Attawan Guerino Locatel Suela

Universidade Federal de Viçosa

Cicero Zanetti de Lima

Faculdade Getúlio Vargas AGRO

Rayan Wolf

Universidade de Purdue GTAP

Ian Michael Trotter

Universidade Federal de Viçosa

***COMPUTABLE GENERAL EQUILIBRIUM MODEL FOR ANALYSIS OF THE PAYMENT FOR ENVIRONMENTAL SERVICES IN THE BRAZILIAN CERRADO***

Modelo de equilíbrio geral computável para análise do pagamento por serviços ambientais no cerrado brasileiro

*Modelo de equilibrio general computable para el análisis del pago por servicios ambientales en el cerrado brasileño*

DOI: 10.48075/igepec.29i1.34440

**Informe GEPEC,** ISSN: 1679-415X, TOLEDO, v. 29, n.1, p.184-204, jan./jun. 2025.

***COMPUTABLE GENERAL EQUILIBRIUM MODEL FOR ANALYSIS OF THE PAYMENT FOR ENVIRONMENTAL SERVICES IN THE BRAZILIAN CERRADO***

Modelo de equilíbrio geral computável para análise do pagamento por serviços ambientais no cerrado brasileiro

*Modelo de equilibrio general computable para el análisis del pago por servicios ambientales en el cerrado brasileño*

Attawan Guerino Locatel Suela[[1]](#footnote-1)

Cicero Zanetti de Lima[[2]](#footnote-2)

Rayan Wolf[[3]](#footnote-3)

Ian Michael Trotter[[4]](#footnote-4)

***Abstract****: The provision of food, fiber, bioenergy and water is essential to meet the growing global demand, but it faces environmental challenges such as deforestation and habitat loss. Although the new Brazilian Forest Code aims to protect the environment, its effectiveness is limited, especially due to the diversity of biomes. The forest conversion in the Cerrado, particularly in the MATOPIBA region, demands immediate solutions. This research calculates the amount of Payment for Environmental Services (PES) required to encourage producers to adopt protective measures that prevent the conversion of the Legal Reserve Surplus (LRS) in agricultural areas. Using the model of Computable General Equilibrium (CGE) Brazilian Economic Analysis (BREA), two scenarios were simulated: Base and PES (BT). In the Base scenario, 400,000 hectares of LRS would be converted to crop production in the Cerrado biome. In the PES (BT) scenario, the converted area would be 191,000 hectares destined for soybean production and livestock rearing in the same territory. Financially, the soybean production in the PES (BT) scenario would generate R$ 541.2 million, while the production of pastures would reach R$ 2.4 billion. The results provide valuable inputs for public policy formulation, highlighting the importance of balancing agricultural production with environmental conservation in order to meet producers' needs and protect ecosystems.*

***Keywords****: Brazilian Center-West, LRS, MATOPIBA, PES.*

**Resumo**: O fornecimento de alimentos, fibras, bioenergia e água é essencial para atender a crescente demanda global, mas enfrenta desafios ambientais como desmatamento e perda de habitat. Embora o novo Código Florestal tenha como objetivo proteger o meio ambiente, sua eficácia é limitada, principalmente devido à diversidade de biomas. A conversão florestal no Cerrado, particularmente na região do MATOPIBA, exige soluções imediatas. Esta pesquisa calcula o valor do Pagamento por Serviços Ambientais (PSA) necessário para incentivar os produtores a adotarem medidas de proteção que impeçam a conversão do Excedente de Reserva Legal (ERL) em áreas agrícolas. Utilizando o modelo de Equilíbrio Geral Computável (EGC) da Análise Econômica Brasileira (BREA), foram simulados dois cenários: Base e PAS (BT). No cenário base, 400.000 hectares de ERL seriam convertidos para a produção agrícola no bioma do Cerrado. No cenário PAS (BT), a área convertida seria de 191.000 hectares destinados à produção de soja e criação de gado no mesmo território. Financeiramente, a produção de soja no cenário PAS (BT) geraria R$ 541,2 milhões, enquanto a produção de pastagens atingiria R$ 2,4 bilhões. Os resultados fornecem insumos valiosos para a formulação de políticas públicas, destacando a importância do equilíbrio entre produção agrícola e conservação ambiental, a fim de atender às necessidades dos produtores e proteger os ecossistemas.

**Palavras-chave**: Centro-Oeste brasileiro, ERL, MATOPIBA, PSA.

***Resumen****: El suministro de alimentos, fibras, bioenergía y agua es esencial para satisfacer la creciente demanda global, pero enfrenta desafíos ambientales como la deforestación y la pérdida de hábitat. Aunque el nuevo Código Forestal tiene como objetivo proteger el medio ambiente, su eficacia es limitada, principalmente debido a la diversidad de los biomos. La conversión forestal en el Cerrado, particularmente en la región de MATOPIBA, requiere soluciones inmediatas. Esta investigación calcula el valor del Pago por Servicios Ambientales (PSA) necesario para incentivar a los productores a adoptar medidas de protección que impidan la conversión del Excedente de Reserva Legal (ERL) en áreas agrícolas. Utilizando el modelo de Equilibrio General Computable (EGC) del Análisis Económico Brasileño (BREA), se simularon dos escenarios: Base y PAS (BT). En el escenario base, 400.000 hectáreas de ERL serían convertidas para la producción agrícola en el bioma del Cerrado. En el escenario PAS (BT), la superficie convertida sería de 191.000 hectáreas destinadas a la producción de soja y ganadería en el mismo territorio. Financieramente, la producción de soja en el escenario PAS (BT) generaría R$ 541,2 millones, mientras que la producción de pastos alcanzaría R$ 2,4 mil millones. Los resultados proporcionan insumos valiosos para la formulación de políticas públicas, destacando la importancia del equilibrio entre producción agrícola y conservación ambiental, con el fin de atender las necesidades de los productores y proteger los ecosistemas.*

***Palabras clave****: Centro-Oeste brasileño, ERL, MATOPIBA, PSA.*

**INTRODUCTION**

The provision of food, fiber, bioenergy, and water is essential to meet growing global demand. However, this production faces significant environmental challenges, including deforestation, habitat loss, biodiversity impacts, and greenhouse gas (GHG) emissions (Sparovek et al., 2018; Xu et al., 2021). In Brazil, one of the world’s largest producers and exporters of agricultural commodities, agricultural expansion could further exacerbate forest loss if adequate protection measures are not implemented (Kalamandeen et al., 2018; Suela et al., 2021; Christ et al., 2022; Ferreira-Paiva et al., 2022; Suela, 2024a; Suela et al., 2024b).

The preservation of native vegetation in Brazil depends on effective legislation, such as the Forest Code (FC), which establishes standards for vegetation protection. However, the effectiveness of this legislation is limited by the diversity of Brazilian biomes (Nepstad et al., 2014; Soterroni et al., 2019; Polizel et al., 2021; Suela et al., 2023a; Suela et al., 2023b). This limitation arises because the Forest Code adopts general rules for the entire national territory without adequately considering the ecological, climatic, and socioeconomic particularities of each biome. For example, the requirements for Legal Reserves (LR) and Permanent Preservation Areas (PPAs) may not be suitable for biomes like the Pantanal, where water dynamics are unique, or the Caatinga, which has vegetation adapted to semi-arid conditions (Soares-Filho et al., 2014).

Additionally, the uniform application of legislation in biomes such as the Amazon and the *Cerrado* faces distinct challenges, as these regions have historically high deforestation rates and are subject to different economic pressures (Adams et al., 2021). In the *Cerrado*, only 20% of the area is protected, while in the Amazon, the legislation mandates the conservation of 80% of vegetation on private lands (Brasil, 2012). Regulatory measures, such as the Soy Moratorium (MS) in the Amazon—which prohibits the marketing of soybeans from deforested areas and promotes zero deforestation—have not been implemented in the *Cerrado* due to a lack of political will (Nepstad et al., 2014; Soterroni et al., 2019; Suela, 2022; Cabral et al., 2023). A viable alternative to reduce forest conversion would be to expand agriculture on already deforested land (Soterroni et al., 2019).

This research focuses on the MATOPIBA region (an acronym for the *Cerrado* biome areas in the states of Maranhão, Tocantins, Piauí, and Bahia) (Figure 1), which has experienced significant forest loss over the past two decades (*Ministério da Agricultura, Pecuária e Abastecimento* - MAPA, 2020; Magalhães et al., 2021). Soybean production in MATOPIBA grew from 5.7 million tons (Mt) in 2008 to 12.8 Mt in 2018/2019, representing 12% of the national crop (*Companhia Nacional de Abastecimento* - CONAB, 2020). According to MAPA (2020), the MATOPIBA agricultural frontier is projected to produce approximately 32.7 Mt of grain by 2029/30, with a planted area of 8.9 million hectares (Mha) by the end of the projection period. This agricultural expansion could intensify pressure on native vegetation and exacerbate environmental degradation (Solidaridad, 2021).

Since the implementation of the Soy Moratorium in the Amazon, the *Cerrado* has become a key area for soybean expansion, resulting in significant deforestation and environmental impacts (Solidaridad, 2021; Cabral et al., 2023). The *Cerrado* is now considered a "buffer zone" for the Amazon, requiring more stringent protection measures (FIAN, 2018; MAPA, 2020; Magalhães et al., 2020; Cabral et al., 2023). Despite the deforestation reduction goals established in the New Forest Code (NFC), Law No. 12.651 of May 25, 2012, and the Conferences of the Parties (COP 15, 21, and 23), MATOPIBA accounted for 76% of total *Cerrado* deforestation between 2015 and 2022 (Brasil, 2012; Solidaridad, 2021; Cabral et al., 2023; MapBiomas, 2024). Economic activities aimed at agricultural expansion in the region generate negative externalities, affecting human health, natural resource quality, and ecosystem balance (Rippel & Rippel, 2008; Tietenberg, 2018; Suela et al., 2020; De Souza et al., 2023).

Figure 1 – Map containing the Brazilian biomes as well as the region of MATOPIBA in an explicit way.

****

Source: author's elaboration.

In Brazil, there are 101 million hectares (Mha) of Legal Reserve Surplus (LRS), with 37 Mha located in the *Cerrado* biome. The LRS consists of native vegetation on rural properties that exceeds the minimum preservation requirements set by the Forest Code. However, as its preservation is not mandatory, these areas are vulnerable to legal deforestation, especially under economic pressure (Brasil, 2012; Solidaridad, 2021). In the MATOPIBA region, the LRS covers 16.9 Mha, of which 4.6 Mha are suitable for agriculture (Agrosatélite, 2020). This scenario highlights a critical challenge: balancing agricultural expansion with the conservation of native vegetation, which is vital for biodiversity, water resources, and climate regulation.

The Payment for Environmental Services (PES) is a strategic tool to address this issue. PES is a market-based mechanism that provides financial incentives to landowners who conserve or restore ecosystems, promoting sustainable land use. In the *Cerrado*, PES can help preserve the LRS by compensating landowners for maintaining these areas instead of converting them into agricultural land. This approach reduces deforestation and encourages agricultural intensification on already cleared areas, minimizing further land conversion (Wunder et al., 2008; Solidaridad, 2021). By implementing PES, a win-win scenario can be achieved: agricultural productivity increases through improved practices, while the LRS is preserved, contributing to the conservation of the *Cerrado* ecosystem. This dual benefit is particularly relevant in regions like MATOPIBA, where agricultural expansion drives deforestation and environmental degradation. Additionally, PES aligns economic incentives with environmental goals, fostering a more sustainable and resilient agricultural sector (Pagiola et al., 2005; Börner et al., 2017).

In 2017, civil society and private actors launched the Manifesto of the *Cerrado* Biome, committing to grow soybeans only in already deforested areas (Manifesto, 2017). In 2019, Bill No. 4203 was proposed, establishing a ten-year moratorium on deforestation in the *Cerrado* (MC). However, resistance from large soybean companies has left the *Cerrado* vulnerable (Brasil, 2019). According to Soterroni et al. (2019), the situation of forest conversion in the *Cerrado* requires an immediate solution.

This research aims to calculate the total PES required for producers in the *Cerrado* biome, especially in the MATOPIBA region, to adopt measures that prevent the conversion of LRS into crops like soybeans, corn, and pasture. The Brazilian Economic Analysis (BREA) model, a computable general equilibrium (CGE) model, was chosen for this purpose (Lima, 2017). Unlike direct surveys with producers, which are limited to specific contexts, the BREA model provides a systemic and scalable analysis of the economy, capturing interdependencies between sectors, regions, and agents. It allows for the simulation of complex scenarios, such as PES implementation, and evaluates their impacts on production, land use, and income distribution, including indirect effects and feedback mechanisms (Dixon & Rimmer, 2001; Burfisher, 2021). This makes the BREA model a robust tool for estimating the PES needed to promote forest protection and sustainable land use practices at a broader scale (Dixon & Rimmer, 2001; Lima, 2017; Burfisher, 2021).

 The importance of native forests extends beyond economic aspects, encompassing critical ecological functions such as biodiversity conservation, climate regulation, and water cycle maintenance. This research focuses on calculating the PES required to prevent the conversion of LRS into agricultural land in the MATOPIBA region of the *Cerrado* biome. While numerous studies have estimated PES in other contexts (Wunder, 2005; Engel et al., 2008; Farley & Costanza, 2010; Muradian et al., 2010; Perevochtchikova et al., 2021), this study stands out by employing a CGE model. This approach captures systemic economic and environmental interactions that are often overlooked in traditional methods, providing a more comprehensive analysis. By offering a scalable and robust framework for evaluating forest protection measures, this research contributes to a deeper understanding of environmental externalities and provides practical insights for policymakers. In doing so, it addresses a critical gap in the literature on *Cerrado* conservation.

This research, in addition to the Introduction, is organized into the following sections: Contextualization, Methodology, Results, and Final Considerations. In the Contextualization, the PES and its relevance to the *Cerrado* are discussed. The Methodology describes the CGE model and the simulated scenarios. In the Results, the PES values that make producers indifferent between converting or preserving the LRS in MATOPIBA are presented. Finally, in the Final Considerations, the implications of the study for sustainable development policies in the region are discussed.

**2 - CONTEXTUALIZATION**

**2.1 – PAYMENTS FOR ENVIRONMENTAL SERVICES**

Since the late 1990s, PES have gained prominence as market-based tools for environmental protection and have been incorporated into public policies, particularly in Latin America (Wunder, 2005; Engel et al., 2008; Farley & Costanza, 2010; Muradian et al., 2010; Perevochtchikova et al., 2021). Emerging as an alternative to traditional regulatory instruments and conservation projects from the 1970s to the 1990s, PES encourages conservation through financial transfers between social actors, aligning land use with the promotion of natural capital (Pagiola et al., 2002; Pesche et al., 2012). According to Wunder (2005), PES is a voluntary transaction in which a buyer pays a supplier for an environmental service, conditional on the delivery of that service.

The economic logic of PES aims to make environmental preservation a competitive alternative to more profitable land uses, such as agriculture, by compensating rural landowners for environmental services that generate indirect benefits, such as water regulation and carbon sequestration (Pagiola & Platais, 2006).

There are two main types of PES programs: those directly funded by service users and those financed by third parties, primarily governments. User-funded programs tend to be more effective due to the alignment of interests and closer supervision. In contrast, government-funded programs, although covering larger areas, often face challenges related to efficiency and political pressure (Pagiola & Platais, 2006; Engel et al., 2008).

In Brazil, PES was first implemented in 2006 in Extrema, Minas Gerais, and later expanded to several regions. In 2016, PES was integrated into Brazil’s Nationally Determined Contribution (NDC) under the Paris Agreement, committing the country to GHG emission reduction and vegetation restoration targets. Law 14.119/2021 formally regulated PES, highlighting its importance for Brazil. By 2019, Brazil had reduced its emissions by 17% compared to 2005 levels, although it remains far from the target of 37% by 2030 (Brasil, 2021; Winkel et al., 2022; SEEG, 2023).

**3 – METHODOLOGY**

Computable General Equilibrium (CGE) Models represent the economy at global, national, and regional levels, using mathematical equations to describe interactions between economic agents such as households, governments, and the productive sector. These models allow for the simulation of public policies with economic implications, making them widely used in studies on climate change, agricultural policies, and deforestation reduction. CGE models capture both micro- and macroeconomic reactions to changes, such as technological innovations or shifts in consumer preferences (Rutherford & Paltsev, 2000; Rutherford, 2005; Lima & Gurgel, 2018; Stocco et al., 2020).

The BREA model used in this study is a static, multiregional, and multisectoral model designed to represent the Brazilian economy across six regions: South, Southeast, North, Northeast, Center-West, and MATOPIBA, which together encompass the *Cerrado* biome (Figure 2) (Lima, 2017). In the model, final demand includes consumption, investment, and public and private spending, guided by the optimization of consumption and production. Consumers seek to maximize utility under budgetary constraints, generating demand functions that depend on relative prices. The BREA model was developed using the Mathematical Programming System for General Equilibrium (MPSGE) programming language within the GTAPinGAMS framework (Rutherford & Paltsev, 2000; Rutherford, 2005; Lima, 2017).

The BREA model integrates economic and land-use data from various sources. Data from the *Instituto Brasileiro de Geografia* e *Estatística* (IBGE, 2020b) provide information on agricultural production and state GDP from 2009 to 2019. Additionally, data on grassland quality—classified as degraded, intermediate, or intact—cover the years 2009, 2010, 2019, and 2020 (*Laboratório de Processamento de Imagens* e *Geoprocessamento* - LAPIG, 2024). The BREA model also incorporates land-use maps, including legal reserves, conservation units, cultivated areas, and planted forests, enabling a comprehensive analysis of the costs and productivity of land-use conversions (Guilhoto et al., 2010; Lima, 2017).

Figure 2 – Regional aggregation of Brazil in the BREA model

Fonte: Adapted from Lima (2017)

These data are organized into two modules: The Economic Module: This module uses National Accounts and an input-output table based on Guilhoto et al. (2010). The Land-Use Module: This module is detailed across 36 sectors and three production factors—capital, labor, and land. The segmentation of land use, including cultivation areas, pastures, preservation areas, and infrastructure, is essential for detailed predictive analyses (see Table 1).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **REGIONS** |   | **SECTORS** |   |  **PRIMARY FACTOR INPUTS** |
| South | STH |   | Mineral Iron | MIN |   | Capital | CAP |
| Southeast | SST |   | Coal | COAL |   | Labor | LAB |
| Center-West | CST |   | Mineral Estraction | NMM |   | Land | LND |
| North | NTH |   | Meats | MEAT |   | *Cropland* | *CROP* |
| Northeast | NST |   | Soy Oil | OSD |   | *Pasture* | *PAST* |
| Northeast *Cerrado* (MATOPIBA) | NSTC |   | Foods | FOOD |   | *Degraded Pasture* | *DPAS* |
|   | Textile and Wood | TEX |   | *Planted Forest* | *PFOR* |
|   |   |   | Refined Oil | ROIL |   | *Legal Reserve Surplus* | *LRS* |
| **SECTORS** |   | Ethanol | ETH |   | *Unused Land*  | *UNU\** |
| Rice | RICE |   | Chemistry | CHM |   |   |   |
| Meize | CORN |   | Fertilizer | FERT |   |   |   |
| Caner | CANE |   | Defensives | DFN |   |   |   |
| Soy | SOY |   | Steel Metal non-metalic | MMI |   |   |   |
| Fruit | FRIT |   | Machines | MAC |   |   |   |
| Other Cultures | OCUL |   | Other Industry | OIND |   |   |   |
| Forestry | FRST |   | Electricity | ELEC |   |   |   |
| Cattle | CTTL |   | Pipe gas | PGAS |   |   |   |
| Other Live Animals | OLA |   | Water | WTR |   |   |   |
| Swine | SWIN |   | Public Service | PSRV |   |   |   |
| Poultry | PTRY |   | Construction | CONS |   |   |   |
| Milk | MILK |   | Services | SERV |   |   |   |
| Oil | OIL |   | Transportation | TRNS |   |   |   |
| Gas | GAS |   |   |   |   |   |   |

Table 1 **–** Regions, sectors, primary and land use categories

Note: (\*) (Legally protected units) UNU: Legal Reserve; Conservation Units; Planted Forests; Indigenous Lands; Military Areas; *Quilombola* Areas; Public Non-designated Areas; Infrastructure and Rivers.

Source: author's elaboration

To ensure the accuracy of the results, data were reviewed and integrated from reliable sources, such as IBGE, *Instituto Nacional de Pesquisas Espaciais* (INPE), *Ministério do Meio Ambiente* (MMA), MAPA, CONAB, and SOS *Mata Atlântica*. These sources provided information on key aspects, including pasture degradation and Legal Reserve Surplus (LRS). The BREA model adopts a market-based approach with flexible prices, assuming fixed investments, capital flows, and a balanced payment structure, while not accounting for unemployment. Changes in prices, activity levels, and consumption directly affect government spending and tax revenue. With this comprehensive framework, the BREA model serves as a robust tool for projecting the economic and environmental impacts of policies, such as the implementation of Payment for Environmental Services (PES) (da Silva et al., 2023; Fernandes & Ferreira, 2023). It provides a solid foundation for informed decision-making (Lima, 2017; Lima & Gurgel, 2018; Stocco et al., 2020).

**3.1 – HISTORICAL VALIDATION IN THE BREA MODEL**

The historical validation of the BREA model involves comparing its predictions with real-world data, a standard practice in general equilibrium modeling. This process evaluates the model’s accuracy in replicating short- and long-term economic patterns in Brazil, using data from 2009 to 2020 on land use, GDP, and agricultural production. While BREA is based on the GTAP framework, it incorporates significant modifications to better reflect Brazil’s economic and environmental context. These modifications include: The inclusion of degraded pasture mapping for Brazil for the years 2009-2010 and 2019-2020; A new land-use mapping; Detailed information on land allocated to temporary and permanent crops; Updated GDP values up to 2020.

The initial 2019 calibration was adjusted with fundamental parameters and variables to ensure that the model accurately reflected the economic conditions of the analyzed period. This calibration process involved updating key economic data, such as GDP, land use, and agricultural production, and incorporating specific elasticities to better capture Brazil’s economic and environmental dynamics. The elasticities used in the model were defined based on studies conducted by Chen et al. (2013), Chen et al. (2017), and Lima (2017), which provide robust estimates for the Brazilian context. These elasticities were chosen to refine the model’s responsiveness to changes in prices, production, and resource allocation, ensuring a more accurate representation of Brazil’s economic behavior. By integrating these adjustments, the model was able to replicate historical trends and provide a reliable basis for projecting future scenarios (Rutherford & Paltsev, 2000; Rutherford, 2005; Guilhoto et al., 2010).

Figure 3 shows that the model has adequate precision in broader regions, such as the South, Southeast, and Center-West, with error variations between -2 and 4 percentage points. The data presented in the figure refer to the Gross Domestic Product (GDP). However, less aggregated regions, such as the Northeast and MATOPIBA, show higher discrepancies, with variations of up to 7 percentage points. These differences reflect the challenges of projections in highly disaggregated databases, where regional specificities and data limitations can affect accuracy.

While the model demonstrates good performance in historical validation up to 2020 and in projections until 2030, its reliability decreases for forecasts beyond 2031. This limitation is common in long-term economic modeling, as uncertainties and external factors—such as technological changes, policy shifts, or climate impacts—become more pronounced over time (Babatunde et al., 2017; Fernandes & Ferreira, 2023). Despite these deviations in long-term projections, the model remains valid and useful for analyzing medium-term scenarios (up to 2030), providing robust insights for policy evaluation and decision-making. Its accuracy in broader regions and its ability to capture key economic trends make it a reliable tool, even with the noted limitations in highly disaggregated or long-term contexts.

Figure 3 – BREA model calibration for the year 2019

**Change in GDP in percentage points**

**South**

**Southeast**

**Center-West**

**North**

**Northeast**

**MATOPIBA**

**Source**: author's elaboration

**3.2 – SIMULATED SCENARIOS**

The simulation exercises involve two scenarios: the Base Scenario (reference scenario) and the PES Scenario, which includes the analysis of Payment for Environmental Services (PES). The BREA model, as previously described, underwent an initial calibration process using 2009 data, followed by projections up to 2019. For the period from 2020 to 2030, an exogenous shock was applied to simulate the introduction of PES as a mechanism to incentivize the preservation of Legal Reserve Surplus (LRS) and Native Protected Areas (UNU). The magnitude of the shock was determined based on the opportunity cost of land, which represents the amount required to compensate producers for not converting LRS into agricultural areas. This approach ensures that the shock reflects real-world economic conditions and is grounded in empirical data.

The shock was modeled as a change in production costs and resource allocation, reflecting the economic incentives provided by PES. It propagates through the economy by altering relative prices, land allocation, and agricultural production, particularly affecting key sectors such as soybeans, corn, and pasture. Specifically, the shock impacts the Constant Elasticity of Transformation (CET) land supply function, which captures the reallocation of land between alternative uses—for example, preservation versus agricultural production. The CET function reflects the willingness of landowners to change land use in response to economic incentives, such as those provided by PES (Chen et al., 2013; Chen et al., 2017).

The PES value was estimated as the amount needed to make producers indifferent between converting LRS into agricultural areas or preserving it. This value was calculated based on the opportunity cost of land, taking into account the profitability of soybean, corn, and pasture crops, as well as production costs and market prices.

* **Base scenario (Reference or Baseline):** This scenario represents a business-as-usual trajectory, with projections for economic variables such as GDP, investment, consumption, and exports. In this scenario, there are no restrictions on the conversion of native vegetation (LRS and UNU) into other uses, allowing the full exploitation of these areas.
* **PES (BT) Scenario for Soybean, Corn, and Pasture Production in LRS Areas:** This scenario simulates the amount of new soybean, corn, and pasture production areas in LRS areas. The objective is to evaluate the volume of forest areas converted for these crops by 2030.

The Base Scenario serves as a reference for projecting economic variables until 2030, considering the unrestricted use of LRS and UNUs (legally protected units). The PES (BT) Scenario focuses on specific PES policies for crops such as soybeans, corn, and pastures, imposing restrictions on forest use through shocks in the BREA model. These shocks include policies to limit deforestation and enforce forest regulations, allowing the assessment of impacts on agricultural production, land use, deforestation rates, and economic indicators.

The macroeconomic closure of the BREA model follows the neoclassical methodology. In this framework: The supply of productive factors (capital, labor, and land) is fixed, with no mobility between regions. Land is specific to the agricultural sectors and, like other factors, has no mobility. The model assumes flexible prices and does not account for unemployment. Investments and the balance of payments are treated as fixed, while adjustments in the real exchange rate accommodate changes in exports and imports. Government expenditure reacts to variations in prices and tax revenues. These assumptions shape land-use projections that, although detailed, may not fully capture all regional trends observed in Brazil (Rutherford & Paltsev, 2000; Rutherford, 2005).

**4 – RESULTS**

A detailed representation of land use in Computable General Equilibrium (CGE) Models allows for the investigation of how economic activities impact the environment, as natural areas—including forests and non-forest lands—are included in the database. Land-use changes are driven by factors such as demand for food, fuel, and fiber, the need for environmental conservation, and the agricultural suitability of the areas. Thus, this study analyzed the value of Payment for Environmental Services (PES) necessary to make producers indifferent to the conversion of their Legal Reserve Surplus (LRS) areas, establishing an economic value that considers production costs and supports Law 14.119/2021, which regulates PES in Brazil (Brasil, 2021; Winkel et al., 2022).

To simulate the value of PES at the national level, a scenario focused on the conversion of LRS areas for agricultural production was developed, called the PES Scenario (BT). This scenario aims to avoid the conversion of legally protected units (UNU) and allows the conversion only of LRS. The costs of forest land acquisition and its transformation into agricultural crops were considered, as detailed in Appendix A. The research focused on the conversion of LRS to soybean, corn, and pasture due to high levels of deforestation in the *Cerrado* biome (Nepstad et al., 2019; Magalhães et al., 2020) and the actions of the Soy Moratorium (MS), which aims to prevent soybean production in deforested areas from 2020 (Brasil, 2019). The inclusion of corn occurred due to its integration into crop rotation systems, although no conversion of LRS to corn was observed. The choice of pastures reflects the potential for expanding barriers against beef production, as already seen in the North region due to the MS in the Amazon.

Figure 5 illustrates the total LRS converted for soybean and pasture production in the Cerrado biome (Center-West and MATOPIBA) in the Base and PES (BT) scenarios. The data include soybean and grassland areas in the Cerrado, allowing for the observation of differences in converted areas between crops. In the Base Scenario, without protective measures, approximately 400,000 hectares of LRS would be converted, resulting in less incentive for pro-environmental actions and greater conversion of LRS to soybean and pasture production by 2030. In the PES (BT) Scenario, which restricts conversion to soybean, corn, and pasture, the converted area would be approximately 191,000 hectares by 2030, a reduction of 52% due to deforestation restrictions.

Figure 5 – LRS conversion for PES (BT) and Base

**LRS PASTURE C. W.**

**LRS SOY MATOPIBA**

**112.328**

**283.762**

**116.555**

**79.238**

**100%**

**100%**

***CERRADO***

**LRS MATOPIBA**

**LRS C. W.**

**400.317**

**191.620**

Source: author's elaboration

Figure 5 also indicates that the largest forest conversion in the *Cerrado* occurs for pasture production in both scenarios. This result suggests that the Center-West would tend to specialize in animal protein production by 2030, focusing on converting LRS to new grazing areas. On the other hand, MATOPIBA would continue converting LRS to soybean production, maintaining its growth and specialization in this crop. This result supports the idea that, with the development of the agricultural area of the *Cerrado*, MATOPIBA would specialize in soybean production, reinforcing the importance of the Soy Moratorium (MS) to avoid new forest conversions for this crop (Brasil, 2019; Soterroni et al., 2019).

For the financial analysis of PES, the research considered the PES (BT) and Base scenarios, focusing on the conversion of LRS to soybean, corn, and pasture. It should be noted that the model did not identify the conversion of new areas for corn production. Figure 6 shows the values obtained by producers in 2030 from the sale of soybeans or cattle, considering both scenarios. In the PES (BT) Scenario, soybean production in the *Cerrado* would yield approximately R$541.2 million over an area of 79,000 hectares, with an emphasis on MATOPIBA. This value reinforces the relevance of the region for soybean production and its impact on Brazilian GDP. In the case of pastures, the model simulated approximately R$2.4 billion over an area of 112,000 hectares.

Figure 6 –Total PES values that could make producers indifferent about whether or not to convert their LRS areas in the Base and PES (BT) scenarios



**Source**: author's elaboration

In the Base Scenario, pasture production through LRS in the *Cerrado* region, specifically in the Center-West, would result in approximately R$6 billion, covering an area of about 283,000 hectares. In contrast, soybean production would generate around R$724 million over an area of approximately 116,500 hectares (see Figure 6). These figures highlight the importance of cattle production within the Brazilian agricultural and economic context, demonstrating the potential of pasture production as a significant source of income for producers in both the PES (BT) and Base scenarios.

Figure 7 shows the annual values in reais per hectare (R$/ha/year) that producers would obtain in 2030 in the Center-West and MATOPIBA regions, considering soybean crops and pastures separately, in the PES (BT) and Base scenarios. It is observed that soybean production in the Center-West is limited in both scenarios, while in MATOPIBA, the conversion of LRS to pasture production is non-existent. In MATOPIBA, if the PES (BT) Scenario were implemented, producers would receive about R$21,404.00/ha/year, while the PES (BT) presented R$21,322.00/ha/year, a difference of only 0.4%.

Figure 7 – Value gained per hectare of soybean and pasture in 2030 for the Base and PES (BT) scenarios

Source: author's elaboration

Although soybean production in MATOPIBA shows a pro-environmental incentive in the PES Scenario, this does not occur for grasslands in the Center-West. However, the adoption of the PES Scenario (BT) would indicate that, with minimal financial impact, producers could be motivated to conserve forests. In addition, the success of PES actions requires government support not only financial but also through public policies that integrate rural extension practices, reinforcing the importance of preservation.

The results obtained from the analysis of LRS conversion for agricultural production in the *Cerrado* biome demonstrate the complexity of the interactions between economic activities and environmental preservation. The evidence that pasture production generates significantly higher economic value compared to soybean production underscores the importance of cattle ranching in the Brazilian economy. According to Adams et al. (2021) and Fernandes & Ferreira (2023), effective governance of forest restoration is crucial for balancing economic development and environmental conservation. This suggests that policies promoting sustainable pasture production could be an effective strategy to mitigate the negative environmental impacts associated with agricultural expansion.

Furthermore, research by Börner et al. (2017) on the effectiveness of PES highlights that financial incentives play a key role in promoting sustainable agricultural practices. In the context of the PES (BT) Scenario, where land conversion is restricted and producers are compensated for avoiding deforestation, there is significant potential to reduce pressure on native forests. The implementation of robust and well-structured policies is essential to motivate producers to adopt conservation-friendly practices, aligning their economic interests with environmental needs.

Finally, as discussed by Muradian et al. (2010), Babatunde et al. (2017), and Suela et al. (2023), the application of CGE models provides valuable insights into the economic implications of climate change mitigation policies, including the impacts of restricting LRS conversion. These models allow for a comprehensive analysis of trade-offs between economic growth and environmental preservation, offering a solid foundation for evidence-based policymaking.

**FINAL CONSIDERATIONS**

This study addresses the issue of forest conversion in the *Cerrado* biome, with a particular focus on the agricultural frontier region of MATOPIBA. Utilizing the BREA Computable General Equilibrium (CGE) model, which provides a detailed representation of agricultural sectors and various land-use categories, the research integrates economic theories with qualitative insights on public policy preferences and possibilities. The main objective was to quantify a mechanism for Payment for Environmental Services (PES) related to the Legal Reserve Surplus (LRS) in the *Cerrado*, specifically targeting the MATOPIBA region until 2030. This integrated approach combines economic theory, detailed sectoral representation, and environmental policy considerations to understand and address the challenges associated with environmental preservation and economic development in agricultural frontier areas. A key research question guiding this study is the concern regarding the Moratorium on Soybean in the *Cerrado* (MC), which may have significant implications in the near future.

In this context, several initiatives have potential to support producers who maintain forest areas on their properties, such as the Low Carbon Agriculture Plan (ABC Plan), REDD+ (Reducing Emissions from Deforestation and Forest Degradation), and Law 14.119/2021, which establishes guidelines for PES. This research simulated the PES values needed to make landowners indifferent between converting or preserving their native forest areas, specifically those classified as LRS in the *Cerrado* biome. In the PES (BT) scenario, PES values in the *Cerrado* ranged from R$ 6,830.00/ha/year for soybean production to R$ 21,404.00/ha/year for pasture production. The analysis indicated that landowners in the Center-West would not convert native forests to soybean production; however, such conversions could occur in MATOPIBA. For MATOPIBA, a PES of R$ 6,830.00/ha/year was necessary to make producers indifferent to converting LRS into new productive areas. In contrast, there was no projected forest conversion for pasture production in MATOPIBA; in the Center-West, a PES of R$ 21,322.00/ha/year was required for landowners to remain indifferent.

These PES values serve as important references for policymakers when designing future public policies. The trade-off between increasing agricultural production and avoiding the conversion of new areas of native forest must consider rural producers' needs. This research presents an introductory exploration of this complex issue, with hopes that its findings will yield positive impacts. However, many open questions remain that require ongoing attention and efforts to advance forest protection.

While this analysis provides valuable insights into the interactions between economic activities and environmental conservation in the *Cerrado*, it is important to acknowledge several limitations of the CGE model used. One limitation is its rigidity of assumptions; for example, the model assumes a fixed supply of production factors and lacks regional mobility, which may not accurately reflect real market dynamics. Additionally, it does not account for social and cultural factors influencing producers' decisions, such as community acceptance of sustainable practices and public policy impacts on local communities. Another limitation is its narrow focus on specific crops like soybeans and pastures without exploring other relevant agricultural alternatives in the *Cerrado*. To enhance applicability and relevance, future research should incorporate socioeconomic factors and adopt a more comprehensive approach to agricultural practices. This could ultimately contribute to better formulation of environmental policies that align with both economic development and conservation goals.

**REFERENCE**

ADAMS, C. et al. Governança da restauração florestal da paisagem no Brasil: desafios e oportunidades. **Desenvolvimento e Meio Ambiente**, v. 58, p. 450-73, 2021. <https://doi.org/10.5380/dma.v58i0.78415>.

AGROSATÉLITE GEOTECNOLOGIA APLICADA LTDA. Análise geoespacial da expansão da soja no bioma Cerrado: 2000/01 a 2020/21. – Florianópolis-SC, Brasil. p. 25. 2021. Available: <https://abiove.org.br/abiove_content/Abiove/relat_cerrado_21.pdf>. Access on: 12 nov. 2024.

BABATUNDE, K. A.; BEGUM, R. A.; SAID, F. F. Application of computable general equilibrium (CGE) to climate change mitigation policy: A systematic review. **Renewable and Sustainable Energy Reviews**, v. 78, p. 61-71, 2017. <https://doi.org/10.1016/j.rser.2017.04.064>.

BÖRNER, J. et al. The effectiveness of payments for environmental services. **World development**, v. 96, p. 359-374, 2017. <https://doi.org/10.1016/j.worlddev.2017.03.020>

BRASIL. Projeto de Lei n° 4203, de 2019. Access on: 12 nov. 2024. Available: <https://legis.senado.leg.br/sdleg-getter/documento?dm=7982420&ts=1630421338863&disposition=inline>. Access on: 12 nov. 2024. 2019.

BRASIL. Lei Federal nº 12.651, de 25 de maio de 2012. Available: <https://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm>. Access on: 12 nov. 2024.

BRASIL. Lei n. 14.119, de 2021 – Institui a Política Nacional de Pagamento por Serviços Ambientais. Available: http://planalto.gov.br/ccivil\_03/\_Ato2019- 2022/2021/Lei/L14119.htm. Access on: 01 jan. 2025.

BURFISHER, M. E. Introduction to computable general equilibrium models. Cambridge University Press, 2021.

CABRAL, L.; SAUER, S.; SHANKLAND, A. Introduction: Reclaiming the Cerrado–A Territorial Account of a Disputed Frontier. **IDS Bulletin** v. 54. nº 1. p. 18. 2023. <https://doi.org/10.19088/1968-2023.102>.

CAETANO BACHA, C. J.; STEGE, A. L.; HARBS, R. Ciclos de preços de terras agrícolas no Brasil. **Revista de Política Agrícola**, v. 25, n. 4, p. 18-37, 2016.

CHRIST, G. D. et al. O Agronegócio Brasileiro No Comércio Internacional: Vulnerabilidade, Retrocesso, Oportunidade Perdida Ou Situação Ótima?. **Informe Gepec**, v. 26, n. 2, p. 190-209, 2022. <https://doi.org/10.48075/igepec.v26i2.28426>.

COMPANHIA NACIONAL DE ABASTECIMENTO - CONAB. Acompanhamento da Safra Brasileira de grãos, v. 8 – Safra 2020/21, n. 1 - Primeiro levantamento, Brasília, p. 1-77, oct. 2020. Available: <https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos?start=40>. Access on: 12 nov. 2024.

DA SILVA, J. G.; DE ALMEIDA, R. B.; CARVALHO, L. V. An economic analysis of a zero-deforestation policy in the Brazilian Amazon. **Ecological Economics**, v. 203, p. 107613, 2023. <https://doi.org/10.1016/j.ecolecon.2022.107613>

DE SOUZA, V. B. et al. Modelo Insumo-Produto Inter-Regional Para A Avaliação Econômica De Fenômenos Climáticos Na Oferta De Cereais No Rio Grande Do Sul. **Informe Gepec**, v. 27, n. 2, p. 262-385. [https://doi.org/10.48075/igepec.v27i2.31063. 2023](https://doi.org/10.48075/igepec.v27i2.31063.%202023).

DIXON, P. B.; RIMMER, M. T. (Ed.). Dynamic general equilibrium modelling for forecasting and policy: a practical guide and documentation of MONASH. **Emerald Group Publishing Limited**, 2001.

ENGEL, S., PAGIOLA, S. & WUNDER, S. Designing payments for environmental services in theory and practice: An overview of the issues. **Ecological Economics**, 65, 663-674. <https://doi.org/10.1016/j.ecolecon.2008.03.011>. 2008.

FARLEY, J.; COSTANZA, R.. Payments for ecosystem services: from local to global. **Ecological economics**, v. 69, n. 11, p. 2060-2068, 2010. <https://doi.org/10.1016/j.ecolecon.2010.06.010>

FERNANDES, B. B.; FERREIRA, P. C. Network and general equilibrium effects of carbon taxes and deforestation. 2023. <https://repositorio.fgv.br/server/api/core/bitstreams/e1b4589e-5b81-4ce9-89ad-03e6f28353ea/content>.

FERREIRA-PAIVA, Lucas et al. A k-means-based-approach to analyze the emissions of GHG in the municipalities of MATOPIBA region, Brazil. IEEE Latin America Transactions, v. 20, n. 11, p. 2339-2345, 2022. [10.1109/TLA.2022.9904758](https://doi.org/10.1109/TLA.2022.9904758)

FIAN INTERNACIONAL. The Human and Environmental Cost of Land Business The case of MATOPIBA, Brazil. Available: <https://www.fian.org/files/files/The_Human_and_Environmental_Cost_of_Land_Business-The_case_of_MATOPIBA_240818.pdf>. Access on: 12 nov. 2024. 2018.

GUILHOTO, J. et al. Estimação da Matriz Insumo-Produto Utilizando Dados Preliminares das Contas Nacionais: Aplicação e Análise de Indicadores Econômicos para o Brasil em 2005. Available at **SSRN** 1836495. <http://dx.doi.org/10.2139/ssrn.1836495>. 2010.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. Sistema de Contas Regionais. Rio de Janeiro, 2020b. Available: <https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9054-contas-regionais-do-brasil.html?edicao=32020&t=resultados>. Access on:12 de may. 2024.

KALAMANDEEN, M. et al. Pervasive rise of small-scale deforestation in Amazonia. **Scientific reports**, v. 8, n. 1, p. 1-10. <https://doi.org/10.1038/s41598-018-19358-2>. 2018.

LABORATÓRIO DE PROCESSAMENTO DE IMAGENS E GEOPROCESSAMENTO - LAPIG. Atlas Digital das Pastagens Brasileiras. 2020. Available: <http://atlasdaspastagens.ufg.br/>. Access on: 19 may. 2024.

LIMA, C. Z. Impacts of Low Carbon Agriculture in Brazil: a CGE aplication. 2017. 113f. Doctoral Thesis. Thesis Agricultural Economics–Universidade Federal de Viçosa, Minas Gerais. Available: <https://www.locus.ufv.br/handle/123456789/19866>. Access on: 19 may. 2024. 2017.

LIMA C. Z., GURGEL A. C. The role of double cropping modeling for policy assessment in Brazil. In 21th GTAP Conference. p. 19. Available: <https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5606>. Access on: 19 may. 2024. 2018.

MAGALHÃES, I. B. et al. Brazilian Cerrado and Soy moratorium: Effects on biome preservation and consequences on grain production. **Land use policy**, v. 99, p. 105030. <https://doi.org/10.1016/j.landusepol.2020.105030>. 2020.

MANIFESTO, Cerrado The Future of the Cerrado in the Hands of the Market: Deforestation and Native Vegetation Conversion must be Stopped. Available: <http://d3nehc6yl9qzo4.cloudfront.net/downloads/cerradoconversionzero_sept2017_2.pdf>. Access on: 19 may. 2024. 2017.

MAPBIOMAS. Desmatamento. Available: <https://plataforma.brasil.mapbiomas.org/>. Access on: 19 may. 2024. 2024.

MINISTÉRIO DA AGRICULTURA, PECUÁRIA E ABASTECIMENTO - MAPA. Brasil Projeções do Agronegócio 2019/2020 a 2029/2030. Available: <https://www.gov.br/agricultura/pt-br/assuntos/politica-agricola/todas-publicacoes-de-politica-agricola/projecoes-do-agronegocio/projecoes-do-agronegocio_2019_20-a-2029_30.pdf>. Access on: 19 may. 2024. 2020.

MURADIAN, R. et al. Reconciling theory and practice: An alternative conceptual framework for understanding payments for environmental services. **Ecological economics**, v. 69, n. 6, p. 1202-1208, 2010. <https://doi.org/10.1016/j.ecolecon.2009.11.006>

NEPSTAD, D. et al. Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. **Science**, v. 344, n. 6188, p. 1118-1123. Available: <https://1248525.nepstad.sm.pdf>. Access on: 19 may. 2024. 2014.

NEPSTAD, L. S. et al. Pathways for recent Cerrado soybean expansion: extending the soy moratorium and implementing integrated crop livestock systems with soybeans. **Environmental Research Letters**, v. 14, n. 4, p. 044029. <https://iopscience.iop.org/article/10.1088/1748-9326/aafb85/meta>. 2019.

PAGIOLA, S.; BISHOP, J.; LANDELL-MILLS, N. Selling forest environmental services: market-based mechanisms for conservation and development, London, UK: Earthscan. Available: <https://www.iied.org/9178iied>. Access on: 19 may. 2024. 2002.

PAGIOLA, S.; PLATAIS, G. Payments for Environmental Services: From Theory to Practice. Washington: **World Bank**. Available: <http://hdl.handle.net/10919/65833>. Access on: 19 may. 2024. 2006.

PEREVOCHTCHIKOVA, M. et al. A systematic review of scientific publications on the effects of payments for ecosystem services in Latin America, 2000–2020. **Ecosystem Services**, v. 49, p. 101270, 2021. <https://doi.org/10.1016/j.ecoser.2021.101270>

PESCHE, D.; MÉRAL, P.; HRABANSKI, M.; BONNIN, M. Ecosystem services: emergence of new paradigms within the economics of ecosystem. In: MURADIAN, R.; RIVAL, L. (eds.) Governing the provision of environmental services. **Springer**. <https://doi.org/10.1007/978-94-007-5176-7_4>. 2012.

POLIZEL, S. P. et al. Analysing the dynamics of land use in the context of current conservation policies and land tenure in the Cerrado–MATOPIBA region (Brazil). **Land Use Policy**, v. 109, p. 105713. <https://doi.org/10.1016/j.landusepol.2021.105713>. 2021.

RAJÃO, R.; SOARES-FILHO, B. Cotas de reserva ambiental (CRA): potencial e viabilidade econômica do mercado no Brasil. Belo Horizonte. Available: <https://www.researchgate.net/profile/Raoni-Rajao/publication/297760103_Cotas_de_reserva_ambiental_CRA_potencial_e_viabilidade_economica_do_mercado_no_Brasil/links/5707270908aeda83af53808a/Cotas-de-reserva-ambiental-CRA-potencial-e-viabilidade-economica-do-mercado-no-Brasil.pdf>. Access on: 19 may. 2024. 2015.

RICHETTI, A. Viabilidade econômica da cultura da soja para a safra 2021/2022, em Mato Grosso do Sul. Embrapa Agropecuária Oeste-Comunicado Técnico (**INFOTECA-E**). Available: <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/224888/1/COT-262-2021.pdf>. Access on: 19 may. 2024. 2021.

RIPPEL, R.; RIPPEL, V, C. L. Considerações a respeito das origens, dos acontecimentos e das consequências da crise econômica mundial atual. **Informe Gepec**, v. 12, n. 2, p. 6-27, 2008. <https://doi.org/10.48075/igepec.v12i2.2298>.

RUTHERFORD T. F.; PATSEV S. V. GTAPinGAMS and GTAP-EG: global datasets for economic reserach and illustrative models. Available: <https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=b0e98427160579668f2b86015f0a071c8272cd69>. Access on: 19 may. 2024. 2000.

RUTHERFORD T. F. GTAP6inGAMS: The dataset and static model. Available: <http://www.mpsge.org/gtap6/gtap6gams.pdf>. Access on: 19 may. 2024. 2005.

SILVEIRA, G. B.; MÚNIZ, S. T. G. Pagamento por Serviços Ambientais: o caso da compensação de Reserva Legal. **Revista de Estudos Ambientais**, v. 16, n. 1, p. 16-26. <https://doi.org/10.7867/1983-1501.2014v16n1p16-26>. 2014.

SISTEMA DE ESTIMATIVAS DE EMISSÃO DE GASES DO EFEITO ESTUFA – SEEG. Análise Das Emissões De 2023 1970-2022 Gases De Efeito Estufa E Suas Implicações Para As Metas Climáticas Do Brasil. Período 1970 – 2022. Brasília. Available: <https://oc.eco.br/wp-content/uploads/2023/11/Relatorio-SEEG_gases-estufa_2023FINAL.pdf>. Access on: 19 may. 2024. 2023.

SOARES-FILHO, Britaldo et al. Cracking Brazil's forest code. **Science**, v. 344, n. 6182, p. 363-364, 2014. DOI: 10.1126/science.1246663.

SOLIDARIDAD. Potencial regional de expansão da soja no MATOPIBA; São Paulo. Available: <https://solidaridadlatam.org/brasil/wp-content/uploads/2023/07/potencial_regional_de_expansao_da_soja_no_matopiba.pdf>. Access on: 19 may. 2024. 2021.

SOTERRONI, A. C. et al. Expanding the soy moratorium to Brazil’s Cerrado. **Science advances**, v. 5, n. 7, p. eaav7336. <https://www.science.org/doi/full/10.1126/sciadv.aav7336>. 2019.

SPAROVEK, G. et al. Asymmetries of cattle and crop productivity and efficiency during Brazil’s agricultural expansion from 1975 to 2006. Elementa: **Science of the Anthropocene**, v. 6. <https://doi.org/10.1525/elementa.187>. 2018.

STOCCO, L.; DE SOUZA FERREIRA FILHO, J. B.; HORRIDGE, M. Closing the Yield Gap in Livestock Production in Brazil: New Results and Emissions Insights. In: Environmental Economics and Computable General Equilibrium Analysis. **Springer**, Singapore. p. 153-170. <https://doi.org/10.1007/978-981-15-3970-1_7>. 2020.

SUELA, A. G. L. et al. Conhecimento, percepção climática e comportamento pró-ambiental na agricultura. **Revista Econômica do Nordeste**, v. 51, n. 3, p. 193-206. 2020 [https://doi.org/10.61673/ren.2020.1126. 2020](https://doi.org/10.61673/ren.2020.1126.%202020).

SUELA, A. G. L. et al. Análise de impacto econômico e relações setoriais entre MATOPIBA e o restante do brasil: uma abordagem por insumo-produto. **Informe Gepec**, v. 26, n. 1, p. 62-86, 2021. <https://doi.org/10.48075/igepec.v26i1.27994>.

SUELA, A. G. L. Sectoral analysis and identification of key sectors in MATOPIBA: an input-product approach. **Economia & Região**, v. 10, n. 3, p. 194-217, 2022. <https://doi.org/10.54766/rberu.v14i4.654>.

SUELA, A. G. L. et al. Impact of gross domestic product growth on Brazilian native forests: a computable general balance analysis. **Informe Gepec**, v. 27, n. 1, p. 228-245. <https://doi.org/10.48075/igepec.v27i1.30378>. 2023a.

SUELA, A. G. L.; SUELA, G. L.; DE MATOS CARLOS, S. Fatores que Influenciam a Recuperação de Pastagens Degradadas Pelos Agricultores da Bacia Hidrográfica do Rio das Contas. **Revista de Economia e Agronegócio**, v. 21, n. 1, p. 1-17, 2023b. <https://doi.org/10.25070/rea.v21i1.13106>

SUELA, A. G. L. Análise econômica da conversão de florestas nativas e seu impacto no PIB do Brasil até 2030. **Caderno Pedagógico**, v. 21, n. 3, p. e3054-e3054. <https://doi.org/10.54033/cadpedv21n3-042>. 2024a.

SUELA, A. G. L. et al. Impactos do novo código florestal no bioma cerrado: foco no MATOPIBA. **Caderno Pedagógico**, v. 21, n. 9, p. e8194-e8194, 2024b. <https://doi.org/10.54033/cadpedv21n9-266>

TIETENBERG, T.; LEWIS, L. Environmental and natural resource economics. Routledge. <https://doi.org/10.4324/9781315208343>. 2018.

WINKEL, G. et al. Governing Europe's forests for multiple ecosystem services: Opportunities, challenges, and policy options. **Forest Policy and Economics**, v. 145, p. 102849. <https://doi.org/10.1016/j.forpol.2022.102849>. 2022.

WUNDER, S. Payments for environmental services: some nuts and bolts., Bogor, Indonesia: CIFOR Occasional Paper No. 42. Center for International Forestry research. Available: <https://montagneinrete.it/wp-content/uploads/2024/03/op-42-wunder-on-payments_1495540914-1.pdf>. Access on: 19 may. 2024. 2005.

XU, J. et al. Double cropping and cropland expansion boost grain production in Brazil. **Nature Food**, v. 2, n. 4, p. 264-273. [https://doi.org/10.1038/s43016-021-00255-3. 2021](https://doi.org/10.1038/s43016-021-00255-3.%202021).

Recebido em 15/11/2024.

Aceito em 30/04/2025.

1. Doutor em Economia Aplicada. Pós-doutorando do Programa de Pós Graduação em Desenvolvimento e Meio Ambiente da Universidade Estadual de Santa Cruz (UESC) – Email: attawan\_zull@hotmail.com. [↑](#footnote-ref-1)
2. Doutor em Economia Aplicada pela Universidade Federal de Viçosa (UFV). Pesquisador do Centro de Estudos do Agronegócio (FGV) - Email: cicero.lima@fgv.br. [↑](#footnote-ref-2)
3. Doutor em Economia Aplicada pela Universidade Federal de Viçosa (UFV). Pesquisador Associado de Pós-Doutorado do Departamento de Economia Agrícola, Universidade Purdue (GTAP). Email: rayanwolf@gmail.com [↑](#footnote-ref-3)
4. Doutor em Economia Aplicada pela Universidade Federal de Viçosa (UFV). Professor do Programas de Pós-Graduação em Economia Aplicada (PPGEA). ian.trotter@gmail.com. [↑](#footnote-ref-4)