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Modeling the Impacts of the Ecological Transformation Plan

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Acronyms

ABNT, acronym in Portuguese Brazilian Association of Technical Standards.

BAU *Business as Usual.*

BNDES, acronym in Portuguese Brazilian Development Bank.

CETESB Companhia Ambiental do Estado de São Paulo.

CNI Confederação Nacional da Indústria.

CO$_2$ Carbon Dioxide.

CO$_2$eq CO2 equivalent.

ETP Ecological Transformation Plan.

FGV Fundação Getúlio Vargas.

Finep, acronym in Portuguese Funding Authority for Studies and Projects.

GHG Greenhouse Gases.

GIC Grupo de Indústria e Competitividade.

GO Gross Ouptut.

Gt Giga tons.

HP Hodrick-Prescott.

IBGE Instituto Brasileiro de Geografia e Estatística.

IMF International Monetary Fund.

IOM Input-Output Matrix.

IPCC Intergovernamental Panel for Climate Change.

MCTI Ministry of Science and Technology (acronym in Portuguese).

MDIC/SECEX Secretaria de Comércio Exterior do Ministério do Desenvolvimento, Indústria, Comércio e Serviços.

MIP Matriz Insumo-Produto.

MOVER, acronym in Portuguese Green Mobility and Innovation Program.

NDC Nationally Determined Contributions.

NIB New Industry Brazil.

Novo PAC, acronym in Portuguese New Program of Growth Acceleration.

OECD Organisation for Economic Co-operation and Development.

PAGE Partnership for Action on Green Economy.

POF, acronym in Portuguese Household Budget Survey.

SAF Sustainable Aviation Fuel.

SAM Social Accounting Matrix.

SEEG Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa.

SNA System of National Accounts.

UNEP United Nations Environment Programme.

UNFCCC United Nations Framework Convention on Climate Change.

1 Introduction

This project is framed within the Partnership for Action on Green Economy (PAGE), a collaborative initiative formed by five United Nations agencies. Recognizing the potential impact of the ETP, PAGE was approached by the Brazilian Ministry of Finance to quantify the macroeconomic, social, and environmental impacts of the plan.

The Brazilian government has sought to implement various environmental policies to manage and reduce GHG emissions in response to global climate change and its goals to achieve net-zero emissions by 2050 (Brasil, 2023). This concern involves identifying critical sectors for de-carbonizing the Brazilian economy. The ETP, aligned with various policies adopted by developed and developing countries (Peres et al., 2024), aims to build and adopt a coherent set of economic policies geared toward climate neutrality by 2050, following the commitments made in the Paris Agreement of 2015 and the Nationally Determined Contributions (NDC).

Within the scope of the ETP – comprising six main axes: Sustainable Finance, Technological Densification, Bioeconomy and Agri-Food Systems, Energy Transition, Circular Economy, Green Infrastructure, and Adaptation – the Brazilian government recently proposed policies to achieve climate neutrality commitments by 2050. These include plans like MOVER (transport sector), New Industry Brazil (productive densification, technological change, among others), Climate Plan, and ABC+ Plan (both targeting the agricultural sector), among others. This set of measures aims to reduce the trajectory of Brazilian economy emissions in a relatively short time-frame, requiring sector-specific policies for de-carbonizing critical sectors for transitioning to a low-carbon economy.

In this context, the Institute of Economics of the Federal University of Rio de Janeiro was approached to offer United Nations Environment Programme (UNEP) and the Brazilian Ministry of Finance an assessment of the potential impacts of the ETP, focusing on the following aspects:

- The overall level of economic activity, including the trajectory of per capita income;
- Employment and inequality dimensions;
- GHG emissions trajectories;
- Manufacturing sectors based on their potential for job creation, income generation, and value addition;
- Inclusion of government deforestation targets in the emissions trajectory.

The goal of this report is to present the key elements developed by our team for analyzing the impacts of the ETP, as well as the main results and their policy implications.

We developed an ecological-economic model, with its economic core based on the dynamic input-output framework, expanded in sub-modules to more accurately account for the trajectories of GHG emissions in Brazil. The reference year adopted is 2019, and annual estimates extends to 2050.

The dynamic input-output model constitutes the model's core, relying on input-output matrices and data derived from the System of National Accounts, published by the IBGE. The IBGE's five-year input-output matrices are transformed into annual series. Also, using various survey data produced by IBGE, our team produced a Social Accounting Matrix compatible with the System of National Accounts, allowing us to expand the input-output matrices by disaggregating data by income strata (deciles). Final demand is endogenized to include household consumption of non-durable goods and gross fixed capital formation, while the capital flow matrix precisely relates investment to the sectors that supply capital goods. Productive capacity and investment are treated as endogenous in the model, while exports are decomposed by trade partner, influenced by income growth in destination countries and regions.

Exogenous model components include private consumption of durable goods, government consumption and investment, and residential investment, whose trajectories are scenarized based on historical time series patterns. We estimate GHG emissions per sector using Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa (SEEG) data, aligned at the product level and later aggregated for activity sectors.

Projections through 2050 use IBGE population data and, inspired by the Kaldor-Verdoorn law (Kaldor, 1978; Verdoorn, 1949), relates endogenously the evolution of labor productivity as a function of sectoral output, with a proportion econometrically estimated from historical data from 2001–2019.

Although the economic model covers a significant portion of Brazil's GHG emissions, focusing on emissions associated with the production of goods and services, it is complemented by auxiliary modules. These modules deploy information from the economic model to estimate emissions from other relevant sources in Brazil, such as land-use changes, use of motor vehicles, and electricity production, capturing potential changes in the country's energy matrix.

The selection of these topics reflects the particular structure of Brazilian emissions. Brazil's emission structure differs from major global emitters, where most emissions originate from the energy and industrial sectors. In Brazil, a significant share of emissions stems from land-use changes. This phenomenon is closely tied to agricultural and livestock activities, which, directly or indirectly, involve practices such as burning, deforestation, and land grabbing.

Another notable point is the transport sector, which includes activities captured by the System of National Accounts (such as freight transportation, commercial aviation, and transport services, all of which accounted for in the economic model) and the use of various modes of transport, including the national fleet of motor vehicles. This fleet, accumulated over decades, is largely powered by internal combustion and highly dependent on fossil fuels, although Brazil internationally stands out for its significant use of biofuels, such as ethanol.

The remainder of the report is structured as follows. Section 2 describes the six interconnected axes of the ETP: Sustainable Finance, Technological Advancement, Bioeconomy and Agro-Food Systems, Energy Transition, Circular Economy, and Resilience and Adaptation. It also presents an analysis of Brazil's GHG emissions by sector, emphasizing the dominant role of land-use change, deforestation, and the farming sector. Section 3 outlines the main methods and strategies used to model the impacts of the ETP. Section 4 introduces the scenario matrix developed to analyze the economic and emissions impacts, considering both policy and macroeconomic performance dimensions. Section 5 presents the key results of the model, focusing on GHG emissions, economic activity, employment, and inequality. Finally, Section 6 discusses the policy implications derived from the model's results.

2 Context

2.1 The Ecological Transformation Plan

The ETP is a large-scale strategy to address the urgent challenges posed by climate change while leveraging the country's vast environmental resources for sustainable development. As one of the most biodiverse nations in the world and a leader in renewable energy production, Brazil holds a pivotal role in global efforts to combat environmental degradation and transition toward a low-carbon economy. The plan aligns with Brazil's commitments under the Paris Agreement and the United Nations Sustainable Development Goals, proposing an integrated framework to balance economic growth, social equity, and ecological preservation.

The ETP outlines six interconnected axes to foster sustainable development and environmental conservation. Together, these axes provide a framework to guide Brazil toward a sustainable and resilient future, balancing environmental protection with economic growth and social inclusion:

Sustainable Finance: The first axis aims to mobilize resources for environmentally beneficial projects through several mechanisms and instruments. It aims to direct public resources toward sustainable activities and attract private investments, both domestic and international, to sectors related to ecological transformation. Several policies have already been implemented or are underway to support this objective, including Sustainable Sovereign Bonds, the Climate Fund, the Brazilian Emissions Trading System, the Brazilian Sustainable Taxonomy, and the Eco Invest Brasil plan, among others. Furthermore, the Brazilian Development Bank (BNDES, acronym in Portuguese) and the Funding Authority for Studies and Projects (Finep, acronym in Portuguese) play key roles, focusing on credit lines aimed at fostering innovation and ecological transformation.

Technological Densification: The second axis focuses on encouraging innovation and adopting green technologies by supporting research and development in sustainable solutions, promoting digital tools to enhance environmental monitoring and resource efficiency, fostering economic productivity growth through technological innovation and professional training and promoting more complex products and processes with higher added value, strengthens supply chains and creates qualified and well-paid jobs. Initiatives include the expansion of public research and development funds, the use of technology procurement and other innovation tools, and the adoption of well-calibrated local content rules in government purchases for energy transition and sustainable mobility. Additionally, there are incentives for the domestic processing of strategic minerals, agricultural products, and inputs, strengthening supply chains and creating skilled jobs. The New Legal Framework for Innovation also stands out, enhancing research partnerships between the government and the private sector. These actions are connected to the New Industry Brazil (NIB), which encompasses six missions with initiatives focused on fostering sustainable agriculture, the bioeconomy, decarbonization, and energy transition.

Bioeconomy and Agri-Food Systems: The third axis integrates biodiversity conservation with economic activities through the bioeconomy and agro-food systems. It emphasizes sustainable agricultural practices, forest management via concessions, and payment schemes for environmental services to incentivize conservation efforts aiming at the generation of income and promotion of technological development. Key actions in this area include the Plano Safra and Pronaf programs, which offer financial and tax incentives and technical assistance focused on more sustainable, low-carbon, and agro-industrial practices. The National Bioeconomy Strategy was established to strengthen the competitiveness of national bio-based production and promote innovation, scientific knowledge, and the equitable sharing of benefits with local populations. Other initiatives promote investments in sustainable biome management, expansion of forest concessions, export of non-timber forest products, and payments for environmental services.

Energy Transition: The fourth axis aims to shift Brazil's energy matrix towards low-carbon sources. It prioritizes investments in renewable energy, energy efficiency programs, and the development of green hydrogen as a clean energy alternative with cutting-edge national technologies in renewable energy sources and strengthening their production chains. It promotes the use of clean energy sources in the productive sector, focusing on green products and fostering decarbonization in land, maritime, and air transportation, aiming for neutrality in emissions. Main initiatives include the Future Fuel Law to set a clear advancement in biofuels – such as biodiesel, green diesel, ethanol, biomethane, Sustainable Aviation Fuel (SAF), and carbon capture technologies. It also supports new wind and solar energy concessions, including distributed mini-generation. Another key mechanism is the Green Mobility and Innovation Program (MOVER, acronym in Portuguese), ensuring new investments in producing less polluting vehicles.

Circular Economy: The fifth axis seeks to optimize resource use by enhancing recycling rates, advancing waste-to-energy technologies, and promoting product designs that support reuse and recycling, fostering the transition to a circular and sustainable model of production and consumption. Key initiatives include the new National Circular Economy Strategy, with fiscal and regulatory incentives for innovation, culture, education, and capacity building to reduce, reuse, and promote the circular redesign of production. It establishes the Recycling Support Fund and the Recycling Projects Investment Funds, providing fiscal incentives for the recycling chain and focusing on waste picker cooperatives. It also supports the National Solid Waste Policy Law, regulating Brazil's recycling system.

Green Infrastructure and Adaptation: The sixth axis addresses the impacts of climate change by strengthening disaster risk management, improving water resource conservation, and bolstering urban resilience to environmental challenges, enabling mechanisms for private and public financing of new infrastructure projects with a reduced environmental footprint. It promotes resilient cities adapted to the impacts of climate change, such as floods, heatwaves, droughts, and landslides. The New Program of Growth Acceleration (Novo PAC, acronym in Portuguese) promotes urban mobility initiatives, such as the acquisition of electric buses and disaster prevention – slope containment and drainage systems. Resources are also allocated to housing financing via the Minha Casa Minha Vida program to directly enhance people's safety and reduce risks associated with precarious housing conditions. Public policies are being implemented for risk prevention, mitigation, and preparation for extreme situations. This includes new monitoring systems, emergency actions for real-time responses, and protocols with environmental emergency decrees to address impacts in affected municipalities. Partnerships with other Ministries ensure a swift response to assist populations and support reconstruction efforts.

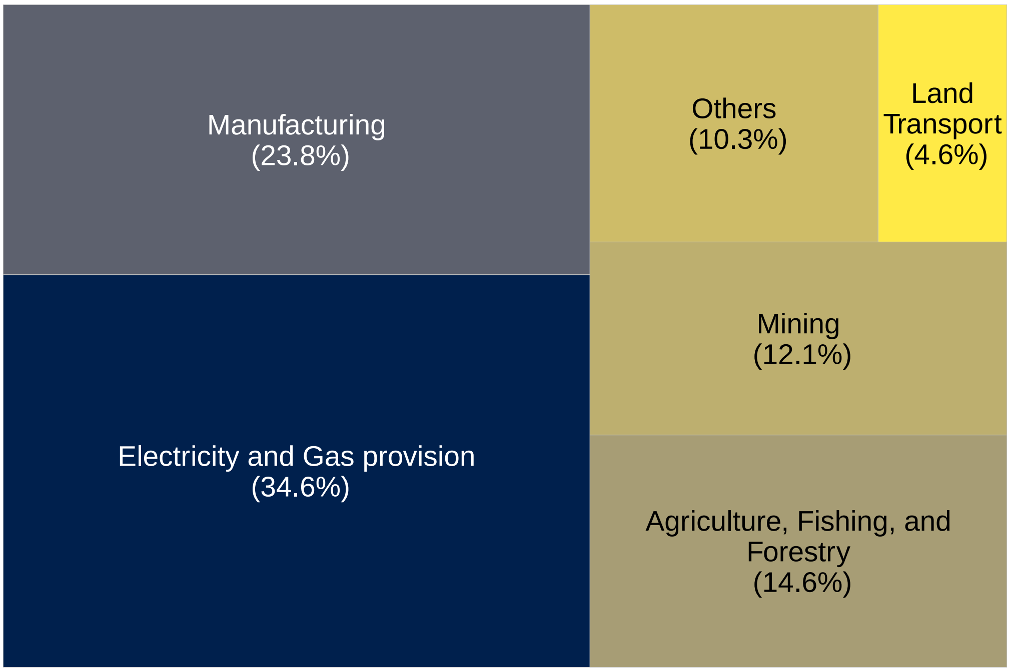
Overall, the ETP represents a bold and necessary step toward addressing climate change and ensuring long-term ecological and economic resilience. By focusing on renewable energy expansion, biodiversity conservation, and decarbonization, the plan aligns environmental goals with national development priorities. Its success will depend on sustained political will, international collaboration, and active participation from all sectors of society.

2.2 Brazilian GHG Emissions

The Paris Agreement has implications for the development of not only energy and transportation systems but also the industrial sector. In 2019, the industrial sector accounted for approximately 9 Giga tons (Gt) of direct CO_2 emissions globally, along with an additional 7 Gt in indirect emissions from energy use. This combined total represents nearly half of all energy-related CO_2 emissions, with energy- and emissions-intensive sectors such as steel, chemicals, cement, and aluminum contributing over 70% of direct industrial emissions worldwide (Agency, 2020). The latest information from global models considered by the Intergovernmental Panel for Climate Change (IPCC) to support United Nations Framework Convention on Climate Change (UNFCCC) negotiations indicates that CO_2 emissions from the industrial sector must decrease by 58% to 93% by 2050 (compared to 2010 levels for developed countries) to align with the broad range between the 10th and 90th percentiles of all 1.5°C scenarios (Huppmann et al., 2018; Masson-Delmotte et al., 2018).

As shown in Figure 1, the electricity generation sector is the largest global emitter of GHG, accounting for 35% of total sectoral emissions worldwide. The manufacturing sector contributes 24%, with emissions dominated by hard-to-abate industries such as cement, steel, glass, chemicals, aluminum, and paper and pulp, primarily concentrated in countries like China, the United States, India, Russia, and Germany. Agriculture (15%), mining (12%), and other sectors (10%) collectively account for 37% of global emissions.

Figure 1: Share of sectors in global total emissions (% of total emission), (2019)



Source: elaborated using data from Organisation for Economic Co-operation and Development (OECD).

The sustainable taxonomy (Brasil, 2023), recently introduced by the Brazilian government (and other foreign governments), was developed in alignment with the commitments established under the Paris Agreement and its subsequent reviews. Its primary objective is to identify critical sectors essential for achieving the climate neutrality targets outlined in the NDC (Brasil, 2023). This taxonomy is based on the concept of direct emissions from sectors deemed critical for the de-carbonization of the Brazilian economy. However, emissions arise from various interactions between sectors within a country's productive structure.

It is essential to consider the trajectories, interdependencies, and environmentally significant key sectors through the direct and indirect effects of the demand and supply relationships within a country's productive structure. While evaluating sectors based on their direct carbon emissions is common practice, this approach overlooks that producing goods and services generates both direct and indirect emissions. Carbon emissions associated with production processes encompass both types: direct emissions, caused by the consumption of energy and the release of various pollutants, and indirect emissions, resulting from the use of intermediate inputs from other sectors (WBCSD & WRI, 2009).

Although some producers may exhibit lower direct emissions, their reliance on intermediate inputs can lead to significant indirect emissions. These indirect emissions, embedded within the production process of intermediate inputs, are a crucial factor for assessing a producer's overall carbon footprint (Costa, 2024). Therefore, evaluating indirect emissions is equally important for a comprehensive understanding of a producer's environmental impact.

Brazil exhibits a particular pattern of emissions. In 2019, farming and land-use changes related to deforestation accounted for more than three-fourths of GHG emissions (SEEG, 2023b). Consequently, in addition to considering indirect emissions from production, it is crucial to account for emissions arising from land-use change and carbon storage in soil – factors that are particularly significant for the farming sector but not always reflected in national accounts.

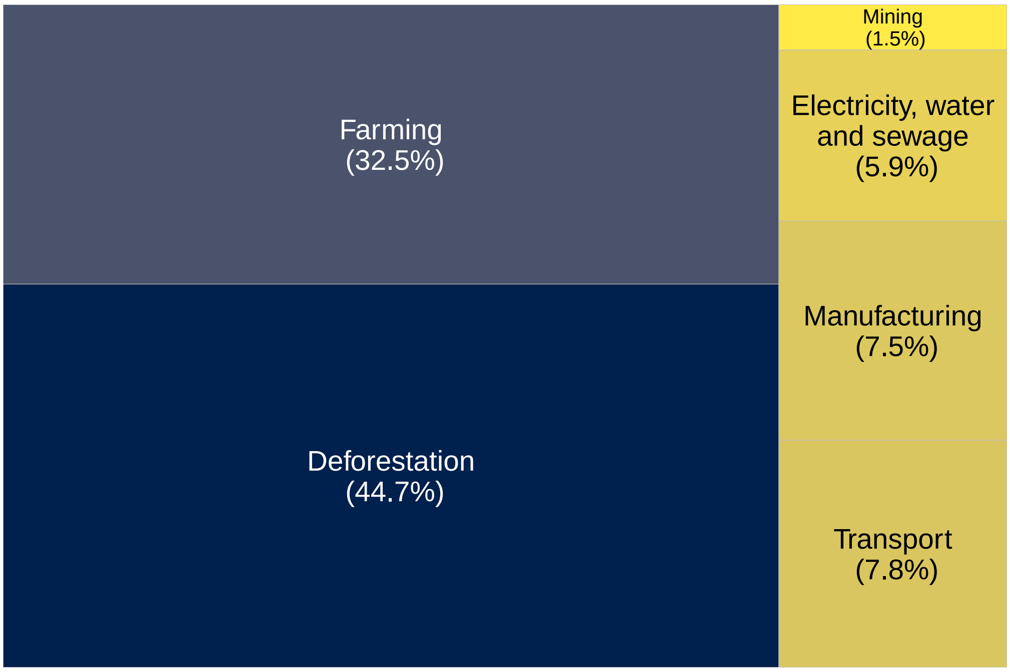
The 4th National Inventory of Anthropic Emissions and Removals of Greenhouse Gases (Brasil, 2021b), published by the Ministry of Science and Technology (acronym in Portuguese) (MCTI), provides a methodology for GHG accounting tailored to Brazil's national conditions. These statistics are classified as Tier 2 under IPCC (2006) standards, offering a more precise estimation of emissions than the global default IPCC coefficients. The SEEG, developed by the Climate Observatory (SEEG, 2023b), builds on the MCTI methodology while aiming for greater precision in land-use estimations. Specifically, the SEEG includes the carbon stock stored in the soil, a critical factor omitted by the MCTI. Since soil carbon storage is the primary source of carbon sequestration incorporated into our model, we rely on data provided by SEEG. From this point forward, all references to emissions or removals are based on the estimates from SEEG (2023b).

According to Figure 2, of Brazil's 2.6 Gt CO_2eq emitted in 2019, 46% originated from land-use change, with 95% of emissions from land-use being related to deforestation. The farming sector – agriculture, livestock raising, and forestry – accounts for 31.8% of GHG emissions, with the largest contribution (44% of it) coming from enteric fermentation of ruminants that release carbon monoxides. If we consider deforestation to be led by farming economic activities, then the farming sector is responsible alone for 77.2% of all GHG emissions (SEEG, 2023e).

The manufacturing industry and other sectors contribute approximately 22% of Brazil's GHG emissions. Within the manufacturing industry, the most significant emitters are the hard-to-abate sectors, including cement, steel, glass, chemicals, aluminum, and paper and pulp. In other sectors, construction and waste treatment are notable sources of emissions.

In contrast, emissions from electricity generation represent only 5.9% of Brazil's total emissions, a considerably smaller share compared to the global average of 35%. This difference is largely due to Brazil's energy matrix, nearly half of which is derived from renewable sources, positioning the country as a global leader in renewable energy generation.

Figure 2: Share of sectors in total emissions from Brazil (% of total emission), (2019)



Source: elaborated using data from OECD.

The analysis of CO_2 emissions trajectories in the Brazilian economy across 42 activities required harmonizing data from SEEG (2021) and the domestic System of National Accounts (CNAE 1.0 and CNAE 2.0). This harmonization was a critical step in constructing and selecting the modules for the analysis. The two primary datasets used were: (i) annual input-output tables at constant prices (base year 2010) estimated by Alves-Passoni and Freitas (Alves-Passoni & Freitas, 2022), and (ii) national emissions data extracted from SEEG, published by the SEEG (2023b).

Both datasets cover the period from 2010 to 2020 and provide information at varying levels of disaggregation: (i) 42 sectors and 91 products, and (ii) 67 sectors and 127 products. For defining modules and analyzing emissions trajectories across scenarios, the more aggregated version with 42 sectors was used.

Since open-access data on emission coefficients was unavailable, we relied on the database compiled by Costa et al. (2023), which was based on data extracted from input-output tables and SEEG.

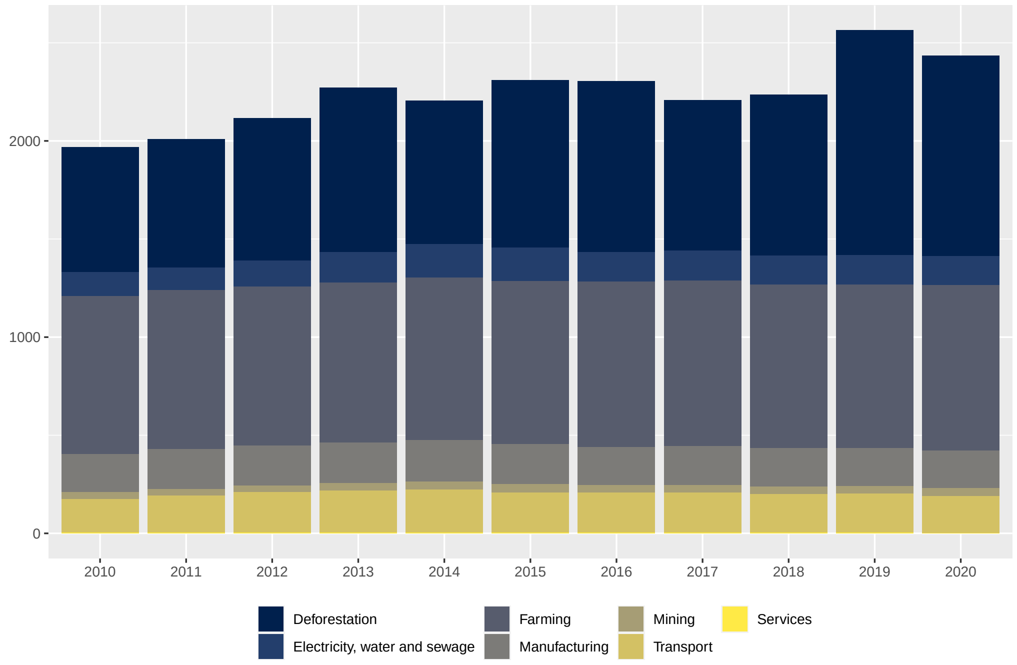
Regarding direct emissions, Figure 3 presents the emissions trajectory, measured in tons of CO_2eq, for the period from 2010 to 2019. During this period, farming was the largest contributor to total emissions in the Brazilian economy, driven primarily by deforestation and enteric fermentation in cattle. Following farming, the manufacturing sector (dominated by cement and steel production) and the transport sector (led by road transport) were the next largest emitters.

In contrast, the electricity sector stands out as one of the cleanest in the Brazilian economy, a result of the significant share of hydroelectric power and other renewable energy sources, such as wind and solar, in the country's energy matrix. This highlights Brazil's unique advantage in renewable energy utilization.

When analyzing emissions growth rates, farming showed the highest increase (37%), primarily driven by its impact on deforestation. Emissions from deforestation rose by an accumulated 79% from 2010 to 2019, although they started from a much lower level after a sharp decline (-57%) during the 2000–2010 period. This earlier reduction was achieved through strict command-and-control policies. However, with the relaxation of these policies, particularly after 2016, emissions from deforestation increased dramatically, though they still remained below 2003 levels. Other emissions from farming grew modestly, with an accumulated increase of just 3.4% over the period.

The second highest growth in emissions was observed in the electricity, water, sewage, and waste management sector, which saw a 24.8% increase. This was followed by mining (16%) and transportation (15%). In contrast, emissions from manufacturing remained stable over the decade (-0.1%), while emissions from the services sector saw a slight decline (-1.8%), likely reflecting its more dynamic growth during the previous decade.

Figure 3: Total emissions by groups of sectors in Brazil (MtCO2eq), (2010-2020)

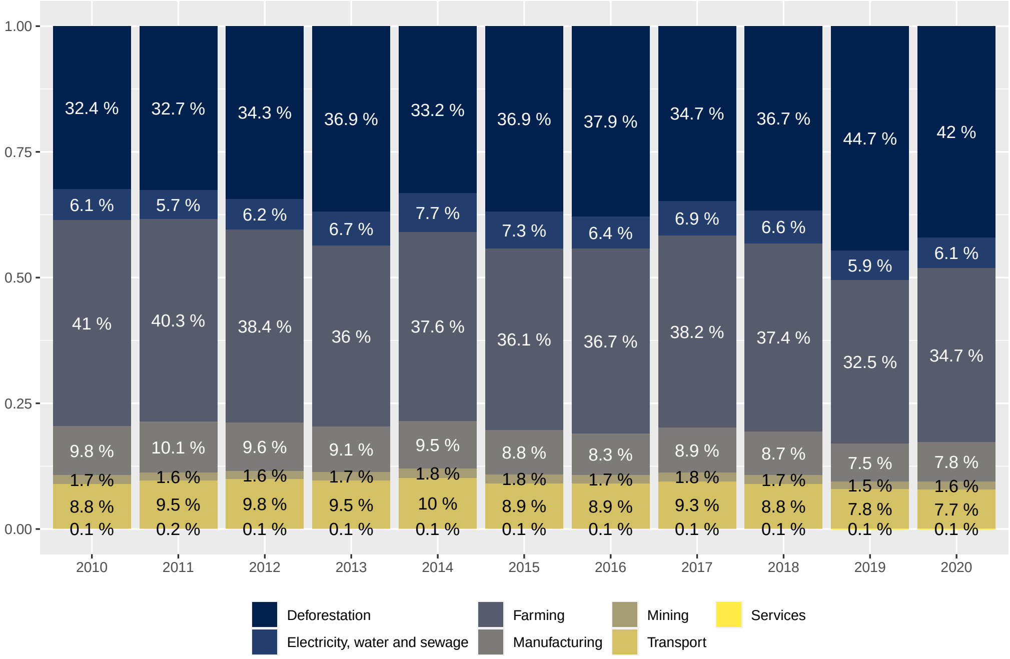


Source: elaborated using data from SEEG. Note: all data is compatible with the System of National Accounts (SNA).

Figure 4 below show the evolution of the sectoral share of greenhouse gas emissions in Brazil. Farming – encompassing agriculture, livestock raising, and forestry – has been the dominant sector in emissions, contributing an average of nearly 74% of total emissions over the period, with approximately half of this linked to deforestation. The manufacturing and transportation sectors each account for roughly 9% of total emissions. Within the transportation sector, about 90% of emissions stem from road transport. This increase in emissions is likely influenced by Brazilian government subsidies for private cars and trucks powered by fossil fuels (INESC, 2022). The IEA (2021) highlights that road freight transport is one of the most challenging sectors to de-carbonize.

The hard-to-abate sectors – cement, steel, glass, chemicals, aluminum, paper, and pulp – are grouped within the industrial sector. These sectors contribute to about 66% of emissions from manufacturing and, on average, account for 6% of total emissions in the Brazilian economy over the period.

Figure 4: Share in total emissions by groups of sectors in Brazil (% of total emissions), (2010-2020)



Source: elaborated using data from SEEG. Note: all data is compatible with the SNA

Regarding GHG removals, sustainable agricultural practices, and reforestation are the primary activities contributing to reductions. The MCTI (Brasil, 2021b) reports carbon removals from land-use changes amounting to approximately 620 million tons of CO_2eq in 2019, predominantly through forest preservation and restoration efforts. Additionally, SEEG (2023b) estimates removals from sustainable farming practices, including planted forests, direct plantation agriculture, high-quality pastures, and integrated forest-plantation-pasture systems. Together, these practices accounted for nearly 390 million tons of CO_2eq in 2019.

When removals are factored in, net emissions for 2019 are reduced to 1.6 billion tons of CO_2eq. Table 1 provides a detailed summary of the emissions and removals for that year.

Overall, the analysis highlights the key sectors for the de-carbonization of the Brazilian economy. The farming sector is the most significant, accounting for approximately three-fourths of total emissions. However, a substantial portion of these emissions is linked to deforestation, which is mildly related to the sector's land requirement to increase production. Transport and manufacturing follow, contributing 7.8% and 7.5% of emissions, respectively. In the manufacturing sector, the primary contributors are the hard-to-abate industries (cement, iron and steel, chemicals, paper, and pulp) and the oil refining sector, which together account for 77% of manufacturing emissions. Lastly, the electricity sector contributed 5.9% of total emissions in 2019.

Table 1: Brazilian CO_2 Emissions and Removals - 2019

Emissions from National Accounts (MCTI)	
Sectors	**Tons CO_2eq**
Farming	585,286,110
Land-Use Change	
Deforestation	1,144,376,833
Other Land-Use Changes	53,848,367
Mining	39,656,153
Manufacturing	
Hard-to-Abate Sectors	149,629,868
Oil Refining	24,090,399
Other Manufacturing Sectors	18,606,482
Electricity, Water, and Sewage	150,193,698
Transport	
Road Transport	178,802,162
Other Transport	20,677,104
Services	2,870,589
Total Emissions (MCTI)	**2,368,037,767**
Emissions not in National Accounts (NCI)	
Farming	271,160,985
Land-Use Change	12,365,400
Total Emissions (NCI)	**283,526,385**
Total Tons CO_2eq Emissions	**2,651,564,151**
Removals from National Accounts	
Land-Use Change	-619,330,218
Removals not in National Accounts (NCI)	
Farming	-389,655,192
Total Tons CO_2eq Removals	**-1,008,985,410**
Total Net Emissions	**1,642,578,742**

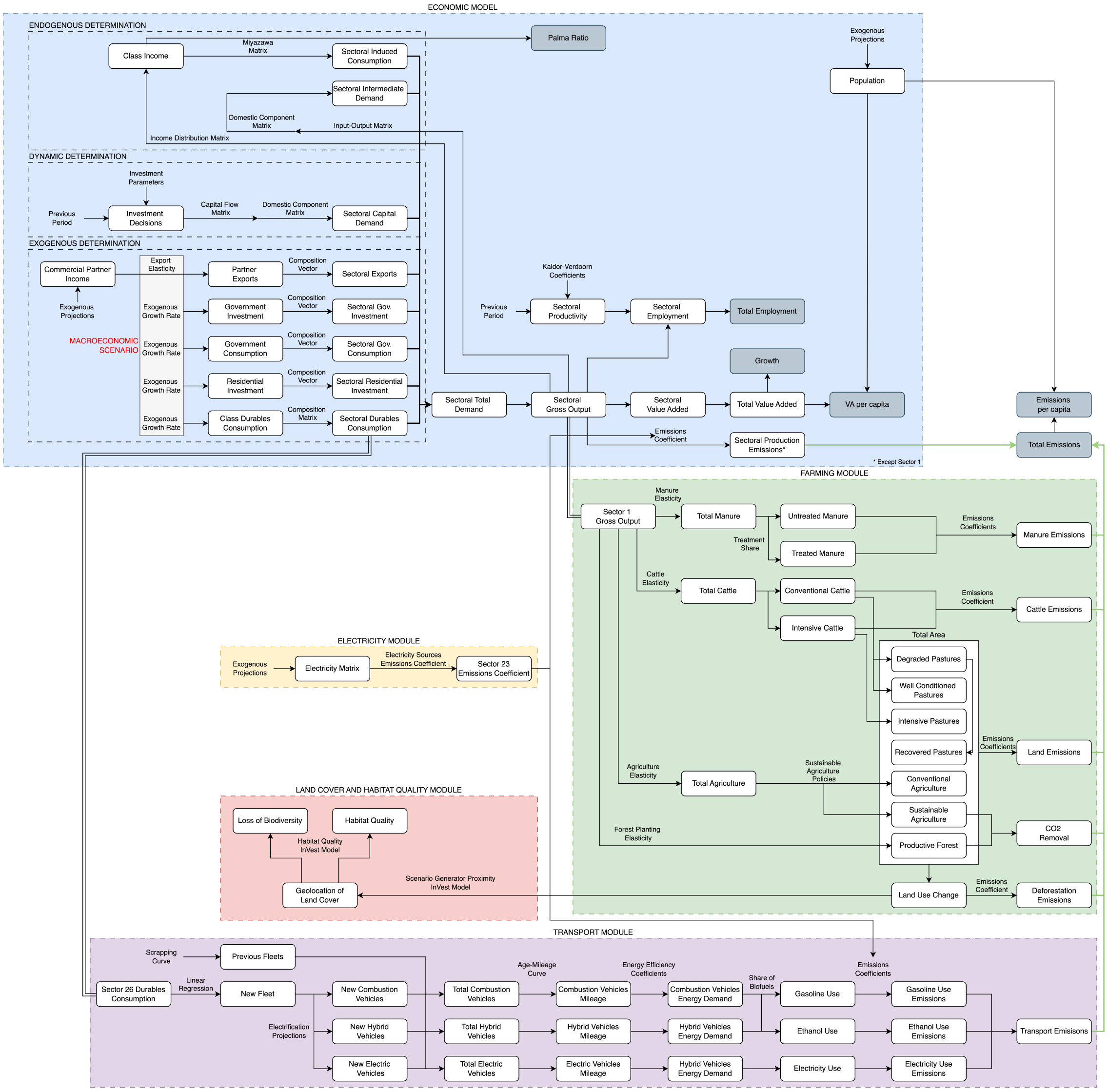
3 Method

3.1 Overall approach and model structure

Figure 5 provides a schematic representation of the model's interrelations.

The economic core of the model relies on the dynamic input-output approach, which represents both multi-sectoral and macroeconomic dimensions. This approach extends input-output analysis, originally developed by Leontief (1953, 1970), to make investment an induced component that explains the investment requirements needed to maintain productive capacity. In Leontief's original version, the model assumes full utilization of productive capacity, with investment endogenized through relationships between capital stock and gross output. Later, Duchin and Szyld (1985), Leontief and Duchin (1986), and Kalmbach and Kurz (1990) expanded the model by allowing capacity utilization to fall below full capacity (100%).

Figure 5: Representation of the Model



The economic model developed in this study builds on the foundational work of Freitas and Dweck (2010) and subsequent contributions by Cornelio (2017) and Cornelio et al. (2023). It integrates investment with a key component of input-output analysis: the Leontief-Miyazawa multipliers. This approach models household consumption as an income-dependent function, rooted in Keynesian and Kaleckian traditions. The model requires input data, including sector- and income-class-specific consumption propensities and the relationships between income and Gross Ouptut (GO), both categorized by income class and sector. All input data must align methodologically with the input-output matrices utilized in the analysis.

In summary, the model is largely based on the input-output matrix but incorporates other databases to endogenize consumption and investment. Other components[1] of final demand, such as exports, government consumption, durable goods consumption, public investment, and residential investment, are kept exogenous. However, these exogenous variables do not need to be predetermined and can be used to construct specific scenarios. For example, in our model exports depend on global economic performance expectations using income elasticities that relate exports to the economic performance of Brazil's main commercial partners.

The economic core of the model integrates an environmental vector that links GO to direct emissions, enabling the calculation of production-related emissions at both sectoral and aggregate levels. To analyze the environmental impacts of the productive structure and the ETP, the model extends its economic core with three auxiliary modules to enhance the precision of emissions and other environmental impact calculations.

The electricity module endogenously determines the electricity generation emission coefficient by analyzing the electricity matrix's composition across various energy sources and their corresponding emission coefficients. The transport module calculates emissions from motor vehicle use based on the transport sector's production and depreciation, accounting for vehicle types, fuel sources, and the associated emission coefficients. Its output is integrated into the core model's emissions results, as it captures emissions from vehicle use—complementing the economic core model, which only considers emissions from vehicle production and fleet use to achieving production of goods and services goals.

The farming module estimates emissions from the agriculture and livestock sectors by analyzing the internal composition of activities with varying pollution levels and their respective emission coefficients. Notably, some coefficients may be negative, indicating instances of CO_2 capture rather than emissions.

Timeline of Events: the following timeline of events describes the logical sequence of the model working at each period:

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[1] There are also some smaller components assumed to grow at similar rates to their counterparts, particularly the consumption of non-profit institutions serving households, inventory changes, and the margins (trade and transportation) of investment.

1. Update commercial partners' incomes and calculate total and sectoral exports.
2. Update government variables and compute total and sectoral government consumption and investment.
3. Update autonomous spending by income classes, and calculate total and sectoral durable goods consumption as well as residential investment.
4. Update residual autonomous spending, and compute total and sectoral residual consumption and investment.
5. Sectors determine desired investment based on previous growth, current capacity utilization, and normal capacity utilization.
6. Distribute sectoral desired investment as demand across sectors using a capital flow matrix.
7. Calculate sectoral autonomous final demand by summing exports, government consumption and investment, residual consumption and investment, durable goods consumption, and residential investment.
8. Compute sectoral total demand based on autonomous final demand, using a matrix of input technical coefficients to determine intermediate consumption demand, and a matrix of propensities to consume to calculate induced non-durable goods consumption.
9. Apply the ex-post effective demand principle, where sectoral gross output equals sectoral total demand. Constrain sectoral output by productive capacity and compute unmet demand as additional imports.
10. Update sectoral labor productivity using the Kaldor-Verdoorn law, and calculate sectoral employment based on sectoral gross output and sectoral labor productivity.
11. Adjust sectoral direct emissions coefficients depending on the scenario, and calculate sectoral direct emissions based on sectoral gross output and direct emissions coefficients.
12. Compute sectoral value added from sectoral gross output and intermediate consumption, and distribute value added to each income class using a distribution matrix.
13. Calculate sectoral taxation from sectoral gross output and a vector of tax coefficients, and compute class taxation from class income and a vector of tax coefficients.
14. Compute additional sectoral variables such as capacity utilization and sectoral participation rates.
15. Update aggregate variables and compute aggregate results, including the Palma Ratio and aggregate growth rates.

16. Update the sectoral capital stock based on actual investment.
17. Pass GO data to auxiliary modules, where each module internally calculates activities' CO_2 emissions.

3.2 Economic model: overview

The economic model uses a dynamic input-output framework to capture the interdependencies between economic activities, sectoral dynamics, and environmental impacts related to producing goods and services. This structure provides the foundation for analyzing the effects of the ETP and incorporates auxiliary modules to enhance the coverage of GHG emissions. This multi-sector and macroeconomic framework plays a crucial role in analyzing the green transition prospects because it identifies constraints and bottlenecks that may hinder the plan's goals.

Below, we outline the economic model's core relationships:

- **Final demand and production of goods and services:** Final demand includes both induced components – spending directly tied to the income-generating process, such as wages spent on necessities – and autonomous components, which encompass spending unrelated to current domestic income, such as exports, government consumption, and investment. Each producing sector receives demand from these components, determining gross output based on effective demand while remaining potentially constrained by productive capacity. Sectoral demand received by each producing sector combines autonomous components such as exports, government consumption, investment, and household spending on durable goods, with induced components like non-durable consumption and intermediate demand. Each sector's gross output (corresponding to total production in monetary terms) is determined by effective demand but is potentially constrained by productive capacity.

- **Sectoral interactions:** Technical coefficients from the input-output table capture the interdependencies between sectors, allowing the model to simulate structural changes, such as shifts in energy use or technological transitions.

- **Investment and capital stock:** Corporate desired investment follows the capital stock adjustment principle, which dynamically adjusts the capital stock to an envisioned target. Capital stock target is influenced by expected demand growth (proxying perceived demand forecasts), capacity utilization, and depreciation rates. Realized investment update the capital stock at a sectoral level, determining the future productive capacity.

- **Emissions and environmental metrics:** Direct emissions are estimated by linking sectoral gross output to specific emission coefficients. The model accounts for emissions from key sectors, including agriculture, transport, and energy, through specialized auxiliary modules.

- **Employment and productivity:** Employment needs are determined by sectoral gross output and labor productivity, which evolves dynamically based on sectoral output growth in line with Kaldor-Verdoorn dynamics.
- **Income and inequality:** Sectoral value-added is distributed across income classes, enabling detailed analysis of economic inequality and income growth.

This brief overview highlights model's core relationships. Technical readers can find a detailed description of the economic model in Output 2.2.

3.3 Farming Module

The module takes as input the GO of Sector 1 (Agriculture, forestry, logging, livestock, and fishing) generated by the economic model. It then monitors land use across three activities: agriculture, cattle, and forestry, as well as total livestock production residues and the size of beef and dairy cattle herds. Additionally, the module relies on parameters that link agricultural GO with relevant areas, herd sizes, and livestock residues. Elasticities are estimated using linear regression analysis of the variables.

Pastureland falls into two categories: well-maintained pastures and degraded lands. Recovering pastures involves transforming degraded areas into well-maintained ones. The analysis highlights intensive beef finishing and animal waste management to evaluate how the plan's policies influence the environmental scenarios under implementation.

The total agricultural area includes conventional planting areas and areas associated with public policies under the ABC+ Plan, such as direct grain planting, direct planting systems, direct planting systems for vegetables, integrated systems, irrigated systems, and areas using bio-inputs. Following the ABC+ Plan, these areas are treated separately in the module, each contributing specifically to the emissions or removal of CO_2.

Using the data from 2019 on area, animals, and residues, this module calculates emissions associated with each variable by applying specific emission coefficients. These coefficients are derived from databases such as the Climate Observatory SEEG (2023d, 2023e) and the ABC+ Plan Brasil (2021a). The Climate Observatory determines emissions based on methodologies aligned with IPCC guidelines (IPCC, 2006) and Brazil's 4th National Greenhouse Gas Inventory (Brasil, 2021b).

Scenario implementation in the model uses ABC+ Plan targets and intensification parameters from Palermo et al. (2014). ABC+ Plan policies are treated as annual hectare expansions, averaging the ten-year targets of the plan. Scenarios reflect the average percentages of annual target achievement. Expansion for each cultivation type is incremental, converging toward ABC+ Plan targets. Productive intensification in cattle farming follows

Palermo et al. (2014). Scenarios with this policy consider the share of beef cattle managed under rotational grazing systems. The primary impact of this policy is on land-use demand, minimizing the need for new areas to accommodate herd growth.

Gains in land productivity could increase profits or lower prices, leading to feedback effects on deforestation - the so-called rebound effect (Meyfroidt, 2018). This mechanism is not incorporated into the model. On the one hand, new farming production in the model depends on sectoral demand and not on accumulated profits, while on the other hand, the model does not deal with changes in relative prices making it impossible to consider such price-effects. Land productivity has only effects on the output per hectare in the model.

The largest emissions impact stems from deforestation. Emission coefficients for new agricultural areas are estimated via linear regression between new agricultural areas (MapBiomas data) and emissions from land-use changes, including deforestation for agriculture (SEEG, 2023a). The coefficient is calculated for 1990–2022.

Therefore, the module calculates both direct emissions from agricultural and livestock activities and indirect emissions resulting from deforestation due to agricultural and livestock expansion.

3.4 Land Cover and Habitat Quality Module

This module addresses the economic and policy impacts on land use and biodiversity loss, modelling the ecological impacts of the ETP beyond the analysis of GHG emissions. It feeds from the farming module outputs in terms of land-use change to produce maps of the land cover of Brazil with and without the ETP and calculate the impact of those simulated changes on the quality of natural habitats.

Its approach is based on the United Nations (2021) Policy Scenario Report and on the Natural Capital Project (2024) modelling framework. As the name suggests, the module uses two models to assess separately: land cover and habitat quality. The underlying idea supporting both modules is that land is used productively, so economic changes impact the country's land cover and the natural habitats in them may be erased or damaged by these changes.

The land cover section of the module utilizes the 'Scenario Generator: Proximity Based' model (Natural Capital Project, 2024) to map the change in land-use types simulated in the Farming Module. This model assumes that new productive land areas will be located near existing areas with the same productive use. The initial condition of the Brazilian landscape is set using the map generated by MapBiomas (2023). The data from the map is made compatible with the farming module's information by taking agriculture, livestock raising, and productive forest areas as aggregates and by assuming mosaic of uses to be part of agriculture (as we did in the farming module).

The model tracks land-use change as the transformation of the use in each hectare from one type to another. It is thus assumed that all new land for agriculture, cattle raising, and forest plantation comes from natural forest. Analogously, decreases in the total land use of pasture (due to restoration or land intensification policies) are assumed to represent a change from pasture to natural forest. Land use types tracked are: (natural) forest; water; forest plantation; non-vegetated (urban) areas; herbaceous and shrubby vegetation; agriculture; and pasture areas. Changes in land use are represented for Scenario 0 - No-ETP with baseline macro (the *business-as-usual*) and Scenario 2 – Full-ETP with baseline macro, to focus on the impact of the ETP policies alone.

The habitat quality section of the module is based on the Habitat Quality model (Natural Capital Project, 2024), which takes the maps generated by the land cover section as inputs to calculate a habitat quality index which functions as a proxy to biodiversity conditions.

Each type of land use is assigned a 1 if it is a natural habitat and a 0 if it is a non-habitat, an area changed by economic activity. Each non-habitat is also a threat to natural habitats, possessing parameters that represent the weight of their threat and the way they affect natural habitats geographically (if linearly of exponentially with proximity). Habitats, on the other hand, are assigned a sensitivity parameter to each type of threat to assess how much that type of activity may affect its natural conditions. Habitats are: (natural) forests, water, and herbaceous and shrubby vegetation (mostly in *Pantanal*) areas; while non-habitats are: agriculture, pasture, forest plantation, and urban (non-vegetated) areas.

From this information, the model calculates for each land-unit of the map a habitat quality index as a function of these parameters.[2] Each non-habitat has an index of 0, while habitats may have an index from 0 to 1 depending on the threats they face. An average national habitat quality index is calculated for the initial year (2023) and for the final year (2050) of the *Business as Usual* (BAU) and Full-ETP scenarios. The variation of this index provides a proxy of the economic impact on biodiversity with and without the ETP policies.

It should be noted that the module uses a simple land-use model which assumes land expansions are uniformly distributed by proximity, not taking into full consideration the areas of recent deforestation nor institutional restrictions. Moreover, the habitat quality model considers biodiversity broadly regarding all natural habitats equally in terms of providing conditions for life, while considering all economic activities as presenting poor conditions for life sustenance. Simplifications made to be able to proxy the diverse realm of biodiversity. Despite these limitations, the module still provides very interesting insights into the impacts of the ETP policies and economic activity on biodiversity and on land-use changes, crucial aspects of the ecological crisis.

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[2] Parameter values were taken from default model values always when available, consult report 2.4 of this project to check each parameter value used.

3.5 Transport and Electricity Modules

The transport and electricity modules are integrated as both sectors are included in the fourth axis of the ETP, which outlines measures for Brazil's energy transition. The methodology for these modules is based on Carvalho (2024) and de Carvalho et al. (2023), adapted to our framework.

The transport module calculates emissions from Brazil's motor vehicle fleet used for passenger transport. The module estimates the vehicle stock evolution by combining annual licensing of new vehicles, based on inputs from the economic model, with depreciation rates obtained from MMA (2013). Initial fleet data from 2019, including internal combustion, hybrid, and electric vehicles, are sourced from Carvalho (2024). Vehicle usage follows the Brazilian Association of Technical Standards (ABNT, acronym in Portuguese) driving cycle (NBR6601), which provides information on total displacement, maximum speed, and duration. Energy requirements per kilometer are calculated for reference models representing each vehicle type: Hyundai HB20 (internal combustion), Toyota Corolla (hybrid), and Nissan LEAF (electric) (Carvalho, 2024). These calculations enable estimating total energy demand based on annual kilometers traveled, derived from odometer data provided by Companhia Ambiental do Estado de São Paulo (CETESB) for São Paulo's state fleet, representing one-third of the national total (Sindipeças, 2024).

The electricity module assesses emissions from electricity generation based on the composition of Brazil's predominantly renewable energy matrix MME/EPE (2024). Using the GO of electricity generation, the module applies a fixed coefficient, derived from 2019 data, to link monetary values with physical electricity production in megawatt-hours. Emissions are calculated by multiplying the electricity generated from each source by its corresponding emission coefficient Barros et al. (2018).

The composition of vehicle fuels (gasoline and ethanol) is determined using historical averages Carvalho (2024), while emission coefficients for fuel combustion are calculated based on calorific values and densities from ANP (2022).

The modules also account for policy scenarios promoting fleet electrification and renewable energy expansion. For transport, scenarios simulate the adoption of hybrid and electric vehicles alongside gasoline and ethanol usage variations, enabling the analysis of biofuel policies. For electricity, scenarios assess shifts in the electricity matrix, favoring sources like wind and solar. The most optimistic scenario assumes a 50% fleet electrification rate, with projections indicating significant reductions in emissions from fossil fuel combustion. Research and development policies are represented by changes in energy efficiency per kilometer traveled.

Together, the transport and electricity modules provide a comprehensive framework for evaluating the emissions impacts of Brazil's energy transition policies, offering insights into strategies for reducing emissions and increasing the use of renewable energy sources.

3.6 Data requirements

The structure of the model is composed of 40 productive sectors (see Table 2), 10 income classes, 5 commercial partners (see Table 3), the government, 8 different energy sources (see Table 4), 25 vehicle fleets (one fleet per year before the initialization of the model in 2019) and 12 different types of land with different techniques used in agriculture (see Table 5).

The primary data source for the model is derived from the SNA, published in Brazil by the IBGE. Specifically, the core of the model uses Input-Output Matrix (IOM) data provided by IBGE on a five-year basis, with data available for 2010 and 2015 in the current SNA reference (SCN-2010). However, to extract trends, annual input-output matrices are estimated using the methodology of Alves-Passoni and Freitas (2023) for current prices and Alves-Passoni and Freitas (2022) for previous-year prices (in volume units with specific deflators and total units with a single deflator). Data at 2010 prices are available on the Grupo de Indústria e Competitividade (GIC) website[3], but the model uses data at 2019 prices, calculated by the authors. The most fundamental information extracted from the IOM includes technical coefficients and final demand vectors, both domestic and imported. This dataset allows a disaggregation level of 91 products and 42 sectors, later aggregated to 40 sectors.

Additional information was required to endogenize part of the final demand, which, while not directly provided by IBGE, was constructed following the methodological framework of the SNA. It is important to recall that the two endogenized components are household consumption and productive investment.

The Social Accounting Matrix (SAM) estimated by Maciel et al. (2024) provides the basic data for household consumption. Maciel et al. (2024) constructs this SAM using information from Krepsky and Dweck (2023), who calculated the data based on the same IOM used in the model. To complete the SAM, Maciel et al. (2024) stratifies the institutional sector “households” by per capita income deciles using data from the Household Budget Survey (POF, acronym in Portuguese). This SAM supplies information on consumption patterns by income deciles and each decile’s share in the total value added.

To implement the model’s sectoral distribution of value added, the process involves calculating a matrix that relates sectoral occupations to sectoral value added, disaggregated by income classes. The share of each income class in the value added of each activity uses data from the POF, acronym in Portuguese. Finally, the method cross-references consumption and income patterns to calculate the Leontief-Miyazawa multipliers.

The other component to explain is gross fixed capital formation, represented as a vector in the IOM. The methodology uses a capital flow matrix calculated by Miguez and Freitas (2021), also available in the GIC webpage, to identify which sectors demand cap-

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[3] https://www.ie.ufrj.br/gic-gicdata.html

Table 2: Sectors Description

Sector	Description
1.	Agriculture, forestry, logging, and livestock and fishing
2.	Extraction of oil and gas, including support activities
3.	Iron ore extraction, including processing and agglomeration
4.	Other extractive industries
5.	Food and beverages
6.	Manufacture of tobacco products
7.	Manufacture of textile products
8.	Manufacture of clothing and accessories
9.	Manufacture of footwear and leather goods
10.	Manufacture of wood products
11.	Manufacture of pulp, paper, and paper products
12.	Printing and reproduction of recordings
13.	Oil refining and coking
14.	Manufacture of biofuels
15.	Manufacture of organic and inorganic chemicals, resins, and elastomers
16.	Pharmaceutical products
17.	Perfumery, hygiene, and cleaning products
18.	Manufacture of pesticides, disinfectants, paints, and various chemicals
19.	Rubber and plastic products
20.	Cement and other non-metallic mineral products
21.	Manufacture of steel and derivatives
22.	Metallurgy of non-ferrous metals
23.	Metal products – excluding machinery and equipment
24.	Machinery, equipment, furniture, and various other industrial products
25.	Household appliances and electronic equipment
26.	Automobiles, vans, trucks, and buses
27.	Parts and accessories for motor vehicles
28.	Other transportation equipment
29.	Production and distribution of electricity, gas, water, sewage, and urban sanitation
30.	Civil construction
31.	Commerce
32.	Transportation, storage, and postal services
33.	Accommodation and food services
34.	Information services
35.	Financial intermediation, insurance, supplementary pension plans, and related services
36.	Real estate activities and rentals
37.	Services provided to businesses and households, and maintenance services
38.	Private education
39.	Private healthcare
40.	Public Education, healthcare, administration, defense, and social security

Note: Sector 40 (Public education, healthcare, administration, defense, and social security) is an aggregation of three sectors from the 42-sector classification: ”Public Education”; ”Public Healthcare”; and ”Public Administration, Defense, and Social Security”. This level of disaggregation is the most detailed available to ensure consistency across all data sources, particularly the capital flow matrix.

ital goods. The authors' methodology creates a matrix that allocates capital goods by first identifying specific-use assets (e.g., livestock assets required by specific sectors) and

Table 3: Commercial Partners Description

Partner	Description	Share of Exports (2019)
1.	Argentina	4.5%
2.	China	28.4%
3.	European Union	13.3%
4.	EUA	13.4%
5.	Rest of the World	40.4%

Table 4: Energy Source Description

Source	Description	Share of Production (2019)	Emissions Coefficient (gCO2/MJ)
1.	Natural Gas	7.9%	119.4
2.	Coal	2%	251.3
3.	Fossil Fuels	3%	187.2
4.	Biomass	7.8%	0
5.	Nuclear	1.1%	0
6.	Wind	9.6%	0
7.	Hydro	67.3%	0
8.	Solar	1.3%	0

Table 5: Land Types Description

Land	Description	Total Area (mi ha in 2019)	Emissions Coefficient (tCO2/ha)
1.	Conventional Planting Agriculture	34.7	1.47
2.	Direct Grain Planting Agriculture	31.5	-1.9
3.	No-Tillage Grain System Agriculture	4.5	-6.4
4.	No-Tillage Vegetable System Agriculture	0	-1.1
5.	Irrigated Systems	8.2	-3.03
6.	Bioinputs Using Lands	10	-1.8
7.	Integrated Systems	14.4	-6.23
8.	Well-Conditioned Pasture	62.5	-3.54
9.	Degraded Pasture	100.5	2.03
10.	Productive Intensification Pasture	0	-3.54
11.	Recovered Lands	8.3	-3.54
12.	Planted Forest	8.4	-0.81

then using sectoral studies to distribute demand for widely used assets (e.g., construction). This process transforms the investment vector into a matrix that relates products to activities, distinguishing between domestically produced and imported components. The capital flow matrix connects the desired sectoral investment values, derived from the investment function, to the products required to meet this demand.

The estimation of normal capacity utilization follows Cornelio (2017) and Cornelio et al. (2023), based on the average historical data of installed capacity utilization rates reported by the Confederação Nacional da Indústria (CNI) for industrial sectors and by the Fundação Getúlio Vargas (FGV) for agriculture and services sectors. These data, derived from self-reported company figures, are not used as effective capacity utilization measures but as good proxies for average utilization, interpreted as the normal utilization level. Potential output estimation follows the methodology of Cornelio (2017) and Cornelio et al. (2023), applying an Hodrick-Prescott (HP) filter (Hodrick & Prescott, 1997) to derive the GO trend, considering this value as the output under normal utilization – i.e., the production level corresponding to normal capacity utilization. Productive capacity is then defined as 100% of this value, allowing effective utilization rates calculation as the ratio of observed GO in the IOM to the maximum capacity GO series.

Additionally, to apply the investment function explaining sectoral investment, further information on the relationship between investment and productive capacity is required, such as the sectoral capital stocks, enabling the calculation of the capital-output technical ratio. The data source is Cornelio et al. (2024), which combines capital flow matrix data with the perpetual inventory method[4] to estimate sectoral capital stocks. As described, the investment function incorporates parameters estimated flexibly to align the series estimated by the model with observed values in the IOM. These parameters include the depreciation rate, sensitivity to deviations between effective and normal utilization levels, and sensitivity to forecasting errors under adaptive expectations.

Exports, a key component of final demand, are modeled to account for Brazil's primary trading partners. Using our estimates for the export income elasticity, this approach links export demand to each partner's income levels. Specifically, we decompose the export vector from the IOM into five trading partners: Argentina, China, the United States, the European Union, and the Rest of the World. To calculate each partner's share, we analyze data from Secretaria de Comércio Exterior do Ministério do Desenvolvimento, Indústria, Comércio e Serviços (MDIC/SECEX) on the destinations of Brazilian exports. These data provide reliable coverage for agriculture and industry activities but lack sufficient detail for services. However, since most services are non-tradable and excluded from exports and imports, this limitation has minimal impact on the model's output. For these products, we assume a unitary income elasticity.

We use growth rates from the International Monetary Fund (IMF)'s World Economic Outlook forecasts to model the economic performance of trading partners. Because the forecasts extend only to 2029, we extrapolate the 2029 projection to cover the remaining simulated years.

The productivity measure was calculated by relating GO data from the IOM series provided by Alves-Passoni and Freitas (2022, 2023) with sectoral occupation information available in the Matriz Insumo-Produto (MIP) series at current prices. We chose this approach to link the output variable from input-output models (GO) to an occupation measure

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[4] See, for example, Souza Júnior and Cornelio (2020, 2024).

methodologically compatible with the SNA framework.

Population estimates[5] follow data provided by IBGE, covering the period from 2000 to 2070. These estimates are already aligned with 2022 demographic census and encompass the entire period to be simulated by the model (up to 2050).

The land cover map for 2023 is used as in input (MapBiomas, 2023) and parameters for the habitat quality index are extracted from the Natural Capital Project (2024) databases.

To simplify the presentation of the model's key variables and their respective sources, Table 6 summarizes the key correspondence between the variables used in the model and the data sources employed in the empirical analysis.

Table 6: Summary of Key Variables and Data Sources

Group	**Sources**
Input-Output Relations	IBGE; Alves-Passoni and Freitas (2022, 2023)
Social Accounting Matrix	Maciel et al. (2024); Krepsky and Dweck (2023)
Trade Partners Growth	IMF
Investment	IBGE; Alves-Passoni and Freitas (2022, 2023)
Productive Capacity	Cornelio et al. (2024)
Capacity Utilization	IBGE; CNI; FGV; Alves-Passoni and Freitas (2022, 2023); Cornelio et al. (2024)
Exports	IBGE; MDIC/SECEX
Productivity	IBGE; Alves-Passoni and Freitas (2022, 2023)
Population	IBGE
Agricultural Area	SEEG (2023c); ABC+ (Brasil, 2021a)
Cattle Heads	IBGE; ABC+ (Brasil, 2021a)
Manure	SEEG (2023c); ABC+ (Brasil, 2021a)
Agro Module Parameters	SEEG (2023c); IBGE, ABC+ (Brasil, 2021a)
Transport Module Parameters	Carvalho (2024); ANP (2022); MME/EPE (2005)
Licencing	ANFAVEA (2024)
Scrapping Curve	MMA (2013)
Electricity Matrix	MME/EPE (2024)
Electricity Emission Coefficients	Barros et al. (2018)

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[5] Population estimates can be found on the IBGE website: https://www.ibge.gov.br/estatisticas/sociais/populacao/9109-projecao-da-populacao.html.

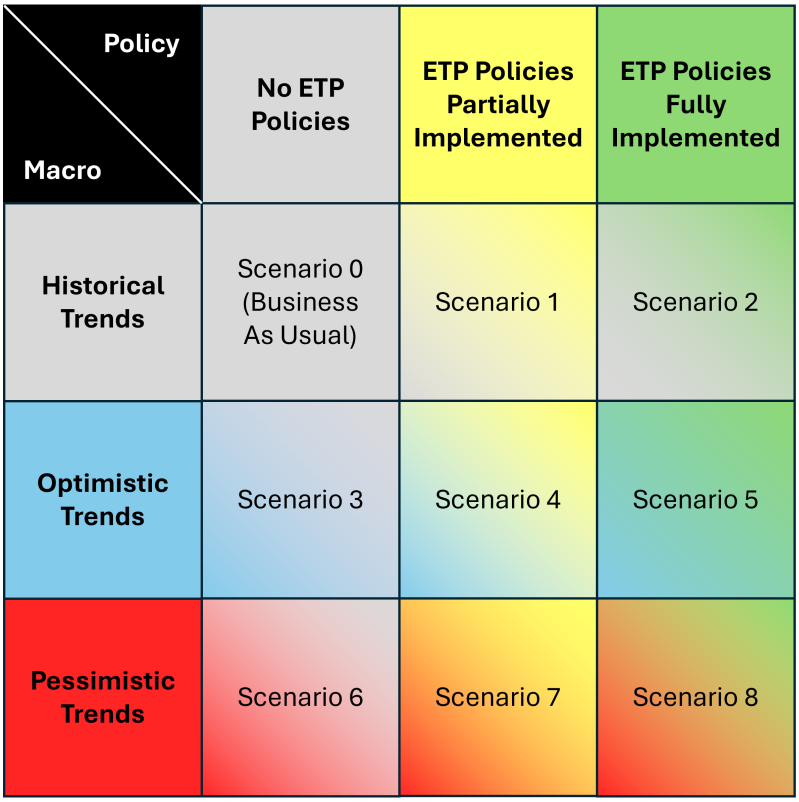
4 Scenarios

This section outlines the scenarios we analyze. Our scenarios focus on two dimensions:

- **The policy dimension**, evaluating different settings of ETP implementation.
- **The macroeconomic dimension**, with which we stress mainly growth scenarios that are related to many macroeconomic variables, such as fiscal policy, external conditions, and monetary policy. These are very important dimensions because they relate to Brazilian development targets.

We have optimistic, intermediate, and pessimistic across both dimensions. Combining them, we analyze nine scenarios, as outlined in Figure 6:

Figure 6: Scenario Matrix



Policy / Macro	No ETP Policies	ETP Policies Partially Implemented	ETP Policies Fully Implemented
Historical Trends	Scenario 0 (Business As Usual)	Scenario 1	Scenario 2
Optimistic Trends	Scenario 3	Scenario 4	Scenario 5
Pessimistic Trends	Scenario 6	Scenario 7	Scenario 8

- **Scenario 0 (BAU)**: Macro Baseline - No ETP: In this scenario, key macroeconomic variables such as the government spending and residential investment grow at historical trends and no ETP policy is implemented at all.
- **Scenario 1**: Macro Baseline - Partial ETP: In this scenario, key macroeconomic variables such as the government spending and residential investment grow at historical trends and all ETP policies are implemented, but these policies only achieve half of their aimed targets.

- **Scenario 2**: Macro Baseline - Full ETP: In this scenario, key macroeconomic variables such as the government spending and residential investment grow at historical trends and all ETP policies are implemented, achieving their aimed target.
- **Scenario 3**: Macro Optimistic - No ETP: In this scenario, key macroeconomic variables such as government spending and residential investment grow at a faster pace than historical averages, and no ETP policy is implemented at all.
- **Scenario 4**: Macro Optimistic - Partial ETP: In this scenario, key macroeconomic variables such as government spending and residential investment grow at a faster pace than historical averages, and all ETP policies are implemented, but these policies only achieve half of their aimed targets.
- **Scenario 5**: Macro Optimistic - Full ETP: In this scenario, key macroeconomic variables such as government spending and residential investment grow at a faster pace than historical averages, and all ETP policies are implemented, achieving their aimed target.
- **Scenario 6**: Macro Pessimistic - No ETP: In this scenario, key macroeconomic variables such as government spending and residential investment grow at a slower rate than the historical trends, following the population growth, and no ETP policy is implemented at all.
- **Scenario 7**: Macro Pessimistic - Partial ETP: In this scenario, key macroeconomic variables such as government spending and residential investment grow at a slower rate than the historical trends, following the population growth, and all ETP policies are implemented, but these policies only achieve half of their aimed targets.
- **Scenario 8**: Macro Pessimistic - Full ETP: In this scenario, key macroeconomic variables such as government spending and residential investment grow at a slower rate than the historical trends, following the population growth, and all ETP policies are implemented, achieving their aimed target.

Below, we present the details across both policy and macroeconomic dimensions.

4.1 Policy Dimension

The policy dimension covers a range of policies across all six axes of the ETP. It is structured into three levels: no implementation (where historical trends persist), partial implementation (representing an intermediate scenario), and full implementation, which reflects a highly optimistic scenario in which all ETP plans are fully realized. The intermediate scenario provides a more balanced perspective by accounting for less pronounced impacts that take longer to materialize.

The model represents ETP policies by focusing on their impacts in a normative perspective. For example, the optimistic scenarios assume full implementation and the achievement of all modeled targets. However, the analysis does not consider positive elements such as costs, policy instruments, or potential political and legal constraints.

Our approach delimitation stems from the broad scope of the ETP, which includes numerous aspects that warrant detailed examination on their own. Given the project's focus on overall and sectoral trends – such as total GHG emissions, overall activity levels, employment, and inequality – it is impractical to incorporate the granular analysis that a more concrete examination of individual policies encompassed by the ETP would require. That said, we strongly recommend conducting specific studies on individual programs to complement our analysis. Furthermore, these specific studies can be integrated into our framework to provide insights into overall impacts that cannot be captured through standalone analyses.

Below, we describe how we incorporate the six axes of the ETP policy dimension into the scenarios:

Technological Change: This element in our scenario represents a change in production techniques towards greener and more ecological methods. It captures policy instruments across the Sustainable Finance axis, such as the Green Finance for Investment, Circular Economy, and the Technological Desification axis, such as R&D spending for ecological transformation. With this policy implemented, some selected technical coefficients of intermediate demand – required for producing final goods – in the input-output matrix change from year to year based on the investment rate of the sector and the technological gap between the current technique and the frontier technique. The frontier technique is obtained every period stochastically – representing uncertainty about magnitudes – around the current technique with a pre-defined direction, which we feed in the model based on the desired changes of the ETP. For instance, the frontier technical coefficient of refined oil used in production has a set downward direction, while the frontier technical coefficient of biofuels has a set upwards direction, meaning that sectors affected will shift intermediate demand towards biofuels, substituting refined oil. Table 7, designed to reflect ETP policies, describes the intermediary input technical coefficients that change.

Table 7: Technical Change Policy: Selected Sectors and Direction of Change

Demanding Sector	**Supplying Sector**
All Sectors except 2, 13, 15, 16, 17, 18, 19	13(-), 14(+) [1]
20	1(+), 3(-), 4(+), 10(+), 15(-), 22(-), 29(-) [2]
21	3(-), 4(-), 21(-), 29(+), 32(+) [2]
22	4(-), 21(-), 29(+), 32(+) [2]
25	4(+) [3]
26	25(+), 27(-) [4]
29	2(-), 4(-) 15(+), 25(+) [5]
32	29(+) [6]

[1] Overall substitution of refined oil for biofuels.
[2] Changes in *hard-to-abate* sectors (20, 21 and 22) are based on specific case studies.
[3] Increased production of batteries using other minerals (lithium).
[4] Production of hybrid and electric automobiles, using less auto parts and more batteries and electric components.
[5] Change in the electricity production matrix, using less oil and coal and more machinery (wind turbines) electric components (solar panels).
[6] Increased use of electricity in the transportation sector.

At the same time, we apply a similar approach to the emissions coefficients of sectors producing goods and services. In this case, we have used approximations to ensure compatibility between Brazilian data and sectoral emissions coefficients for countries including Australia, Canada, Germany, France, United Kingdom, the United States, China, and India. These estimations represent either possible best practices (the technological frontier) from a sectoral perspective or reflect countries with conditions similar to Brazil, such as being developing nations with large territories and populations. Partial implementation use the median emissions coefficient as an achievable technical frontier, whereas optimistic scenarios adopt the best emissions coefficient (in terms of emissions reduction). However, we do not assume that the frontier is fully achieved; it remains a parametric target. In some sectors where Brazil represents the frontier, the coefficients remain unchanged. Additionally, the process is overridden for sectors that are specifically modeled, such as Sector 1 (Agriculture, forestry, logging, and livestock and fishing) and Sector 29 (Production and distribution of electricity, gas, water, sewage, and urban sanitation).

Industrial Policy: This element in our scenario represents a change in the domestic content share of key production chains. It captures policy instruments of the Technological Densification axis, such as the NIB's missions, which lay on six topics:

- **Mission 1:** agro-industrial chains
- **Mission 2:** health
- **Mission 3:** well-being of people in cities

- **Mission 4:** digitally transform
- **Mission 5:** bioeconomy, decarbonization and energy transition and security
- **Mission 6:** defense

With this policy implemented, the domestic share of some selected input technical coefficients and some capital flow matrix coefficients are adjusted yearly based on a fixed annual increment. The increment is set as 1 percentage point per year in a full implementation scenarios and half of that in the partial implementation scenarios. The selection of coefficients and sectors is based on NIB's missions and targets, as described in Table 8. For instance, the share of domestic content in the purchase of machinery and equipment (sector 24) by the farming sector (1) increases to reflect Mission 1 of the Plan.

Table 8: Industrial Policy: Missions and Selected Sectors

Mission	Variable	Demanding Sector	Supplying Sector
Mission 1	Technical Coefficient	1	15
Mission 1	Investment Coefficient	1	24
Mission 2	Technical Coefficient	39	16
Mission 2	Investment Coefficient	39	24
Mission 4	Technical Coefficient	25	24
Mission 4	Technical Coefficient	25	25
Mission 4	Technical Coefficient	25	26
Mission 5	Technical Coefficient	29	24
Mission 5	Investment Coefficient	29	24
Mission 6	Technical Coefficient	28	25
Mission 6	Investment Coefficient	28	25
Mission 6	Technical Coefficient	All Sectors	34
Mission 6	Investment Coefficient	All Sectors	34

Notes: Sectors: (1) Agriculture, forestry, logging, and livestock and fishing; (15) Manufacture of organic and inorganic chemicals, resins, and elastomers; (16) Pharmaceutical products; (24) Machinery, equipment, furniture, and various other industrial products; (25) Household appliances and electronic equipment; (26) Automobiles, vans, trucks, and buses; (28) Other transportation equipment; (29) Production and distribution of electricity, gas, water, sewage, and urban sanitation; (34) Information services; (39) Private healthcare.

Financial Policy: This element in our scenario is represented by ETP policies changing financial conditions to promote investment towards newer and greener machinery and capital goods. It captures policy instruments of the Sustainable Finance and Bioeconomy and Agri-Food Systems axes, such as Climate Fund, Eco Invest Brazil Program and Safra Plan. With this policy implemented, firms have financial incentives to modernize their equipment, replacing old ones with new and greener productive capacity.

Also, financial conditions indirectly influence the pace of technical change through investment, shaping the trajectory of structural change and reductions in emission coefficients via an accelerated depreciation schedule. The concept is that favorable financial conditions facilitate modernization investment, including low interest and green finance, which reduce the cost of replacing old capital goods and technologies with new ones.

The model incorporates accelerated depreciation by adjusting the depreciation rate parameter. Usually, the depreciation rate reflects both replacement of scrapped capital and modernization investment. In our scenarios, modernization rates increase rapidly in the short term, peaking quickly before gradually returning to usual depreciation levels by 2050. This pattern reflects the concentration of ETP efforts in the early years of implementation, combined with the understanding that sustained high modernization rates are unrealistic over the long term without policies that ranges decades.

Both partial and full implementation scenarios follow the same general pattern, differing only in peak depreciation rates. The peak rates take a conservative approach, based on estimates from Cornelio et al. (2024) and our team's analysis of Brazilian historical trends. Specifically, BAU scenarios assume a 6% depreciation rate, intermediate scenarios peak at 7%, and optimistic scenarios peak at 8%.

Energy Efficiency Policy: This element in our scenario is represented by a change in the energy efficiency of automobiles. It captures policy instruments from the Sustainable Finance and Energy Transition axes, such as the MOVER plan, boosting R&D efforts for more efficient technologies. With this policy implemented, a fixed annual adjustment reduces vehicles' energy efficiency coefficient (measured in MJ per KM), which means an increase in vehicle efficiency and less energy consumption. The annual adjustment is 2% in scenarios with full implementation and half of that in the partial implementation scenarios, based on historical data on the energy efficiency of automobiles.

Green Electricity Policy: This element in our scenario is represented by a change in the electricity production matrix, changing the composition of different energy sources. It captures policy instruments from the Energy Transition axis, such as the National Energy Plan. With this policy implemented, the electricity production matrix, measured as the share of each energy source in the total installed capacity, changes based on official projections. The baseline projection assumes that natural gas will continue to be used, hydroelectric will gain even more participation in the electricity matrix but there are no long run improvements in solar and wind power participation (they increase in absolute values but not in relative terms with other sources. The partial implementation projection assumes some increase in wind and solar power but it assumes some non-renewable energy sources will still be used. The full implementation projection assumes that 100% of the electricity production will be from renewable sources by 2050, wind, solar and hydroelectric. The emission coefficient of electricity production is calculated every period based on the fixed emissions coefficient of each energy source and the respective changes in composition of each energy source in each projection.

Electrification Policy: This element in our scenario is represented by the change towards electric and hybrid vehicles in the auto mobile fleets. It captures policy instruments from the Energy Transition axis. With this policy implemented, the share of electric and hybrid vehicles in new fleets increase logistically based on some projections. The baseline projection estimates that by 2050, 11% of new cars will be electric and 61% of new vehicles will be hybrid, with the difference being combustion-based vehicles. The full implementation projection estimates that by 2050, 15% of new cars will be electric and 85% of new vehicles will be hybrid with no new combustion-based vehicles. The partial implementation projection estimates that by 2050, 13% of new cars will be electric and 73% of new vehicles will be hybrid, with the difference being combustion-based vehicles.

Biofuels Policy: This element in our scenario is represented by the change towards biofuels, such as ethanol, instead of gasoline and fossil fuel-based energy sources. It captures policy instruments from the Energy Transition axis. With this policy implemented, the share of hybrid and combustion-based vehicles using biofuels changes yearly. The increment is set to 2.5% in the full implementation scenarios and half in the partial implementation scenarios to reach some projected targets by 2050. The baseline projection assumes that 35% of hybrid and combustion vehicles will use biofuels in 2050 (same as the current share). The intermediate projection assumes that 50% of hybrid and combustion vehicles use biofuels in 2050, and the full implementation projection assumes that all hybrid and combustion-based vehicles will use biofuels in 2050.

Agricultural Policy: This element in our scenario is represented by the change towards good agricultural and livestock production practices. It captures policy instruments from the Bioeconomy and Agri-Food Systems and Sustainable Finance axes, such as the ABC+ plan and the Safra plan. With this policy implemented, areas with sustainable agricultural practices increase with fixed increment while the area of conventional agricultural technique is residual between the total area demand and the areas with good practices. The baseline projection assumes that areas with sustainable practices do not increase. The full implementation projection assumes that these areas grow and meet their specific ABC+ Plan targets in 10 years, while the partial implementation projection assumes that the areas grow at a slower pace (the increment is set as one-quarter of the full implementation projection) and the targets are met only in 40 years.

Intensive Cattle Policy: This element in our scenario is represented by the change in cattle production, becoming more intensive and using fewer areas, reducing potential deforestation. It captures policy instruments from the Bioeconomy and Agri-Food Systems axis, such as the ABC+ plan, and the Technological Densification axis. With this policy implemented, the share of total cattle in more intensive production increases, and the intensive production cattle demand less area than the conventional cattle production. The baseline projection assumes that all cattle is in conventional production technique. The full implementation scenario assumes that 50% of total cattle will be in intensive techniques in 10 years, while the partial implementation projection assumes that this target 25% of the total cattle will be in intensive techniques instead.

Land Recovering Policy: This element in our scenario is represented by the recovery of degraded lands into new forest areas. It captures policy instruments from the Bioeconomy and Agri-Food Systems axis. With this policy implemented, a fixed amount of degraded area is recovered every period, creating carbon capture sources and reducing the need for new areas and deforestation. The baseline projection assumes that no degraded area is recovered. The full implementation scenarios assumes that the target of recovered areas is met in 10 years with an increment of 3 million hectares per year, while the partial implementation projection assumes that this target is only met in 20 years instead, with an increment of 1.5 million hectares per year.

Forest Planting Policy: This element in our scenario is represented by increased productive forest planting. It captures policy instruments from the Bio-Economy and Agro-Food Systems axis. With this policy implemented, a fixed amount of productive forest is planted every year, creating carbon capture sources. The baseline projection assumes that there is no forest planting. The full implementation scenario assumes that the target of planted forest is met in 10 years with an increment of 0.4 million hectares per year, while the partial implementation projection assumes that this target is only met in 40 years instead, with an increment of 0.1 million hectares per year.

Manure Treatment Policy: This element in our scenario is represented by the treatment and reuse of animal manure. It captures policy instruments from the Circular Economy axis. With this policy implemented, the share of total animal manure, which depends on the total cattle, is treated, and treated manure has its specific calculated emission coefficient (negative, representing carbon capture). The baseline projection assumes that no manure is treated. The full implementation scenarios assume that 50% of total manure is treated in 10 years with an increment of 3% per year, while the partial implementation projection assumes that this target is only met in 40 years instead, with an increment of 0.75% per year.

Infrastructure Policy: This element in our scenario is represented by the increase in government investment for infrastructure and adaptation. It captures policy instruments from the Green Infrastructure and Adaptation axis. With this policy implemented, the government investment is added by a fixed increment destined to infrastructure and adaptation constructions and is not constrained by any fiscal policy rules. Recently announced projections by the Ministry of Finance predict between 100 and 150 billion BRL in infrastructure in the next 10 years. Considering that part of this investment is done by the private sector, it is relatively fair to assume that the government will spend around 10 billion BRL per year for the next 10 years on infrastructure and adaptation. In the partial implementation scenarios, it is assumed that half of these amounts will be spent instead.

4.2 Macroeconomic Dimension

The macroeconomic dimension captures three sub-dimensions independently of the ETP policies. Specifically, we analyze the impact of ETP policies under different macroeconomic scenarios: a baseline scenario, where most macroeconomic variables follow historical trends; an optimistic scenario, where macroeconomic variables grow above historical trends; and a pessimistic scenario, where they grow below historical trends.

We define the optimistic macroeconomic scenario such that all autonomous demand components (except exports, which are modeled explicitly) grow at the same rate as government expenditures. This growth rate is constrained by Brazilian most optimistic growth rate of spending according to the current fiscal rules, allowing for a maximum of 2.5% real growth. In the long run, this approach assumes that a balanced growth path must avoid increasing indebtedness across institutional sectors to ensure financial sustainability. For example, imbalances arise if the growth rate of government expenditures (investment and consumption) is lower than that of autonomous private demand, which could lead to rising household indebtedness (e.g., financing residential investment or durable goods consumption) (see for instance Pedrosa et al., 2023).

The intermediate scenario (baseline) assumes that autonomous demand growth for each sub-component follows historical trends, primarily from the early 2000s. From a macroeconomic perspective, this scenario should be the most reliable, as it reflects longer-term historical patterns. Considering the long-run nature of our analysis and the likelihood of different macroeconomic policies under shifting governments, this assumption offers a reasonable and balanced approach.

The pessimistic scenario assumes stagnation in autonomous per capita spending. Specifically, we set a rule where all autonomous demand components (except exports) grow at the population growth rate, effectively maintaining constant per capita spending for each autonomous component. This reflects a potentially low-growth scenario, where economic expansion relies primarily on export-driven growth.

4.3 Scenario Matrix: Key Parametrization

Table 9 summarizes the Policy Dimension, describing the specific policies, the ETP axes related to each policy and the key parameter values for each scenario. Table 10 summarizes the Macroeconomic Dimension, describing the specific policies and the key parameter values in each scenario.

Table 9: Description of the Scenarios: Key Parametrization of the Policy Dimension

Policy	**ETP Axes**[1]	**Variable**	**No ETP**	**Partial ETP**	**Full ETP**
Technological Change	(1), (2), (5)	Speed of Catching Up [2]	0 , 0	0.5 , 2.5	1 , 5
Industrial Policy	(2)	Increment in domestic content	0	0.005	0.01
Financial Policy	(1), (3)	Increment in depreciation [3]	0	0.01	0.02
Energy Efficiency Policy	(1), (4)	Increment in energy efficiency	0%	1%	2%
Green Electricity	(4)	Electricity matrix projection [4]	0%	14%	18%
Electrification Policy	(4)	Share of electric vehicles [5]	11%	13%	15%
Biofuels	(4)	Share of vehicles using biofuels [6]	35%	50%	100%
Agricultural	(1), (3)	Area of sustainable agriculture [7]	72	91	107
Intensive Cattle	(2), (3)	Share of cattle in intensive areas [8]	0%	25%	50%
Land Recovery	(3)	Area of recovered degraded lands [9]	0	15	30
Forest Planting	(3)	Area of planted forest [10]	0	2	4
Manure Treatment	(5)	Share of treated manure [11]	0	100	200
Infrastructure	(6)	Increment in government investment [12]	0	5000	10000

[1] (1) Sustainable Finance; (2) Technological Densification; (3) Bioeconomy and Agri-Food Systems; (4) Energy Transition; (5) Circular Economy; (6) Green Investment and Adaptation
[2] The first value refers to the catching up in technical coefficients while the second value refers to catching up in emission coefficients.
[3] The values illustrate the peak of change, but the change is distributed in time.
[4] Projected share of solar power in electricity production in 2050
[5] Target share of electric vehicles in 2050
[6] Target share of vehicles using biofuels in 2050
[7] Target area of sustainable agriculture in 2030, in millions of hectares
[8] Target share of intensive cattle in 2030
[9] Target area of restored pasture in 2030, in millions of hectares
[10] Target area of planted forest in 2030, in millions of hectares
[11] Target volume of treated manure in 2030, in millions of cubic meters
[12] Annual increase in public investment until 2035, in millions of BRL

Table 10: Description of the Scenarios: Macroeconomic Dimension

Dimension	**Variable**	**Baseline**	**Optimistic**	**Pessimistic**
Fiscal Policy	Growth Rate of Government Consumption	1.4%	2.5%	0.15% [1]
Fiscal Policy	Growth Rate of Government Investment	1.6%	2.5%	0.15% [1]
Monetary Policy	Growth Rate of Durables Consumption	2.2%	2.5%	0.15% [1]
Monetary Policy	Growth Rate of Residential Investment	2.3%	2.5%	0.15% [1]
External Sector	Income Elasticity of Exports	0.86	1.1	0.62

[1] This is the average population growth projected until 2050 for illustrative purposes, but these variables grow differently every year in the simulation, based on the year-by-year calculated growth rate of the population.

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