in the base year of the model are assumed exogenous and declining over time, reducing deficits or surpluses in the current account. Thus, changes in the real exchange rate should occur every period to accommodate changes in the flow of exports and imports. Government consumption can change with fluctuations in commodity prices and revenue from taxes is subject to changes in activity levels and consumption.

Economic data from the EPPA model is based on the Global Trade Analysis Project - GTAP (Hertel 1997; DIMARANAN; MCDOUGALL, 2002; Narayanan; WALMSLEY, 2008), a consistent database on regional macroeconomic consumption, production and bilateral trade flow, in its seventh version. The GTAP7 database presents an input product matrix for 113 countries and regions and 57 sectors in their economies, and includes a detailed representation of energy markets in physical units. The GTAP was created in programming language known as GEMPACK (HARRISON; PEARSON, 1996), but the EPPA uses the platform GAMS (BROOKE et al, 1998). To resolve this incompatibility, the GTAP data is translated and rearranged in a GTAPinGAMS program (RUTHERFORD; PALTSEV, 2000). The land usage data derives from the GTAP database and the work of Hurtt et al. (2006).

Statistics on greenhouse gases are obtained from inventories maintained by the U.S. Environmental Protection Agency. And data regarding other urban pollutants was obtained from the global database, EDGAR (OLIVIER and BERDOWSKI, 2001).

2.2. Land use change

The land use in the EPPA model is divided into five categories: pasture, crops, forests and secondary forests (forest areas, plant extraction and planted forests), natural forests and rangelands. The areas used for crops, pasture and forest, as well as natural forests and pasture are determined by the terrestrial model, Terrestrial Ecosystem Model (TEM) (MELILLO et al, 2009) based on the work of Hurtt et al. (2006). The TEM model classifies, maps and categorizes the different types of vegetation and land use at the level of 0.5° by 0.5° latitude and longitude. The model classified the areas of natural forest vegetation typical of the work of Hurtt et al. (2006) in the category of Natural Forests (NFORS), while areas with characteristics of savannah and fields were classified in the category of Natural Fields (NGRASS) in the EPPA model. Areas of secondary forest vegetation recovery (not yet at vegetative stages of equilibrium) and planted forests were classified in the category of Planted Forests and Secondary (FORS). Table 2 shows the distribution of different types of land use in the EPPA model calibrated to the year 2010 in regions of the model.

[Table 2]

In the Brazilian case, the initial land use in EPPA was compared with the Portalbio data of the Environmental Ministry and the Agricultural Census (IBGE, 2006). These two database are compatible considering that the NFORS category in EPPA includes forest areas in the Amazon, Atlantic Forest and Pantanal biomes. The NGRASS category relate to areas of native vegetation in the *Cerrado*, *Caatinga* (scrublands) and Pampas regions.

Each category of land is considered a renewable resource, which can be modified by its conversion into another category, or left in the unused category (secondary vegetation). In addition, the land is subject to exogenous productivity improvements, set at 1% per year for each category, which reflects the historical trend of progress in agricultural productivity, as well as the historical crop yields, which has shown an increase of 1% to 3% per year, according to Reilly and Fuglie (1998).

In regard to the transformation of land use, the area under a given category can be expanded by converting other land categories. The land use transformation allows one land type to be converted in another. To assure consistency, two conditions must be met: one is to maintain consistency between the physical accounting of the soil and economic accounting in the general equilibrium setting, and the other requires the development of data to be consistent with empirical observations.

In order to model the observed response of the land supply, we use a fixed production factor with an elasticity of substitution between the fixed factor and other parameterized input, to represent the observed response of land supply to changes in prices. The model adopts the observed response of the conversion of land in recent years to represent a long-term effect.

In land use conversions, a hectare of a land in a category is usually converted to a hectare of land in another category. The average productivity of the converted land will depend on the type of land that was converted and on the region. The marginal cost of converting one type of land into another in equilibrium must be equal to the difference between the economic value of the two land types. This procedure allows maintaining the assumption of zero economic profit in general equilibrium models. Moreover, it is required for the conversion to include actual inputs through a transformation function of land.

The value of land use is represented by real transactions as inferred by the economic statistical agencies in each country, so this value must be compatible with the data on revenues, costs of inputs and returns of other factors. The rent of land is obtained from the GTAP database (HERTEL, 1997; DIMARANAN; MCDOUGALL, 2002; NARAYANAN; WALMSLEY, 2008). Since the natural forest and rangeland categories are not used for economic production, because they are not in current use, an estimate is obtained to create an economic value for these categories, for this the procedures adopted by Gurgel; Reilly; Paltsev (2007) have been used. Another source of data was Sohngen and Tennity (2004), who concluded that the cost of converting natural vegetation areas, based on the hypothesis that the cost of access to new areas at the margin and at equilibrium, must be equal to the stock value of plant product (wood) existing in that area plus the present value of future stocks after the regeneration of the vegetation. This data with the average regeneration rate of natural vegetation results in a value of land rents of natural vegetation areas. It is calculated by the net present value of future harvests of timber from natural vegetation, which is obtained after discounting the conversion cost (equivalent to the present value on the balance of the virgin forest) and the sales value of the existing timber stocks. It also considers the time required for future cuts according to the vegetation regeneration rate.

The regional values of land rents per hectare in the base year of the model can be seen in Cabral (2013). In general, income from crop areas is higher than income from grazing areas (except in countries that have very limited grazing areas). The planted areas and secondary forests are generally smaller than those for other productive uses, since this category adds not only areas of forestry, but also areas of secondary vegetation regeneration. Areas of natural vegetation (natural forests and fields) are the lower income of the land, since they are not commercially exploited.

The land use transformation functions are calibrated to represent the observed response of land supply since 1990 until today, considering the rising costs associated with the use of inputs and factors for conversion, the need to extend infrastructure in order to access remote areas of natural vegetation, and formal and informal institutions (laws, standards of conduct, environmental groups and perception of society) that act on the basis of environmental and conservation reasons, hindering such conversions. As such, the price elasticity of land supply for each region is calculated considering the average increase in land prices from 1990 to 2005 and the average annual area of conversion of forest areas in each region. Based on Hyman et al.

(2002), the elasticity of supply is converted to elasticity of substitution between the fixed factor and other inputs used in the conversion, given by dividing the elasticity of supply and the share of costs of other inputs in the cost of the conversion function. In order to calibrate the functions, it is still necessary to estimate the share of the country's forest production generated from cutting down natural forests, as well as the relative area of natural forest being cleared in relation to the total area of the category of land use of planted and secondary forest (FORS). This information can be viewed in Cabral (2013).

In regions where there is no net or apparent deforestation, elasticities are close to zero as well as other parameters. The largest land supply elasticities are obtained for the regions with the highest rates of deforestation, namely the rest of Latin America, Africa and East Asia.

3. Scenarios and Results

3.1. Scenarios

In order to substantially reduce the rate of deforestation, which has been steadily rising in the past decade, the Brazilian government created in 2004, the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm), which focuses on land and spatial planning, monitoring and environmental control, and promoting sustainable productive activities. However, despite efforts under this plan, the rate of deforestation in the Amazon increased again in the second-half of 2007 (BRASIL, 2009b).

As a result, the government has anticipated the enactment of Decree no. 6,321 on December 21, 2007, which establishes a set of measures to control deforestation, such as editing the list of priority municipalities for actions of environmental and land control, prohibiting the issue of new deforestation permits; and the placement of embargoes on products acquired from illegally deforested areas (reinforced by Decree no. 6514 which amended the Environmental Crimes Act). Moreover, in February 2008, the National Monetary Council decided to change the rules for granting agricultural loans, which now requires environmental and land tenure for the letting of rural properties in the Amazon.

In December 2009 the government approved Law no. 12,187, which established the National Policy on Climate Change (PNMC – acronym in Portuguese). It also officiated the voluntary commitment of Brazil to the UN Framework Convention on Climate Change to reduce greenhouse gas emissions by between 36.1% and 38.9% of projected emissions by 2020. Instruments for implementation of PNMC are the National Plan on Climate Change, the National Fund on Climate Change, Communication of Brazil to the Framework UN Convention on Climate Change, the action plans for the prevention and control of deforestation in the biomes, credit lines and funding, and developing lines of research by funding agencies.

Decree 7.390 of December 9, 2010, which regulates the PNMC, takes into account the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm – acronym in Portuguese) and the Action Plan for the Prevention and Control of Slash-and-Burn in the *Cerrado* (PPCerrado – acronym in Portuguese). Meanwhile, to meet the voluntary commitment to reduce national GHG emissions, these plans should consider actions to: reduce by 80% the annual deforestation rates in the Amazon as compared with the average for the years 1996-2005, by 2020; reduce by 40% the annual rates of deforestation in the *Cerrado* biome in relation to the average for the years 1999-2008, by 2020.

Concurrently, the process of drawing up policies to mitigate climate change also gained force and changes were made to the Brazilian Forest Code, which was replaced on May 28, 2012, by Law 12.561 and MP 571/12, known as the new Forest Code.

Based on this information, three scenarios for reduced deforestation were simulated in addition to a baseline scenario. However, before describing them is important to clarify that the specifications of the new Brazilian Forest Code were not simulated in the model due to the complexity of the data collection and the difficulty to describe the situation of the rural properties in the country, which is beyond the scope of this work. Moreover, the focus of this work is to limit the removal of natural vegetation cover and not to recover deforested areas, which even after recovered, could not be considered as forest or natural vegetation.

1. Baseline scenario - REF: Economic indicators are evaluated as if the government had not implemented policies to reduce deforestation. In other words, REF represents the trajectory of the economy projected by the EPPA model, if it were kept under the same dynamic that determines it today, excluding policies to fight deforestation.
2. Scenario of reduction of deforestation considering the current goals - called "C_Goal" scenario: Considers the reduction target of 80% of deforestation in the Amazon and 40%

reduction in deforestation in the *Cerrado* region by 2020. However, these goals are kept until 2050, because it is believed that society (mainly NGOs) will pressure the government to maintain the achievements acquired by 2020.

3. Scenario of zero deforestation for the Amazon by 2050 - AM_Zero: simulates a hypothetical situation that deforestation in the Amazon is completely eliminated by 2050 at cumulative exponential rates every five years, and the current goal of reducing deforestation in the *Cerrado* is maintained by 2050.
4. Scenario of zero deforestation for the Amazon and *Cerrado* by 2050, both at exponential rates - AM_CE_Exp: it is posited that, after completion of the 2020 targets for the *Cerrado* and Amazon, targets for elimination of deforestation are assumed by 2050, at cumulative exponential rates every five years.

Table 3 shows the amount of areas that were allowed to deforest per year per biome. The deforestation allowed in 2020 is based on a reduction target of 80% in annual deforestation rates in the Amazon, at an average of 19,625 km² (1,962,500 acres) recorded between the years 1996-2005, as described in the “Plano Plurianual 2012-2015” (BRASIL, 2011), resulting in 382.9 ha per year of deforestation by 2020. In the *Cerrado*, it is estimated that a reduction of 40% in annual rates compared to an average of 15.7 km² (1,570 acres), which occurred between 1999 and 2008 (BRASIL, 2011), resulting in 942,000 hectares deforested by 2020.

[Table 3]

3.2. Results

3.2.1. Agricultural, Livestock and Food Production

The results show that the introduction of policies to reduce deforestation has a negative effect on the value of agricultural, livestock and food production. Such effects are directly related to the difficulty of the agricultural and livestock sectors to replace the key input of their production, land. However, the impacts are not significant, as shown in the Figure 1. Percentage changes are calculated relative to production observed in the baseline scenario (REF).

[Figure 1]

As can be seen, the rates of changes in agricultural product (CROP), livestock (LIVE) and food industry (FOOD) in the baseline and the scenarios to reduce deforestation are the same for the year 2020 in every sector - a feature which will be repeated in all other reported results. This is because the deforestation reduction rate is the same in all scenarios that year and the expectations of agents are myopic (not considering future indicators for decision making in the present).

Variations in production in these sectors are quite similar in terms of direction and magnitude. However, policies to reduce deforestation have a very significant impact on agricultural and food production, -0.38% by 2020 for the agricultural sector, -0.23% for livestock and -0.19% for the food industry, in the AM_CE_Exp scenario. The maximum loss reaches 1.87% for agriculture, 1.81% for livestock and 1.54% for the food service industry by 2050 in the AM_CE_Exp scenario. These reductions do not mean that production is growing at a negative rate, but only that it is growing at a slower rate than that observed in the absence of the deforestation-reducing policy.

Also note that production losses grow over time, which may be linked to the free land for agriculture and the increase in production costs associated with the need for increased efficiency in land use such as capital investment, job and other inputs.

Another interesting aspect is that the loss is higher with agriculture than with livestock, even though the latter is the biggest culprit for deforestation. This may be due to the large amount of pasture areas that are misused or underused in the country and that can be used more efficiently at a relatively lower cost than just by increasing the crops. It is due to the fact that crop production is more intense on land than livestock and has less of an ability to substitute land for other inputs. As for the food sector, given its interdependence with agriculture, the result of using agricultural products as intermediate inputs can be explained by the unfavorable performance of the agricultural sector.

3.2.2. Land Use Change

Figure 2 shows the trajectory of land use for each end of the four simulated scenarios. The trajectory of the natural forest areas in the EPPA model, NFORS, is represented in the chart "Amazon, Atlantic Forest and Pantanal" in Figure 2. It shows deforestation in these areas would be increased in the absence of policies to reduce deforestation, represented by the REF downslope curve. In the final simulated period, the cumulative avoided deforestation in the scenarios AM_Zero and AM_CE_Exp is almost 17.2 million hectares (4 % of the total NFORS area in 2010) compared with the areas of the REF. The current goal would avoid the deforestation of 15 million ha. Given the characteristics of the soil in Pantanal, which is not favorable for agriculture, and the small area of the Atlantic Forest, most of the removal of vegetation cover recorded in the REF scenario should occur in fact in areas of the Amazon.

[Figure 2]

For the NGRASS category, which consists of the "Cerrado, Caatinga and Pampas" areas, the differential deforested areas between the baseline and policy scenarios is greater than in the case of NFORS. Avoided deforestation between REF and C_Goal scenario reaches more than 36 million hectares, and more than 51 million ha (54% of the total NGRASS area in 2010) compared with the AM_CE_Exp scenario. This result reflects the high rates of deforestation in the baseline scenario of the EPPA model, which predicts deforestation rates similar to the ones observed since the 1980s in the *Cerrado* region. The results suggest that the introduction of policies to limit deforestation is key to preserving the biodiversity of the *Cerrado* biome.

As for the areas used for crops (CROP), the "Agriculture" graph of Figure 2 shows that the amount of land for agricultural purposes does not suffer significant impact. The deforestation reduction scenarios just change slightly the trajectory of the baseline scenario after 2035. The greatest variation occurs between REF and AM_CE_Exp scenarios (as is expected, always), which means nearly 7 million less hectares of cropland by 2050.

In the case of livestock, policies to reduce deforestation led to significant changes on the amount of land used for this activity (graph "Livestock" in Figure 2). While the trajectory of the REF scenario shows the expansion of pasture areas until the end of the period, the trajectories of policy scenarios show a lower increase rate and a slightly decrease after 2045. This suggests a significant intensification in the use of pastures, since the reduction in livestock production is not significant, as seen in the previous subsection. The difference between the REF scenario and AM_CE_Exp scenario is nearly 38 million hectares, and approximately 30 million ha compared to the other scenarios, which show similar results.

One of the most important uses of the land to be analyzed in this context is in the FORS category, which includes the areas of secondary vegetation, managed and cultivated forest areas and former agriculture areas which are in process of degradation and have secondary vegetation recovery. This land category may be converted in agricultural activities without pressuring areas of native vegetation. These areas are labeled "secondary vegetation" in Figure 2. It shows a downward trend in the FORS areas, even in the absence of policies to control deforestation in the REF scenario. However, under the policy scenarios, the total of these areas is 23.7 million hectares less than in the REF scenario in 2050. This result shows the importance of these areas in ensuring the expansion of Brazilian agriculture in the face of restrictions on the incorporation of new agricultural areas, which can be done via technology adoption and best practices in areas that are already deforested, but currently underutilized.

3.2.3. Sectorial trade balance

The model also enables us to assess the performance of the trade balance of the agricultural and food sectors, and any gains or losses of competitiveness in these sectors. Table 4 presents the results of changes in exports and imports of agricultural sectors (CROP) and food (FOOD) in different scenarios for reducing deforestation in relation to the baseline scenario.

In general, changes in exports reflect in some extent the changes in production. The introduction of targets for zero deforestation for the Amazon and the *Cerrado* at exponential rates requires a reduction of only 3.9% in agricultural exports and an increase of 1.74% in imports, both by 2050, while for the food sector, this decline in exports is almost 5% with an import increase of 2.66%. Even though these variations are not very significant, they show some loss of competitiveness in these sectors.

[Table 4]

3.2.4. GDP and Welfare

Table 5 shows the results expected for GDP scenarios from reducing deforestation in relation to the baseline values. The results show that the policy for limiting deforestation has a very insignificant impact on Brazilian GDP. Initially, the policy adopted in 2020 reduces it by around 0.03%, and thereafter, the losses increase over time. The higher loss is 0.15% in the AM_CE_Exp scenario.

[Table 5]

This behavior of GDP reflects the relatively small share of agriculture and livestock activities in the total GDP (around 5% in Brazil), as also as the relatively low impacts of the policies in the agricultural and food sectors. Moreover, the magnitude of the results on GDP also indicate that production costs associated with the increase in the efficiency of land use and implementation of policies on deforestation is not high.

GDP losses are slightly higher in 2025, but decrease after. It is due to the behavior of areas in the FORS category. In the baseline scenario, the availability of these areas declines more smoothly than in the policy scenarios between 2020 and 2030, as seen in the chart "secondary vegetation" of Figure 2. Thus, when policies to reduce deforestation are introduced, there is an increasing expenditure to improve this land, and consequently, a slightly greater loss in sectorial output and GDP at the beginning of the period.

Furthermore, it is important to notice that these results do not take into account the associated economic benefits of controlling deforestation, i.e. reducing the possible damage that would be caused by a loss of biodiversity, emissions of greenhouse gases and the consequent climate changes, limitation or interruption of the provision of other ecosystem services in the baseline REF scenario, characterizing a cost-benefit analysis. Given the difficulty that science has to identify and measure in economic terms all these possible losses, such benefits are not considered in monetary values in the EPPA model, limiting the ability of the cost-benefit analysis type. As such, the EPPA model only allows for assessment of the cost-effectiveness of policies, in other words, it measures only costs associated with a specific goal to reduce deforestation without including the benefits of this goal in terms of economic losses avoided.

The change in welfare (measured as equivalent variation Hicksiana) is a good indicator of how the expected aggregate impact affects the level of comfort and satisfaction of families in a country, taking into account all the changes in prices of goods and services and production factors, which ultimately determine household income. Table 5 also shows the results of changes in welfare in the Brazilian economy from the deforestation reduction scenarios compared to the baseline REF scenario.

The inclusion of targets to reduce deforestation brought small gains of 0.05% in terms of welfare in all policy scenarios for the period of 2020 and 2025. But from 2030, the losses recorded range from -0.01% in all scenarios, reaching the maximum of -0.07% in AM_CE_Exp scenario by 2050. These results represent some modest impacts that do not justify a deeper economic analysis. Thus, it is concluded that the adoption of targets to reduce deforestation should not result in major economic and social loss to Brazil in the major areas to be preserved.

4. Conclusion

This study investigated the economic impact of policies limiting deforestation on agricultural and food sectors, and the national economy. More specifically, it examined how certain economic variables, such as the activity level of the agricultural sectors, trade flows and aggregate output respond to scenarios of deforestation reduction in the Amazon and *Cerrado* regions. These scenarios consider the government's targets of 80% reduction in annual deforestation rates in the Amazon by 2020 (compared to the average between 1996 and 2005), and 40% reduction in the annual rate of deforestation in the *Cerrado* (in relation to the average between 1999 and 2008). From 2020 onwards, some possible scenarios for controlling deforestation were considered, such as: maintaining the rate of deforestation until 2020 in the Amazon and *Cerrado* regions; decreasing deforestation, at exponential rates, in the *Cerrado* and Amazon until reaching zero deforestation by 2050; and maintaining the rate of deforestation of the *Cerrado* until 2020, while exponentially reducing deforestation in the Amazon to achieve zero deforestation by 2050.

The simulations were implemented in a recursive dynamic computable general equilibrium model, the Emissions Prediction and Policy Analysis (EPPA) developed by MIT. The general equilibrium methodology was chosen because the deforestation-reducing policies were expected to generate general equilibrium effects that were far-reaching, on a geographic and economic scale. In the EPPA model, competition among different land uses is explicit and divided into five categories: pasture, crops, forest and secondary forests (forest areas, plant extraction and planted forests), natural forests and rangeland.

The results show negative impacts on agriculture and food production and overall GDP from the anti-deforestation policies. All economic variables suffer more impacts on the scenario in which the reduction of deforestation occurs exponentially until it reached zero deforestation by 2050 in the Amazon and the *Cerrado*. The loss in sectorial output reaches a maximum 1.87 % in agriculture, 1.81% in livestock and 1.54 % in the food sector by 2050. It suggests the possibility of intensifying production is more likely with livestock. Agricultural and food industries lose competitiveness in the international market. Overseas sales decreased by up to 3.9% in the agricultural sector and almost 5% in the food sector by 2050, while imports increased 1.74% in agricultural and 2.66% in food sector by 2050.

The evaluation of the results of economic activity suggests that a sacrifice nationwide in terms of GDP loss is not significant, since the decrease in GDP is only 0.15%. Nevertheless, it is important to note that due to economic and social discrepancies among the different regions and states of Brazil, the impact on the regional GDP may differ, but this analysis is beyond the scope of the model used.

Losses on welfare are more modest, 0.07% by 2050 compared to the baseline scenario. Therefore, if the country continues to reduce the pace of deforestation, the model results indicate very modest losses to Brazil. Moreover, these results do not consider the economic benefits associated with control of deforestation, such as maintaining biodiversity and reducing emissions of greenhouse gases, with a decrease in damage caused by climate change.

The policies to stop deforestation would reduce the total area used for crops compared to the baseline scenario by seven million hectares by 2050. Pasture areas decrease 38 million by 2050. This shows that livestock production may be highly intensified in Brazil when the expansion on areas of natural vegetation is restricted. In addition, simulations suggest that the expansion of the agricultural frontier may occur under the vast area of secondary vegetation, which could be better used given the current technologies and modern agricultural practices.

As positive effects of policies to reduce deforestation, up to 68 million hectares of forests and savannahs are preserved by 2050. These results suggest little significant economic cost on the potential benefits of environmental protection due to the ability to increase productivity by converting underutilized Brazilian pastures and fields and secondary vegetation into agricultural areas.

As a policy recommendation we suggest that actions to curb deforestation and the expansion of the Brazilian agricultural frontier should be accompanied by incentives for the use of more advanced technologies in agriculture. This would lead to an increase in crop and livestock productivity, enabling the recovery of degraded areas and pastures, and accelerating the process of technological diffusion and development in public- and private-sector research institutions. Therefore, the increase in agricultural supply would prevent food prices from rising and the Brazilian industry from losing its competitive edge.

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Table 1 – Aggregations used by the EPPA model

Regions	**Sectors**	**Factors**
United States (USA)	**Não Energia**	Capital
Canada (CAN)	Agriculture – Crops (CROP)	Labor
Mexico (MEX)	Agriculture – Livestock (LIVE)	Oil from shale
Japan (JPN)	Agriculture – Forestry (FORS)	Coal
European Union (EUR)	Food (FOOD)	Natural gas
Australia & N. Zealand (ANZ)	Services (SERV)	Hydro
Russia (RUS)	Chemical, rubber, plastics, paper (CRP)	Nuclear
Eastern Europe (ROE)	Steel and metallurgy (IRON)	Wind & Solar
China (CHN)	Non-ferrous metals (ALUM)	Land:
India (IND)	Nonmetallic minerals (CIME)	- crops
Brazil (BRA)	Other industry (OTHR)	- livestock
East Asian (ASI)	Transportation (TRAN)	- forestry
Middle East (MES)	Own-supplied transport (FTRAN)	Natural forest
Africa (AFR)	**Energy**	Natural livestock
Latin America (LAM)	Coal (COAL)	
Rest of Asia (REA)	Conventional crude oil (OIL)	
	Refined oil (ROIL)	
	Natural gas (GAS)	
	Electricity (ELEC)	
	Hydro electricity (H-ELE)	
	Nuclear electricity (A-NUC)	
	Wind electricity (W-ELE)	
	Solar electricity (S-ELE)	
	Biomass electricity (biELE)	
	Electricity NGCC[1] (NGCC)	
	Electricity NGCC - CCS[2]	
	Electricity IGCC[3] - CCS	
	Gas from coal (SGAS)	
	Biofuel (1º generation)	
	Biofuel (2º generation) (BOIL)	
	Oil from shale (SOIL)	

Source: Paltsev *et al*. (2005) and EBC (2012).

[1] NGCC: converting natural gas into electricity using combined cycle generation

[2] CCS: carbon capture and sequestration

[3] IGCC: generation technology of natural gas from coal

Table 2 – Area by category in each category of the EPPA model calibrated for the year 2010 - in thousand hectares (ha)

Region	CROP	LIVE	FORS	NGRASS	NFORS	OTHER
United States	189162	110558	181805	95177	240753	112908
Canada	51649	22407	64263	-	345084	456539
Mexico	25659	65704	35700	9035	65910	1513
Japan	5245	680	9426	-	26887	206
Australia & N. Zealand	36371	397773	48436	65548	299153	25416
European Union	136931	57926	99655	22292	118626	59920
Eastern Europe	182540	183021	95820	10014	102798	33342
Russia	161477	156579	166834	33589	648485	509364
East Asia	96311	14673	10993	-	198408	23018
China	273455	237672	57835	21252	99075	244079
India	208851	24250	14037	-	59348	14924
Brasil	65334	138846	109622	95491	421307	23941
Africa	260171	905260	217987	106318	661482	850130
Middle East	21700	231880	28883	43583	55925	140829
Latin America	127751	296366	103626	41501	327545	151548
Rest of Asia	121409	143814	48990	61961	97738	33175

Source: TEM/EPPA.

Table 3 - Deforestation in areas permitted by model - in thousand ha

Deforestation rate	**Amazon**						
	2020	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Current goal	382.92	382.92	382.92	382.92	382.92	382.92	382.92
Zero deforestation by 2050 - exp.	382.92	65.94	11.35	1.96	0.34	0.06	0.01
Deforestation rate	**Cerrado**						
	2020	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Current goal	942	942	942	942	942	942	942
Zero deforestation by 2050 - exp.	942	141.30	21.20	3.18	0.48	0.07	0.01

Table 4 - Changes in exports and imports of food and agriculture in the policy scenarios compared to the baseline scenario – in %

Scenario	2020	2025	2030	2035	2040	2045	2050
	Exports						
	CROP						
C_Goal	-0.93	-0.96	-0.18	-0.41	-0.64	-0.92	-1.28
AM_Zero	-0.93	-1.10	-0.38	-0.70	-1.04	-1.51	-2.03
AM_CE_Exp	-0.93	-1.19	-0.63	-1.22	-1.92	-2.84	-3.90
	FOOD						
C_Goal	-1.03	-1.13	-0.33	-0.67	-0.97	-1.32	-1.66
AM_Zero	-1.03	-1.34	-0.62	-1.08	-1.53	-2.03	-2.62
AM_CE_Exp	-1.03	-1.47	-0.98	-1.81	-2.71	-3.74	-4.95
	Imports						
	CROP						
C_Goal	0.44	0.44	0.06	0.14	0.24	0.37	0.54
AM_Zero	0.44	0.49	0.14	0.26	0.41	0.64	0.88
AM_CE_Exp	0.44	0.53	0.24	0.47	0.78	1.24	1.74
	FOOD						
C_Goal	0.64	0.69	0.16	0.34	0.49	0.68	0.85
AM_Zero	0.64	0.80	0.32	0.56	0.80	1.07	1.38
AM_CE_Exp	0.64	0.88	0.51	0.96	1.44	2.00	2.66

Source: Research results.

Table 5 - Changes in GDP and welfare between the policy scenario and the REF scenario - in%

Scenario	2020	2025	2030	2035	2040	2045	2050
	GDP						
C_Goal	-0.03	-0.05	-0.03	-0.03	-0.04	-0.05	-0.07
AM_Zero	-0.03	-0.05	-0.03	-0.04	-0.05	-0.06	-0.09
AM_CE_Exp	-0.03	-0.05	-0.04	-0.05	-0.07	-0.10	-0.15
	Welfare						
C_Goal	0.05	0.05	-0.01	-0.02	-0.03	-0.03	-0.04
AM_Zero	0.05	0.05	-0.01	-0.02	-0.03	-0.03	-0.04
AM_CE_Exp	0.05	0.05	-0.01	-0.02	-0.04	-0.05	-0.07

Source: Research results.

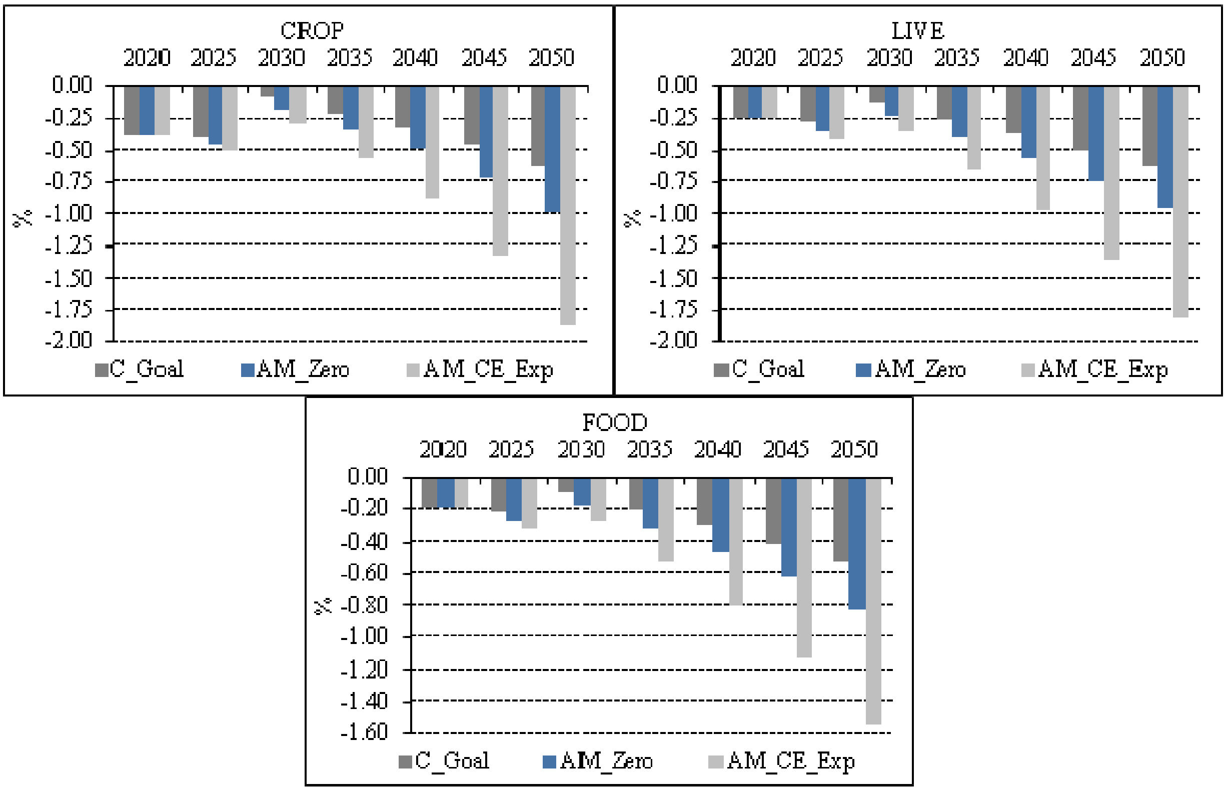

Figure 1 – Changes (%) in agricultural, livestock and food production

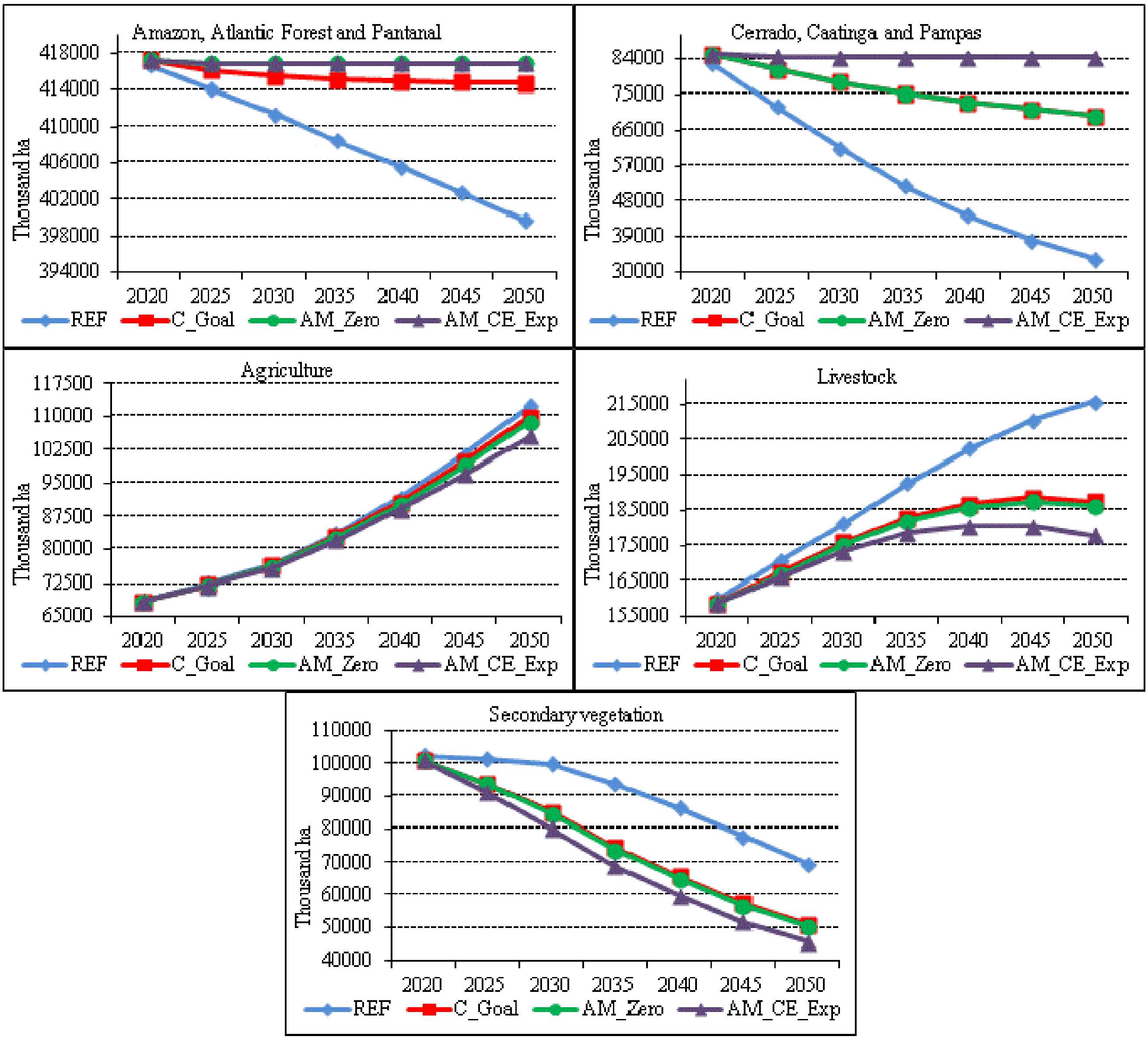

Figure 2 - Trajectory of total areas used by category