ENERGY
TRANSITION
PROGRAM

PHASE 2

Executive Report

The results of the second phase of CEBRI's Energy Transition Program originate from the pathways and scenarios developped by the academic centers and laboratories Cenergia, FIPE and MRTS. For that reason, they do not necessarily express the individual views of the institutions that participated in the Program, nor do they necessarily include other work being developed by these institutions. The sectoral recommendations should be considered in light of the policies, studies and analyses on decarbonization developed by the relevant sectoral institutions/entities in each case. The sectoral analyses and policy recommendations are not exhaustive and are subject to review as to their validity and consistency with the regulatory, technical and political frameworks of the sectors involved and with the specific context of Brazil.

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ENERGY TRANSITION PROGRAM

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Summary

1 About the Energy Transition Program

The Energy Transition Program (PTE) is a collaborative initiative led by CEBRI, in partnership with the Inter-American Development Bank (IDB), the Energy Research Office (EPE) and the National Bank for Economic and Social Development (BNDES), which aims to identify priority sector-oriented actions for Brazil to become carbon neutral by 2050. To achieve this, the Program used the integrated modeling approaches developed by Cenergia/COPPE/UFRJ, FIPE/USP and MRTS/USP — supported by extensive multistakeholder consultations.

In Phase 2, the Energy Transition Program (PTE) updates and expands upon the normative decarbonization scenarios developed in Phase 1, providing deeper insights into what achieving carbon neutrality by 2050 entails for Brazil. In this sense, the PTE seeks to answer the following guiding questions:

1. What is the optimal cost trajectory for Brazil, considering that the country meets its NDC[1]?
2. Can the power industry accommodate the deeper and faster penetration of energy generated from renewable sources?
3. Are GHG neutrality pathways for 2050 compatible with economic growth and job creation?
4. Can the current energy transition national plans and public policies contribute to reducing regional socioeconomic inequalities?

1. A Nationally Determined Contribution (NDC) is each country's climate action plan to reduce its greenhouse gas (GHG) emissions.

In light of these objectives, the following observations can be made:

i. **Scenarios are normative,** meaning that the model's unavoidable task is to achieve the target of net zero greenhouse gas (GHG) emissions by 2050, commonly referred to as "Net Zero".

i. **The pathways presented by the model adhere to the principle of optimal cost.** This means that some scenarios may become temporarily more carbon-intensive because the model determines that using more readily available or cheaper fossil fuels will not jeopardize the achievement of the Net Zero goal by 2050.

i. **The study provides insight into the magnitude of the challenge involved in achieving the energy transition**. On the other hand, it does not quantify the cost of inaction. This would necessitate a separate line of research focused on analyzing climate risks and their impacts on productive sectors, alongside an in-depth assessment of adaptation actions.

The scenarios in this research offer three complementary perspectives on how Brazil can achieve climate neutrality by 2050:

BT

The **Brazil Transition Scenario (BT)** represents the optimal cost pathway for fully achieving Brazil's NDC: reducing greenhouse gas (GHG) emissions by approximately 50% by 2030 (compared to 2005 levels), reducing emissions by 59% to 67% by 2035, and reaching net zero emissions by 2050. This pathway leverages national competitive advantages such as abundant renewable energy, bioenergy, and the reforestation potential.

AT

The **Alternative Transition Scenario (AT)** upholds the full NDC targets but introduces factors that steer the transition along different technological and regulatory pathways compared to the BT scenario — including carbon pricing, climate change impacts on hydropower and electricity demand, and stronger mandates for biofuels and electrification.

GT

The **Global Transition Scenario (GT)** adopts a bolder pathway for Brazil: building on the efforts of the BT and AT scenarios, it implements a carbon budget aligned with the 1.5°C limit, based on a globally cost-optimal allocation of emissions. This scenario requires deeper and faster emission cuts, including the accelerated phase-out of oil and gas, along with the increased use of renewables, nuclear energy, and carbon removal technologies.

Based on these scenarios, particularly BT, the Program proposes roadmaps for five key sectors (AFOLU, Energy, Industry, Cities, and Transportation), including public policy recommendations and strategic guidance for the private sector. The aim is to align Brazil's energy transition with its climate goals, leverage national competitive advantages, and prepare the country to take a leading role in global sustainable solutions.

2 Methodology and Premises

The methodology of the Energy Transition Program (PTE, in its Portuguese acronym) integrates advanced technical-scientific modeling with a structured dialog process involving key institutions and a diversity of stakeholders.

The **Cenergia Laboratory (COPPE)** updates and expands the energy scenarios of the first phase of the Program (PTE 1), using the integrated energy supply and demand and land use assessment model (Brazilian Land-Use and Energy System – BLUES), and introduces climate premises, technological constraints, and sectoral policies. BLUES is an integrated assessment model designed to comprehensively capture the interconnections between land use, energy systems, and greenhouse gas emissions within the Brazilian context and to operate alongside the global COFFEE model (Computable Framework For Energy and the Environment) to support similar assessments at the global level. Cenergia's COFFEE model is among the mitigation scenarios used by the IPCC.

The **University of São Paulo Economic Research Institute (FIPE/USP)** integrates the sectoral and regional results provided by COPPE into its computable general equilibrium and input-output models to provide both aggregated and broken down macroeconomic projections (GDP, employment, investment, foreign trade, and income), as well as the distributional impacts of the energy transition for Brazil. FIPE also performs iterative adjustments to maintain consistency between energy projections and the economic constraints in each scenario.

MRTS Consultoria uses data provided by COPPE to test the technical feasibility of electrical expansion in each scenario. Supply security is assessed through detailed simulations of the power industry — including power balance analyses and risk indicators such as LOLP[2] and CVaR[3] — as well as verification of firm capacity supply criteria. This process identifies bottlenecks, operational restrictions, and flexibility requirements to meet the projected demand.

These organizations cooperated closely, continuously refining their models and results through dynamic cross-interactions. The teams shared data and aligned premises through joint technical meetings, ensuring overall consistency across all scenarios.

Scenario Description

Brazil Transition Scenario (BT)

This is the study's baseline scenario, where Brazil fully meets its current climate targets, aiming for the least-cost pathway to achieve net-zero greenhouse gas emissions by 2050. The goal is to determine how Brazil can achieve its climate targets at the lowest possible cost by leveraging its clean energy potential and other comparative advantages.

The key climate premises for this scenario include reducing greenhouse gas emissions by approximately 50% by 2030 compared to 2005 levels, as well as achieving net-zero greenhouse gas emissions by 2050, in line with the NDC. This scenario further assumes Brazil will achieve its land use targets outlined in the NDC, notably zero illegal deforestation starting in 2030 and the reforestation and forest restoration of approximately 12 million hectares by 2035. These actions are consistent with the scenario's premises and are designed to enhance carbon removals.

2. LOLP (Loss of Load Probability): probability of a supply shortfall occurring within a given period.

3. CVaR (Conditional Value at Risk): expected losses associated with shortfall events that exceed a critical threshold.

Alternative Transition Scenario (AT)

The Alternative Transition (AT) Scenario explores a different pathway for Brazil to achieve net-zero emissions by 2050, introducing alternative technological, climate, and public policy pathways that may influence the pace and choices of the transition. It is a variation of the baseline BT scenario — maintaining the climate targets for 2030, 2035, and 2050 — but with conditions that either restrict or encourage certain technological routes along which the energy transition may unfold.

Essentially, the AT scenario acts as a “stress test”, simulating how Brazil could achieve net-zero emissions under less favorable or more challenging conditions, whether due to direct climate change impacts, delayed dissemination of certain technologies, or policy decisions that stray from the cost-optimization path suggested by integrated modeling.

To this end, a set of additional premises is introduced to model a scenario distinct from BT, reflecting an alternative environment for Brazil’s decarbonization through 2050.

- In the **power industry**, the scenario considers a reduction in the hydropower potential due to decreased capacity factors caused by climate change, an increase in electricity demand (about 7% above the baseline scenario), initial constraints on the growth of wind power, a greater role for battery storage, and a faster-paced expansion of nuclear power.
- For **biofuels**, the scenario assumes full implementation of existing policies, with high blend levels and the gradual introduction of renewable diesel, Sustainable Aviation Fuel (SAF), and biomethane, regardless of short-term costs.
- Introduction of **carbon pricing**, simulating the Brazilian Emissions Trading System (SBCE), which leads to an earlier decline in domestic fossil fuel consumption.
- In the **transportation sector**, the scenario envisions the complete replacement of fossil-based aviation kerosene (QAV) with SAF and marine bunker with biofuels by 2050, along with strong electrification and a shift toward lower-emission transportation modes.
- The scenario assumes that Brazil will position itself as a key player in the **low-carbon hydrogen** economy, reaching around 4.2 million tonnes per year by 2050 (with 38% allocated for export), including production pathways based on biomass and electrolysis (2 million tonnes per year of H2V).

Global Transition Scenario (GT)

The Global Transition (GT) Scenario is based on a global cost-optimization exercise, illustrating Brazil's role in a world that aims to limit the temperature increase to 1.5°C. In this hypothetical scenario, Brazil is assumed to face a highly restrictive carbon budget — meaning a much lower CO_2 emissions cap than the one currently outlined in its NDC. This contrasting scenario depicts a world where there is insufficient global cooperation for the energy transition, marked by weak policies and an uneven sharing of responsibilities. Based on global models (such as COFFEE), Brazil's cumulative carbon budget between 2010 and 2050 was estimated at just ~7.24 Gt of CO_2. This constraint means that, in the GT scenario, Brazil would have to pursue even deeper and faster emission reductions than in the BT scenario to remain within its share of emissions aligned with the global 1.5°C pathway.

Table 1. **Comparison of the premises used across scenarios**

	BT Brazil Transition	**AT** Alternative Transition	**GT** Global Transition
Population	Average growth of 0.2% p.a. between 2020-2050		
AFOLU	Zero illegal deforestation from 2030 Implementation of Brazil's Low Carbon Agriculture (ABC+) Targets of Brazil's native vegetation restoration plan (PLANAVEG) reached with a 5-year delay Maximum annual reforestation limited to 1.2 Mha (forest + savanna)		
Emissions target	Targets set acoording to the NDC for 2025, 2030 and 2035		NA
Climate neutrality	Zero net GHG emissions by 2050		NA
Carbon budget	Implicit to fulfilling national NDC		~7,24 Gt CO_2 (2010–2050) – alocação custo-ótimo global
IMO[4] targets	NA	Included	Included
ICAO[5] targets	NA	Included	Included
Power Industry	Decree 11,042 and Law 14,182/2021 Nuclear Power Plant Angra 3 starts production in 2030	7% increase in electricity demand; reduction in the capacity factor[6] of hydropower plants	Decree 11,042 and Law 14,182/2021 Nuclear Power Plant Angra 3 starts production in 2030
Fuel	B15 diesel from 2025 Gasoline with 27.5% ethanol by volume Expansion of the RNEST refinery in the northeast (230kbpd in 2030)	Gasoline C: 35% ethanol by 2050 Diesel B: 25% by 2050 At least 3% green diesel (HVO) added to diesel B Up to 50% biomethane in the natural gas network by 2050	B15 diesel from 2025 Gasoline with 27.5% ethanol by volume Expansion of the RNEST refinery in the northeast (230kbpd in 2030)
Low-carbon hydrogen	Development based on feasibility (no specific target)	~4.2 Mt produced by 2050 (38% for export; 10% via biomass; ~2Mt via electrolysis)	Development based on feasibility (no specific target)
Transpor-tation	Improvement in road paving	Percentage variation in the share of each transportation mode	Improvement in road paving
Carbon Pricing	NA	According to IEA APS (Announced Pledges Scenario)	NA

4. IMO (International Maritime Organization): UN agency that sets international standards for shipping and maritime transportation.
5. ICAO (International Civil Aviation Organization): UN agency that regulates international civil aviation.
6. Capacity Factor: metric that compares a plant's actual output over a certain period to its maximum possible output if operated continuously at full capacity.

3 Main results

The Program results show that Brazil has multiple viable pathways to successfully achieve climate neutrality by 2050 balancing economic growth, energy security, and emissions reduction. Across all scenarios analyzed, achieving the short-term target of a 50% emissions reduction by 2030 compared to 2005 — and reaching net-zero emissions by mid-century — proved to be feasible. However, this path demands prompt government action and close cooperation between government and non-government stakeholders to enhance Brazil's competitiveness and appeal for private investment.

At a structural level, all scenarios point to a profound transformation in the energy mix, with a growing share of renewables (wind, solar, biomass) and a complementary role for nuclear, hydrogen and storage technologies. Bioenergy also advances, gradually reducing reliance on fossil fuels at varying rates and intensities across scenarios. On the emissions front, the land use sector plays a crucial role, becoming a net carbon sink that offsets residual emissions from hard-to-abate sectors.

From a macroeconomic standpoint, the energy transition is compatible with economic growth, supporting additional GDP expansion and the net creation of 1.5 to 2 million jobs by 2050. However, the data also points to enduring regional inequalities. The Northeast, for instance, has immense potential to attract investment in renewables while still confronting deep social challenges, underscoring the need for an industrial policy targeted to the region.

Another key finding is that the scenario including carbon pricing shows the highest economic growth. This is because carbon pricing drives innovation and enables key technological pathways to net-zero, such as CCUS, BECCS, SAF, biobunker and HVO. These results underscore the critical importance of mechanisms that foster innovation and strengthening public-private partnerships to ensure a successful transition.

Taken together, these shifts position Brazil as a potential leader in clean energy, the bioeconomy, and climate solutions, unlocking opportunities for regional development, technological innovation, and green job creation. It is important to acknowledge the study's limitations: PTE2 did not quantify the costs of inaction through climate risk analysis or assess in detail the adaptation actions needed. These aspects remain a critical agenda for future work to provide a more comprehensive picture of the risks and opportunities associated to the energy transition.

Table 2. **Comparison of the main results across scenarios**

	BT Brazil Transition	AT Alternative Transition	GT Global Transition
Cumulative emissions 2010–2050 ($GtCO_2$)	~11	~10	7.24
Year when climate neutrality is reached	2050	2050	~2045
Net emissions in 2050 ($MtCO_2eq$/year)	≈ 0	≈ 0	-163
Renewable % of the energy mix in 2050	60%	72%	78%
Cumulative GDP growth (%) (2025-2050)	109%	124%	95%
Cumulative job creation (2025-2050)	24 million	28 million	22 million
Feasibility	●●●●○ High	●●●○○ Average	●○○○○ Low
Main constraints			
Governance	Fulfilling NDCs, strengthening of regulatory stability	Implementation of carbon pricing and of the Fuel of the Future Act	Global coordination (difficult in the current geopolitical scenario)
Technology	Renewables integrated with storage and demand response, along with expansion of transmission	Storage and electromobility grow in alignment with the PDE[7]	Large-scale BECCS, accelerated deployment of batteries, demand response, and CCS-equipped thermal power plants
Economy	Energy efficiency and diffuse electrification (industry, buildings, light transportation)	Adjustment of relative prices through carbon pricing and industrial policy to support new green value chains	Pressure on land use: bioenergy strongly displacing agribusiness
Risks to mitigate	Highly AFOLU-dependent (requires strong enforcement against deforestation)	Loss of competitiveness and higher cost	Impact on the trade balance, agribusiness and oil heavily affected

7. EPE 's 2034 Ten-Year Energy Expansion Plan

3.1 Energy Mix

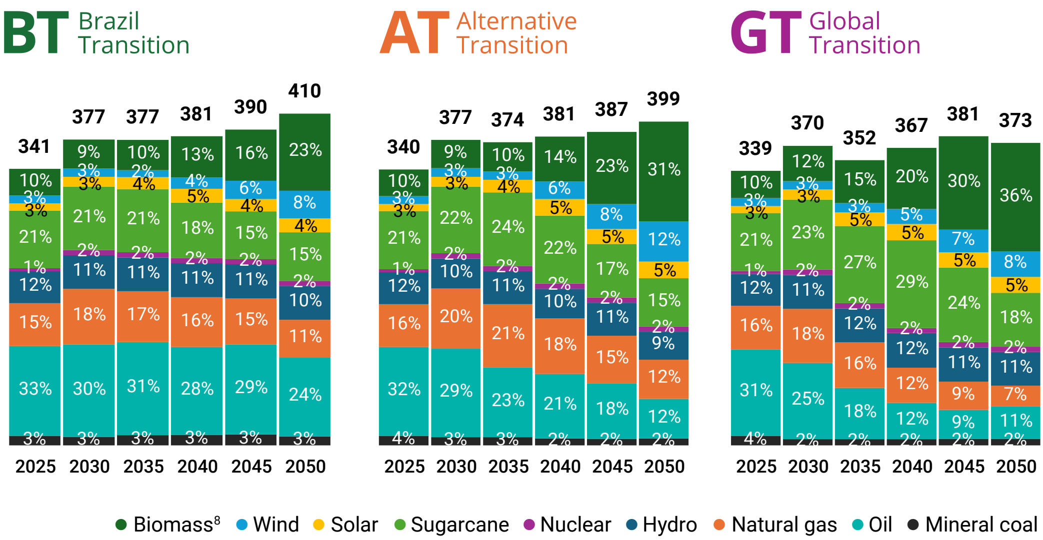
The PTE2 scenarios confirm that Brazil's energy mix can become cleaner and more diversified, reinforcing the country's position as a leader in renewable sources.

In the BT Scenario, the share of renewables in the total primary energy supply rises from around 50% in 2020 to approximately 61% by 2050. This growth is primarily driven by bioenergy along with solar and wind power, which together meet all future increases in demand. Oil and gas retain some relevance, although oil's share declines from about 34% of the current energy mix to around 25% by 2050. Coal remains in the energy mix at a residual level, mainly for industrial use, especially in the steel and metallurgy industries.

Conversely, the AT Scenario, which simulates an environment with different constraints than the BT scenario, sees renewables reach about 72% of the energy mix by 2050, thanks to higher biofuel penetration and to limits on wind power expansion. Domestic oil and gas consumption declines at a rate similar to the GT scenario, but these resources may still contribute to exports depending on global market dynamics.

The GT Scenario, designed as a stress test to explore the limits of Brazil's transition, features an uneven distribution of mitigation efforts, resulting in a disproportionate burden on Brazil. This scenario requires the country to operate under a highly restrictive carbon budget of just ≈7.24 $GtCO_2$ between 2010 and 2050, a level significantly below that implied by its current NDC. To meet this limit, Brazil must substitute oil and gas for bioenergy and clean electricity at an unprecedented pace, so as to push renewables to nearly 80% of the energy mix by 2050. The necessary political decisions come with high costs, requiring massive investment in infrastructure and CCUS/BECCS. This shows that the 1.5°C target cannot be achieved without more coordinated and cooperative international governance.

Chart 1. **Primary Energy (Mtoe)**



3.2 Emissions

The GHG emissions outlook shows that Brazil can achieve net-zero emissions by 2050 in all scenarios, although through different paths in terms of pace and sectoral composition.

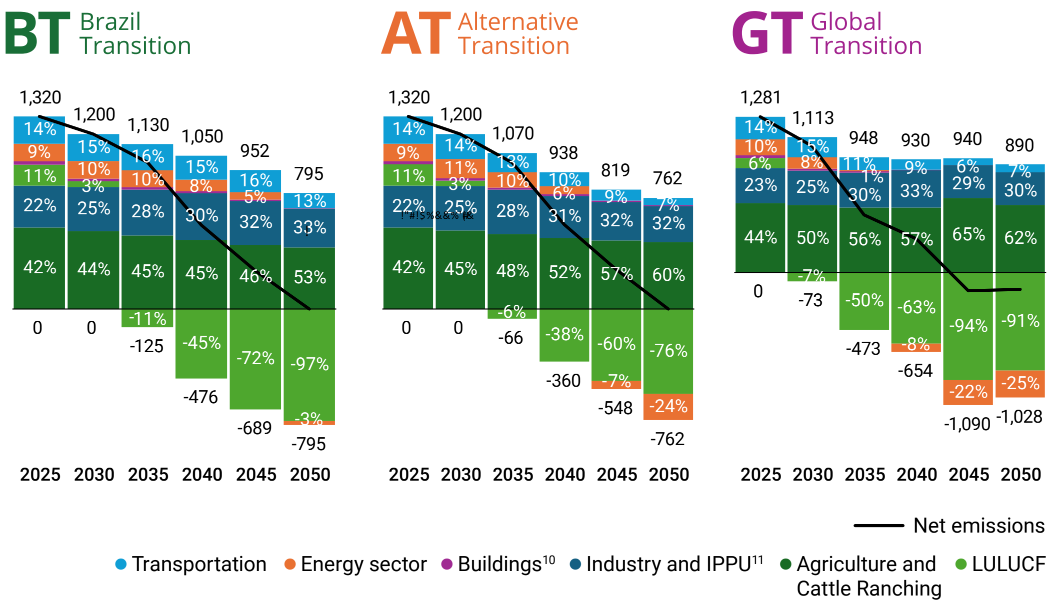
In the BT Scenario, national emissions fall by about 50% by 2030 compared to 2005, in line with the NDC, and reach neutrality by 2050. The land use sector (AFOLU) assumes a decisive role, driven by the implementation of zero illegal deforestation starting in 2030 and the reforestation of 12 million hectares by 2035, leading the sector to transition into a net carbon sink by 2040. Residual emissions — including methane and nitrous oxide from agriculture and cattle ranching, as well as CO_2 from the transportation sector and industry — are offset by forest removals and negative emissions technologies (such as BECCS).

8. Biomass refers to a broad set of agricultural residues, elephant grass, wood resources, vegetable oil, animal fat, and corn, among others. Sugarcane is shown separately in the chart.

The AT Scenario maintains Brazil's NDC targets, but under more challenging conditions. The introduction of carbon pricing and technological mandates quicken the pace of the decline in the domestic use of fossil fuels. Despite the greater difficulty in expanding hydropower and wind sources, the AT Scenario achieves neutrality by 2050 through technological diversification and the use of bioenergy (supported by public policies such as the Fuel of the Future Act).

In the GT Scenario, Brazil faces a more stringent carbon budget9: just 7.24 $GtCO_2$ between 2010 and 2050, making it necessary to speed up reductions in order to reach neutrality before 2050 and a negative balance in the final decade. Offsetting remaining emissions — both non-CO_2 and CO_2 from the transportation sector and industry — requires even greater removals through reforestation, BECCS and forest conservation.

Chart 2. **GHG Emissions ($MtCO_2eq$)**



9. A stricter budget was necessary to meet the carbon limit aligned with the 1.5°C temperature target, as defined in the premises for the GT Scenario. For more details, see Table 1: Comparison of the premises used across scenarios.

10. Buildings refer to the allocation of emissions within the Cities sector, which includes urban buildings (residential, commercial, and public) as well as stationary urban services (such as lighting and water/sewage systems). In the study, the Cities sector does not include urban vehicles — all fuel burned in cars, buses, taxis, etc. is accounted for in the Transportation sector.

11. IPPU (Industrial Processes and Product Use) refers to greenhouse gas emissions from industrial activities not directly related to energy consumption.

3.3 Just energy transition

The pursuit of a just energy transition introduces an additional layer of complexity for Brazil, as millions of people still rely on traditional energy sources to meet their basic needs. Achieving an inclusive and equitable transition to a low-carbon economy requires the integration of several core principles such as fostering social dialog and stakeholder engagement, implementing inclusion-oriented public policies, sustainable economic growth, quality job creation, and workforce reskilling.

The rapid expansion of renewable energy and the gradual long-term decline of the fossil fuel industry affect different regions, sectors and social groups in distinct ways. The macroeconomic study within PTE2 shows that even under more constrained scenarios (GT and AT), Brazil can achieve cumulative GDP growth of 1.2% to 1.5% by 2050 compared to the baseline, along with the net creation of some 28 million jobs over that time. Sectors such as construction and agriculture and cattle ranching account for about a quarter of this job creation and offer significant opportunities for green employment, especially in the North and Northeast regions, where these sectors are projected to originate up to 30% of new jobs by 2050, exceeding their roughly 20% contribution in other regions.

Conversely, the gradual decline of the fossil fuel supply chain is expected to cause job losses concentrated in specific regions (notably the Southeast due to its close ties to oil and gas production), which underscores the essential role of robust workforce retraining and reskilling programs. Achieving a just transition hinges on correcting this imbalance through the redistribution of benefits and mitigation of social costs.

The energy transition can, therefore, open a window of opportunity, not only to create jobs and income by capitalizing on Brazil's energy potential, but also to advance social inclusion, combat energy poverty, and reduce regional inequalities. Turning this opportunity into reality depends on the coordinated action of government, non-government and civil society stakeholders, to ensure that social justice is integrated into every phase of the decarbonization process.

4 Sectoral Roadmaps

The energy transition cannot be realized solely through national targets or aggregate projections; rather, its success hinges on concrete, sector-specific changes that are both coordinated and feasible over time. That is why PTE2 moves beyond macro-level scenario building to offer sectoral roadmaps for five strategic areas: AFOLU (agriculture and cattle ranching, forestry and land use), Industry, Cities, Transportation, and Energy.

These roadmaps are grounded in quantitative modeling results and propose practical actions, outlining interim milestones, critical technologies, necessary public policies, and market opportunities in each sector. More than merely outlining emissions reductions, they suggest enabling actions to achieve the pathways modeled, striking a balance between technical feasibility, economic competitiveness, and social inclusion.

The roadmaps are forward-looking visions and interpretations that are not derived only from modeling results. They may also draw on data from partner organizations, as well as evidence and projections regarding the current state of the transition. As such, they aim to go beyond quantitative scenarios by offering a practical step-by-step approach to achieving these possible pathways, incorporating complementary analyses.

The development of the roadmaps was coordinated by CEBRI and involved close interaction between partner institutions and sectoral stakeholders[12] through closed meetings, consultations, and multisector discussions.

As a consequence, the roadmaps incorporate both the robustness of integrated modeling (energy, economy and land use) and the experience and perspectives of stakeholders from government, business, academia and civil society.

The result is a set of converging sectoral pathways that shed light on viable decarbonization routes for Brazil, identifying key areas of concern, implementation challenges, and strategic opportunities in each sector. These roadmaps thus serve as a guide to inform public policy and private investment, helping Brazil progress toward climate neutrality by 2050 in a coordinated manner.

4.1 AFOLU

The Agriculture, Forestry and Land Use sector (AFOLU) is critical to Brazil's pursuit of climate neutrality and, according to results from the BLUES model, offers the greatest potential for net emissions reductions over the coming decades.

In the PTE2 scenarios, achieving zero illegal deforestation by 2030 and the restoration of 12 million hectares of forests by 2035 lead to a sharp decline in net emissions as early as the next decade. By the mid-2040s, the sector becomes a net carbon sink, removing more CO_2 from the atmosphere than it emits. This turning point is reached through the near elimination of land-use change emissions combined with increased forest carbon sequestration.

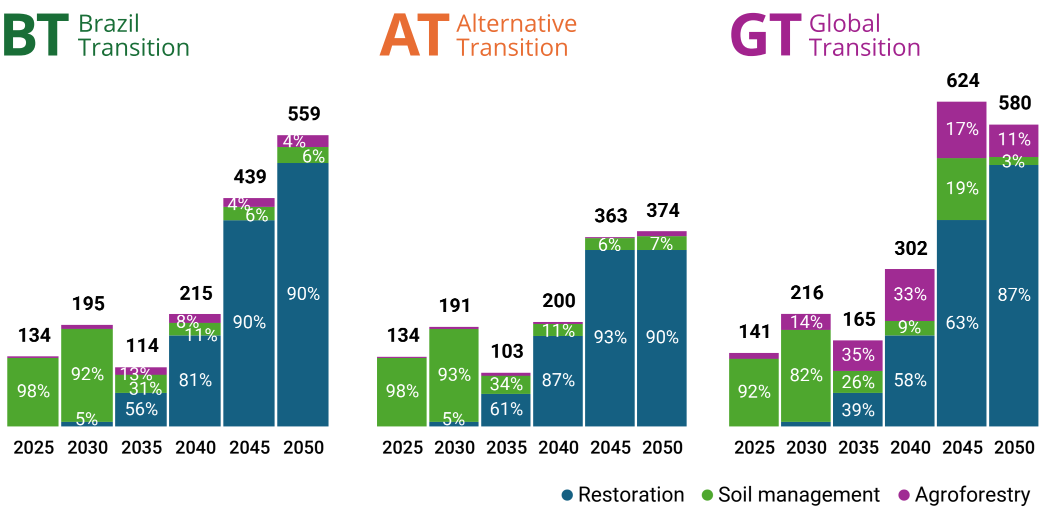
The expansion in the use of biomass takes place without putting significant pressure on deforestation or land use. This maintains the consistency between forest

12. The development of these roadmaps was a collaborative effort involving various stakeholders and partner institutions that provided essential analyses and insights, such as the project's sponsoring companies, IDB, BNDES, Catavento, Climate Emergency Collaboration, CNI, CNT, EPE, FGV, FIESP, iCS, ICAO, IBAMA, Imaflora, Instituto E+ Transição Energética, IPAM, IRENA, IWA Asset Management, MDIC, Ultra and WWF-Brazil, among others. The authors wish to thank all participants for their valuable contributions.

restoration and bioenergy: they do not directly compete but rather interact in a complementary way.

Even when accounting for residual methane and nitrous oxide emissions from agriculture and cattle ranching, the additional removals position AFOLU as a key compensatory pillar for other sectors. By 2050, the sector shows a net negative balance in all scenarios, confirming its central role in Brazil's decarbonization strategy.

Chart 3. **Carbon Removal ($MtCO_2$)**



Short Term (2025-2030):

Elimination of illegal deforestation of native vegetation

- Widespread pasture restoration and adoption of sustainable agricultural practices initiated;
- Improvement of economic models for PES (Payment for Environmental Services) projects;
- Large-scale reforestation and ecological restoration programs begin to be implemented, aiming to restore approximately 12 million hectares by 2035;
- Elimination of fire-based pasture management practices to prevent the sector from contributing to deforestation;

- Significant CO_2 removals as early as 2030 (~180 $MtCO_2$/year through improved soil management) to cut emissions in agriculture;
- Renewal of the agricultural fleet with more efficient machinery - tractors, harvesters, sprayers, with marginal electrification;
- Fostering improved pasture use efficiency through regenerative grazing and technologies that increase the number of animals per hectare, such as corrals and watering systems.

Medium Term (2030-2040):

Progress in the transformation of land use

- Conversion of ~25 Mha into carbon sinks through reforestation (~3 Mha) and Integrated Crop-Livestock-Forestry systems (ILPF) (24 Mha);
- Low-carbon agriculture technologies (such as biological nitrogen fixation, methane-reducing animal diets, waste management) become more widespread, reducing non-CO_2 sectoral emissions;
- Implementation of methane control actions such as waste management (e.g. biodigesters), pasture management and improvements in animal feed;
- Increased forest protection.

Long Term (2040-2050):

AFOLU turns into a net carbon sink sector

- Planted and native forests remove massive amounts of CO_2 (~500 Mt CO_2/year);
- Agroforestry systems and Integrated Crop-Livestock-Forestry (ILPF) are widely adopted, incorporating bio-inputs;
- AFOLU enables over 83% of the carbon removals Brazil needs to achieve climate neutrality, while delivering co-benefits such as supporting biodiversity, enhancing water security, and creating green jobs;
- Reforestation, sustainable forest management, and the restoration of degraded areas boost regional GDP, especially in Brazil's North and Center-West regions.

Role of public policymakers

1. Strict enforcement of zero deforestation targets by 2030.

a. Create more efficient command and control mechanisms.

b. Expand conservation units and indigenous lands to protect natural carbon stocks.

2. Encouraging removals and sustainable agriculture

a. Implement payments for environmental services and carbon credits in line with initiatives such as the National Policy on Payment for Environmental Services (PNPSA).

b. Expand programs like the ABC+ Plan to promote low-emission practices (such as ILPF, no-till farming, and biological nitrogen fixation), along with technical support (agronomists, veterinarians, agricultural technicians) for small-scale farmers.

c. Develop environmental compliance plans for rural properties.

d. Establish a national sustainable rural taxonomy and regulations for health and socio-environmental traceability.

3. Enabling policies and long-term planning

a. Implement clear sectoral targets for CO_2 removal and reduction of agricultural and cattle ranching emissions, in line with the guidelines of Brazil's 2025 Climate Plan ("Plano Clima") (e.g., hectares to be restored per year, percentage of agricultural land under sustainable practices).

b. Create green credit lines and agricultural insurance for farmers adopting low-carbon technologies, and promote R&D in low-emission cattle ranching (such as genetic improvement and anti-methane feed additives).

4. Carbon markets and economic improvement

a. Establish a carbon market that includes AFOLU in order to strengthen the Brazilian Emissions Trading System (SBCE).

b. Leverage Brazil's potential for nature-based solutions (NBS) through international partnerships and access to climate funds.

c. Create commercial incentives for deforestation-free agricultural products.

Opportunities for the private sector

1. Restoration market and carbon credits

a. Growing demand for high-integrity carbon credits encourages large-scale commercial reforestation and ecological restoration.

a. Planting native and exotic species for timber, energy purposes, and emission offsetting.

2. Low-carbon technologies in agriculture and cattle ranching

a. Boosting the market for established companies and startups that develop climate solutions for agriculture and cattle ranching.

b. Opportunities to develop infrastructure and equipment for sustainable agricultural intensification (such as solar-powered irrigation and electric or hybrid agricultural machinery).

3. Bioeconomy and sustainable value chains

a. Growth of bioindustries that add value to the standing forest and to sustainable production, such as sustainable wood management and advanced biofuels.

b. Export of nature-based solutions and low-carbon inputs.

c. Expansion of environmental services driven by industrial sectors seeking to achieve their emissions reduction targets.

d. Enhance agricultural productivity through pasture recovery.

4. Engagement in green finance and insurance

a. Expansion of investment funds and green bonds focused on low-carbon agriculture and restoration.

b. Offering financial instruments tailored to environmentally compliant rural producers (e.g., green Agribusiness Receivables Certificates - CRA).

c. Include sustainability criteria in insurance and agricultural funding, reducing risk for sustainable farmers.

4.2 Industry

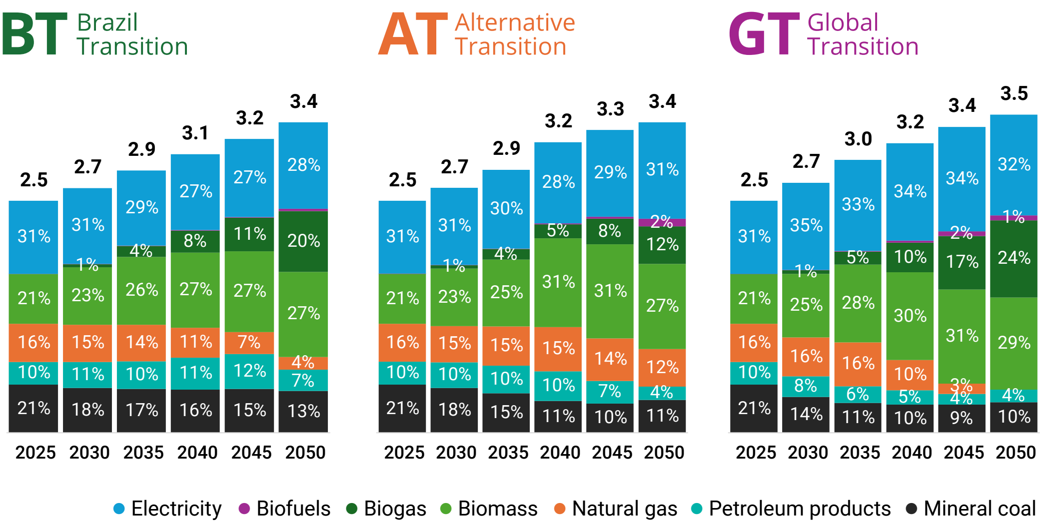
The results from the BLUES model show that Brazil's industry can significantly reduce its emissions by 2050, even as production continues to grow.

In the BT Scenario, industrial energy-related emissions, currently at ~87 $MtCO_2eq$, gradually drop to approximately 66 $MtCO_2eq$ by 2050, thanks to the replacement of fossil fuels with biomass, the electrification of low- and medium-temperature thermal processes, and efficiency gains.

In the AT Scenario, the introduction of carbon pricing accelerates the phase-out of fossil fuels and expands the share of renewable energy pathways, leading to final energy sector emissions of around 66 $MtCO_2eq$ by 2050. Industry's carbon intensity drops markedly across all scenarios, confirming that the sector can remain competitive and continue to grow economically while also contributing to achieve climate neutrality.

In the more restrictive GT Scenario, the decline is even steeper: industrial energy-related emissions approach 40 $MtCO_2eq$ by 2050, which requires the additional introduction of emerging technologies such as green hydrogen in the steel industry and carbon capture and storage (CCUS) in cement and chemical processes.

Chart 4. **Consumption in Industry (EJ)**



Short Term (2025-2030):

Industrial modernization begins, with emphasis on energy efficiency

- Steelmaking: expansion of green steel routes using charcoal in dedicated blast furnaces;
- Cement: increased co-processing of waste and biomass in furnaces (>20% thermal replacement);
- Chemicals and fertilizers: initial use of green feedstocks;
- Launch of initiatives to develop a national “green” capital goods industry (wind turbines, batteries, electrolyzers, etc.);
- Implementation of solutions geared toward improving industrial energy efficiency;
- Development of various circular economy initiatives, such as urban mining and the expansion of the logistics chain for waste reuse in industry.

Medium Term (2030-2040):

Fast-paced technological transformation and fuel switching within Brazilian industry

- Steelmaking: increased use of charcoal and biomass, expanding the production of low-emission steel. Biomethane starts substituting natural gas;
- Cement: increased use of waste and biomass. Installation of pilot CCS units, coupled with the increased use of clinker substitutes, to leverage their potential for emissions mitigation.
- Chemicals and fertilizers: greater use of green feedstocks and increased production of biomaterials;
- Integration of energy and industrial policies to align power generation with industrial demands and vice versa, promoting a dynamic balance between supply and consumption to foster competitive costs and technological innovation.

Long Term (2040-2050):
Final advances in the energy transition

- Steel industry: Increased use of biomethane to replace fossil natural gas;
- Cement: Introduction of CCS to reduce the carbon intensity of cement production;
- Chemicals and fertilizers: Use of green feedstocks surpasses 50% of energy consumption. Increased production of biomaterials;
- Industrial processes shift toward electrification, sustainable biomass and/or CCS;
- Emergence of a competitive “green” capital goods sector.

Role of public policymakers

1. Efficiency regulation and green financing

a. Mandate minimum energy performance standards and energy management plans in energy-intensive industries.

b. Reward factories that meet international energy intensity benchmarks.

c. Expand lines of credit (through BNDES and regional banks) for retrofitting facilities and for heat recovery.

d. Strengthen transition funding for small- and medium-scale industries.

2. Foster innovation and emerging technologies

a. Integrate energy and industrial policies to enhance competitiveness and innovation, so as to enable the development of new value chains.

b. Launch public-private R&D initiatives targeting hard-to-abate sectors (e.g. a national green steel program).

c. Remove taxes on strategic equipment and inputs for decarbonization (electrolyzers, industrial heat pumps, IoT sensors, carbon capture systems).

d. Promote coordinated action between BNDES, FINEP and the Ministry of Science, Technology and Innovation.

3. Market mechanisms and carbon regulations

a. Use carbon pricing to induce fuel switching and mitigation measures.

b. Gradually introduce regulatory carbon standards (e.g., CO_2 intensity per tonne of cement or steel).

c. Use government purchasing power to leverage the demand for green materials (e.g. prioritize low-carbon materials in government construction projects).

4. Enabling infrastructure

a. Support the training and reskilling of the industrial workforce.

b. Promote the creation of industrial clusters by expanding access to shared energy and logistics infrastructure, as well as CCS hubs with carbon injection into depleted reservoirs.

c. Enable the integration of biomethane production hubs into the natural gas grid.

Opportunities for the private sector

1. Clean industrial technology

a. Development of startups focused on more efficient electrolysis, industrial fuel cells, and hydrogen production from biomass/biogas with carbon capture, as well as CCS solutions (new solvents, uses for captured CO_2), and innovative materials.

b. Allocation of venture or private equity capital to these technologies, in alignment with the global industry's effort to achieve net-zero emissions by 2050.

2. Bioenergy and circular economy

a. Expansion of biomass and waste supply chains for industrial use.

b. Planting energy forests, pellet production.

c. Management and processing of agricultural and urban waste for fuel production or circular use of materials, such as metal scrap and reuse of blast furnace slag for cement production.

3. Funding for transition projects

a. Increased demand for capital to modify and build facilities (electric furnaces, electrolyzers, bio-input plants).

b. Expansion of instruments such as industrial green bonds, loans linked to climate targets (Sustainability-Linked Loans), and green infrastructure bonds, which tend to offer favorable conditions and attract high demand.

c. Carbon market regulation encourages demand (offtake) for low-carbon products.

4. Competitiveness and market access

a. Establishing a competitive edge and enhancing market value for companies that comply with potential carbon barriers (such as Europe's CBAM).

b. Meeting the requirements of global buyers to potentially secure price premiums and preferential treatment.

c. Emergence of a competitive capital goods sector in Brazil.

d. Leverage Brazil's highly renewable energy mix as a competitive advantage.

4.3 Energy Sector

Projected modeling reveals a structural metamorphosis for Brazil's energy sector by 2050, marked by a strong reduction in the share of fossil fuels and rapid growth in renewable energy sources.

In the BT Scenario, the share of renewables in primary energy supply rises from about 50% today to ~60% by 2050. Oil and gas will then still account for around 40%, but their role diminishes and they are offset by carbon removals.

In the AT Scenario, renewables will reach ~72% of the energy mix in 2050, with an emphasis on wind and solar bioenergy. This scenario also envisages the addition of ~4GW in new nuclear capacity to compensate for restrictions in hydro- and wind power[13].

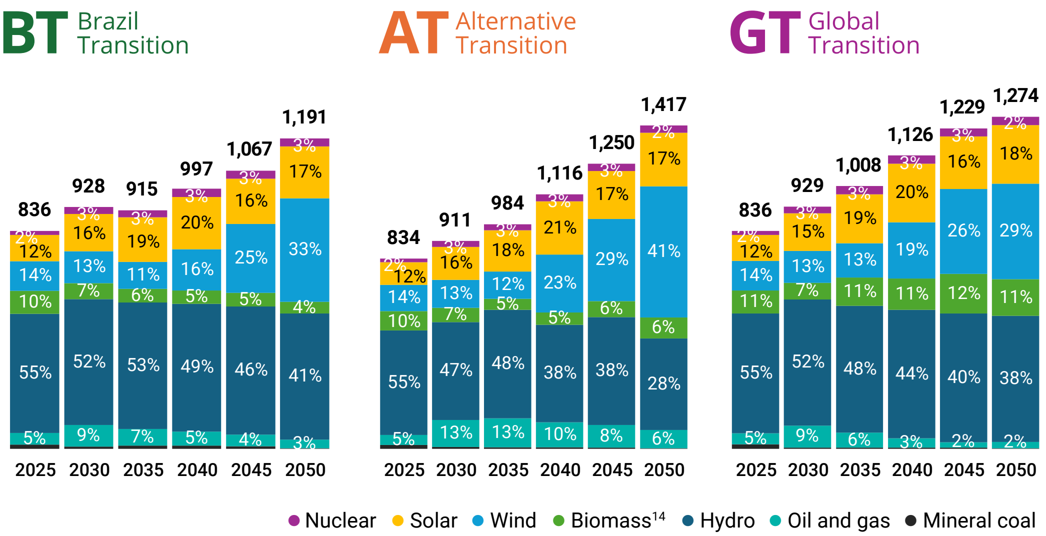
The shift is more profound in the GT Scenario, where renewables represent ~80% of the energy mix by 2050, so that fossil fuels answer for about 20%. This means that oil, gas and coal are effectively phased out of domestic consumption, and nearly all new energy generation comes from solar, wind and bioenergy sources, along with increased contributions from nuclear and CCUS/BECCS.

Power industry

In all scenarios, power generation becomes virtually emission-free by 2050, with wind and solar power taking center stage: wind grows from ~14% in 2025 to over 30% in 2050, and solar significantly increases its share. Hydropower remains significant but loses share, while fossil fuel power plants complement the power industry's capacity during times of low renewable source availability. These results confirm that the power industry will be at the very core of Brazil's decarbonization, combining a decline in fossil fuel consumption with the rapid expansion of modern renewables and new technologies.

13. The limitations on hydro- and wind power stem from premises that simulate a reduction in the capacity factor of large hydropower plants (UHEs) and cap the volume of wind projects coming online early in the projection horizon. This cap is relatively modest compared to the growing competitiveness of photovoltaic solar projects.

Chart 5. **Power Generation (TWh)**



Short Term (2025-2030):

Key actions enabling the success of Brazil's energy transition include massive investments in wind and solar power

Nuclear Power

- Emergence of political and social consensus on the strategic value of strengthening Brazil's nuclear complex, paving the way for planning around new topics and investments;
- Resolution of the impasse surrounding the Angra 3 plant, so that it is completed in the late 2030s, adding 1.4 GW of nuclear power;
- Improvement of the legal-regulatory framework, so as to open Brazil's nuclear complex to new participants and investments.

14. Biomass, in this context, refers to power generated from sugarcane bagasse, which is reused for combustion and steam generation.

Power Industry

- Appropriate price signaling to keep pace with the evolving physical and operational requirements of the power industry;
- Diversification and increased competition in the deployment of power sources, flexibility, and storage, addressing current challenges to the expansion of solar and wind power, including curtailment;
- Planning, expansion and introduction of new technologies to power grids (transmission and distribution), also including investments in climate adaptation and resilience, as well as new demand drivers such as data centers and powershoring;
- Development of new wind farms in Brazil's Northeast and both distributed and centralized solar power plants;
- Adoption of energy efficiency measures (technical and systemic).

Hydrogen

- Regulation and implementation of the current legal framework, including the Brazilian Certification System, Special Incentives Regime for the Production of low carbon Hydrogen (Rehidro) and the Program for Low Carbon Hydrogen Development (PHBC);
- Continued efforts to carry out pilot and demonstration projects in the most promising applications, combining various production routes in line with the strategy defined in the National Hydrogen Program (PNH2);
- Enabling the first industrial-scale projects in Brazil by leveraging the potential of domestic and export markets and overcoming equity, financing, risk allocation and management, infrastructure, and other barriers.

Biofuels and Carbon Removal

- Implementation of a bold BECCS development program aimed at positioning Brazil as a leader in the field;
- Initiate the co-processing of vegetable oil for the production of drop-in fuels with renewable content in refineries;
- Initial investments in BECCS/CCS projects, geological monitoring systems and pilot plants.

Medium Term (2030-2040):

Structural transformation of the energy mix

- Wind, solar and bioenergy gain prominence in the energy mix;
- Storage systems and demand response scale up to manage renewable variability and enhance operational flexibility;
- Oil production peaks and then begins to decline proportionally during this period;
- First commercial low-carbon hydrogen plants connected to industrial hubs and ports;
- Energy-heavy consumers act as "anchors" for infrastructure expansion through long-term contracts and co-investments that enable the construction of new generation and transmission assets.

Long Term (2040-2050):

Emergence of an energy mix aligned with emission neutrality

- Power generation > 97% carbon-free; residual fossil fuels are concentrated in hard-to-electrify uses (industry, aviation, shipping) — contributing to energy security and power backup during times of low renewable resource availability;
- BECCS at ethanol/biomass plants adds negative emissions, offsetting fossil and non-CO_2 emissions and contributing to economy-wide emission neutrality;
- Solar power's share decreases as solar panels installed in the 2020s reach the end of their lifespan and are replaced by more efficient wind power solutions;
- Grid infrastructure is upgraded and digitalized, enabling high levels of interconnection between regions and integration of distributed generation;
- Emergence of biorefineries producing green diesel, biobunker, SAF, green LPG and green naphtha.

Role of public policymakers

1. Improvement of power markets.

a. Introduce time- and location-based signals that value flexibility.

b. Develop purchase mechanisms (auctions/contracts) aligned with the physical and operational needs and dynamics of the power industry.

c. Establish contracts that value the different source attributes, such as firm supply capacity and operational flexibility, implementing competitive market mechanisms.

d. Periodically review the rate impacts of distributed generation and sectoral costs, so as to encourage the transition without compromising the affordability of power.

e. Rationalize and redesign power subsidies, focusing on efficiency and enhanced resource allocation.

2. Design regulations that enable the scaling up of transition pathways

a. SAF, HVO, marine biofuels and biomethane, especially for hard-to-abate uses, in line with the legal framework (Fuel of the Future Act).

b. BECCS and other CCS routes for CO_2 capture and removal in the energy sector.

c. Low-carbon hydrogen and its derivatives.

d. Utility-scale energy storage systems (batteries, pumped hydro).

3. Industrial policy and energy innovation

a. Integrate existing public policies across different levels of government in order to coordinate actions and increase effectiveness.

b. Encourage the competitive production of wind turbines, solar panels, batteries and electrolyzers (for example, through programs similar to the Mover / BNDES Program).

c. Promote energy efficiency by optimizing energy consumption across different sectors.

d. Foster joint R&D (hydrogen, BECCS, CCS) with measurable outcome clauses.

e. Mobilize funding by 2030 through incentives such as green bonds, climate funds, IDB, and BNDES to make low-carbon hydrogen a productive reality and attract international capital.

4. Resilience and just transition

a. Promote price signaling for operating reserves and ancillary services, integrating complementary technologies with varying operational characteristics.

b. Use hydrogen hubs and CCS in port / oil-producing areas to capture industrial synergies, including workforce reskilling.

c. Use funds from the Energy Development Account (CDE) and from the Climate Fund to adjust power rates for vulnerable populations.

Opportunities for the private sector

1. Renewable power generation and infrastructure

a. Continuous expansion in wind and solar power.

b. Availability of long-term corporate Power Purchase Agreements (PPAs) for companies committed to 100% clean electricity.

c. Investment in transmission, storage solutions (utility-scale batteries, pumped hydro), and ancillary services.

d. Investments in digitalization, automation and expansion of T&D grids are essential to optimize energy flow, minimize technical losses, and reduce curtailment.

e. Growth of distributed storage and management of demand to cope with the volatility of renewable generation.

2. Low-carbon fuels

a. High domestic and international demand for HVO diesel, SAF and green naphtha.

b. Carbon credits for integrated BECCS projects at ethanol plants, HVO, SAF, and other biomass and bioelectricity routes.

c. Export potential for advanced biofuels and low-carbon hydrogen, along with domestic use in steel mills, ports, and aviation.

3. Integrated portfolio and carbon management

a. Oil companies reallocate cash flow from fossil fuels toward renewable production or other uses, such as petrochemicals.

b. Brazil's expertise is leveraged in reservoirs for CCS, including for other sectors (industry, BECCS).

c. Increased use of instruments such as green bonds and sustainability-linked loans to reduce the cost of capital by tying investments to clean expansion and emission reduction targets.

4. Data centers and powershoring

a. Development of energy-intensive value chains, focusing on exports with comparative advantages associated with Brazil's low generation costs and high renewable content.

b. Competitive large-volume data processing, especially in data centers whose workloads are not latency-sensitive, such as AI model training, big data processing, and storage.

4.4 Transportation

The transportation sector is currently one of the largest contributors to Brazil's emissions and, at the same time, one of the areas that will require the most transformation to align with climate neutrality by 2050.

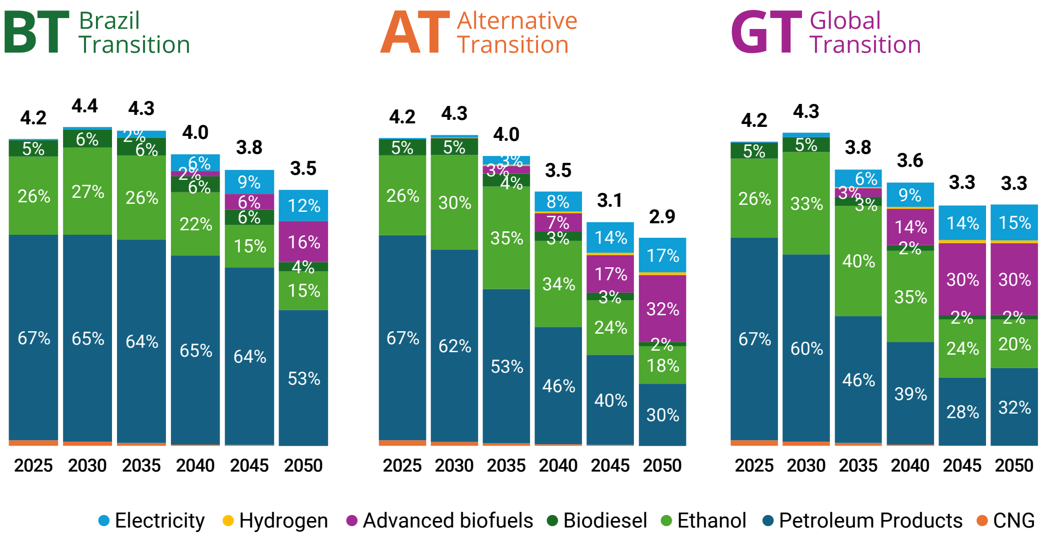
All PTE2 scenarios show a strong downward trend in sectoral emissions driven by a combination of increased use of advanced biofuels, fleet electrification, and a shift toward more efficient transportation modes.

In the Brazil Transition Scenario (BT), emissions are significantly but gradually reduced: from ~185 $MtCO_2eq$ today to ~105 $MtCO_2eq$ by 2050, still with a considerable share of fossil-fuel vehicles and fuels. The Alternative Transition Scenario (AT) introduces measures such as carbon pricing and mandatory targets, accelerating the phase-out of fossil fuels and achieving greater emission reductions in comparison with the BT scenario, even under different climate and technological conditions.

This process involves specific pathways for each transportation mode —passenger, freight, aviation, and maritime — each following its own pace and facing unique challenges. The sections below delve into these four dimensions, emphasizing how sustainable biofuels, electrification, and structural shifts in logistics can work together to ensure Brazil's transportation sector makes a decisive contribution to climate neutrality.

In the Global Transition Scenario (GT), where the carbon budget is more constrained, emissions decline more rapidly and sharply, with nearly the entire urban fleet electrified before 2050 and emissions dropping to around 65 $MtCO_2eq$.

Chart 6. **Consumption in Transportation (EJ)**



4.4.1. Passenger transportation

Short Term (2025-2030):
Transition takes off

- Initial decline in the share of fossil fuels, driven by the growth of ethanol;
- Flexible-fuel light vehicles represent a large share of combustion engine models;
- Early steps toward electrification: BEVs represent a growing share of urban cars and buses, boosting efficiency;
- Support for the rollout of electric buses for municipal services is facilitated through funding facilities such as climate funds (e.g., IDB and World Bank projects), along with incentives for fleets to run on biofuels.

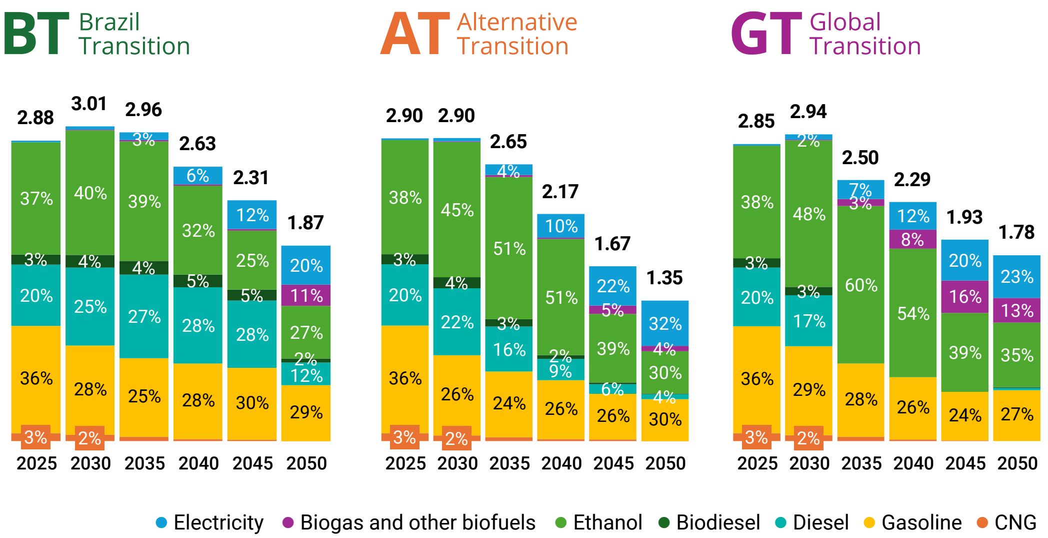
Medium Term (2030-2040):
Scaling up electrification

- Electrification progresses, playing an increasingly important role in light-duty transportation;
- EV gains share in new sales and the charging infrastructure expands, with more charging stations;
- Incentives to increase the use of renewable energy to support the growing share of electricity in transportation.

Long Term (2040-2050):
Progress toward neutrality

- Fossil fuels see a significant decline in their share of passenger mobility;
- Electricity, biofuels and advanced fuels dominate the mix;
- The energy efficiency of electric engines and the use of renewables are included in the sectoral mitigation strategy.

Chart 7. **Consumption in Passenger Transportation (EJ)**



4.4.2. Freight transportation

Short Term (2025-2030):
Despite the challenges of electrification, initial changes are underway

- Manufacturers roll out hybrid and electric trucks for urban deliveries and short-distance hauls;
- The biodiesel content remains at B15, but green diesel blends are now allowed;
- Efficiency improves with upgrades to transportation infrastructure (paving, intermodal terminals, etc.).

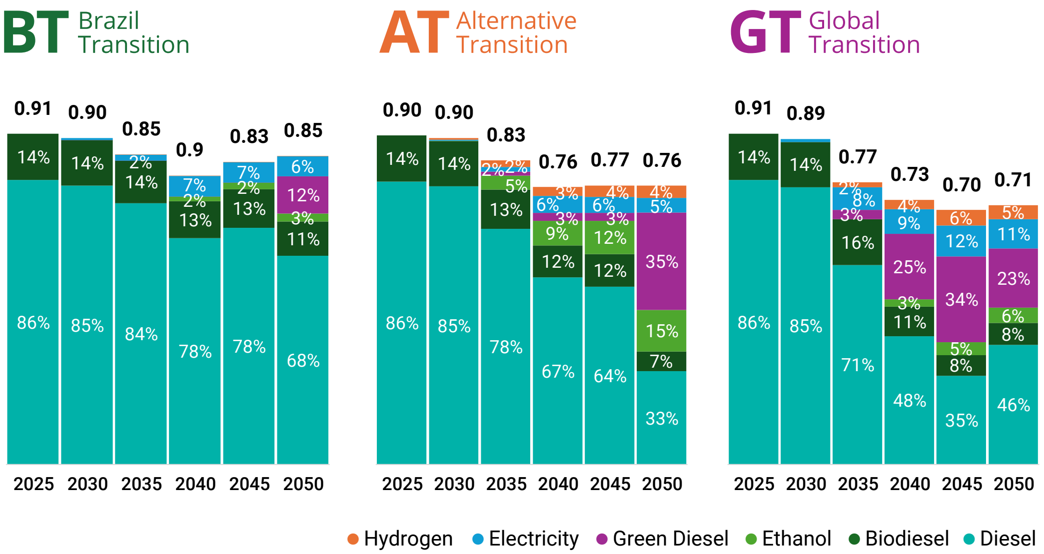
Medium Term (2030-2040):
Progress on multiple fronts

- Pilot projects for ethanol and hydrogen fuel cell trucks on longer hauls start to emerge;
- Logistics becomes more efficient; railroads gains share in freight services;
- Electric urban freight vehicles (UFVs) become significant by 2040;
- Green diesel production begins to scale up.

Long Term (2040-2050):
Commercial dissemination of new technologies

- Energy demand in the sector grows faster than efficiency gains driven by GDP;
- Widespread adoption of alternative fuels, with biofuels (green diesel, biodiesel and ethanol) reaching ~26% renewable content late in the decade;
- Brazil's transportation mix is redesigned by shifting freight to high-capacity, low-emission modes (waterways, railways and cabotage) — matching the transportation mode to the freight profile with a focus on logistics efficiency.

Chart 8. **Consumption in Freight Transportation (EJ)**



4.4.3. Air Transportation

Short Term (2025-2030):

Incipient use of SAF, but with R&D efforts

- Demonstration and commercial flights using aviation biokerosene are conducted.
- Regulations are drafted to meet future emission targets;
- Regulatory frameworks are established (e.g., targets such as those in the "Fuel of the Future act"/ National Program for Sustainable Aviation Fuels - ProBioQAV).

Medium Term (2030-2040):

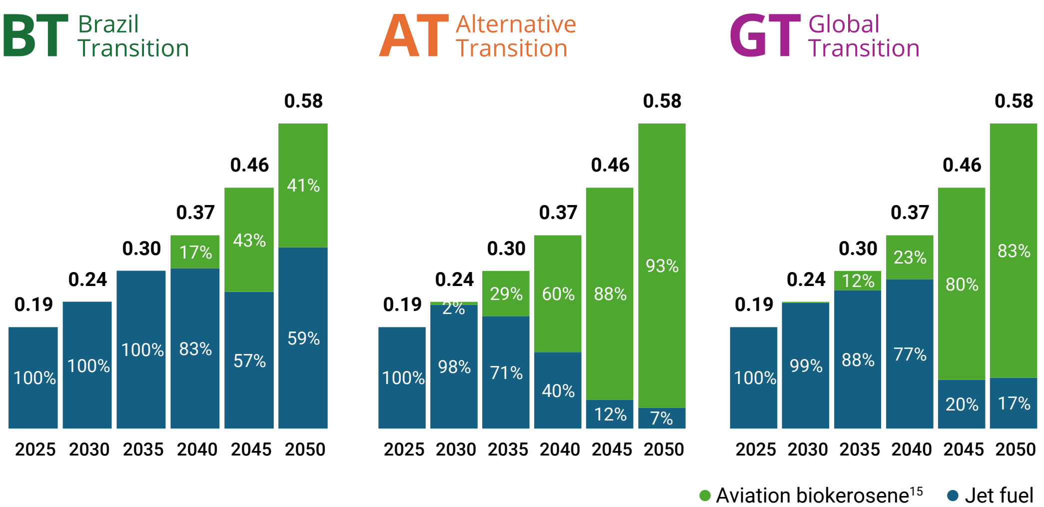
Paving the way post-2040

- Carbon intensity reduction targets for aviation (ProBioQAV) come into effect late in the decade, requiring SAF content to reduce emissions by 10% to 20% compared to conventional jet fuel.

Long Term (2040-2050):
SAF adoption gains speed

- Brazil positions itself as a regional SAF hub, attracting investments in infrastructure;
- Fossil jet fuel still predominates, with a portion of emissions being offset;
- Rising demand late in the decade is constrained by limited aviation biokerosene production capacity.

Chart 9. **Consumption in Air Transportation (EJ)**



15. Aviation biokerosene refers to all aviation biofuel routes (e.g. HEFA, ATJ, etc.) listed in PTE1. Air transportation includes energy consumption within Brazil (domestic and international flights).

4.4.4. Maritime Transportation

Short Term (2025-2030):
Increased efficiency and initial use of biofuels

- Early pilot projects of biofuel blends in cabotage, but with little impact on overall consumption so far;
- Improved vessel efficiency reduces fuel consumption in the short term;
- Optimization of routes, operation and port logistics through Port Decarbonization Programs.

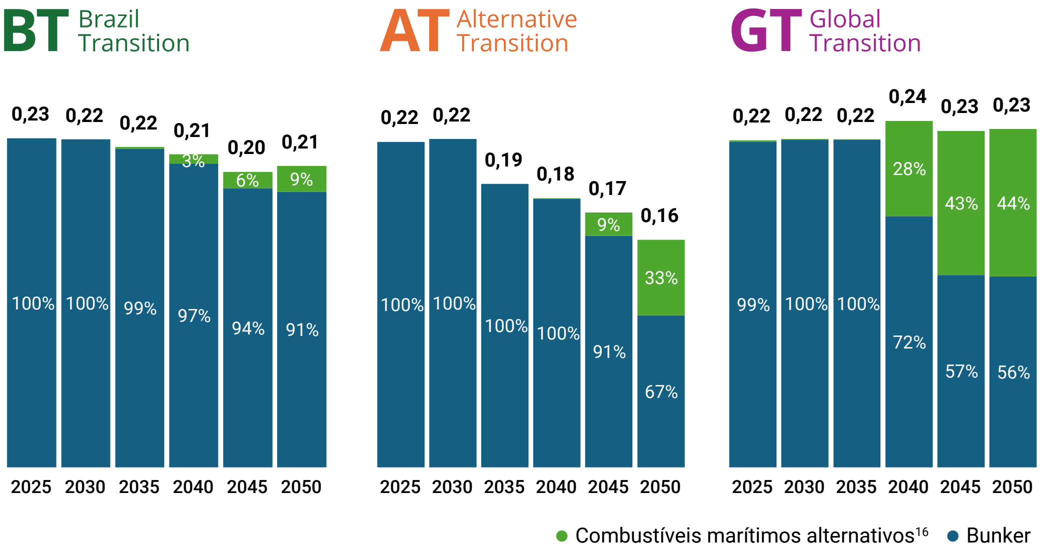
Medium Term (2030-2040):
Experimental operation

- Gradual scaling up of advanced biobunkers along cabotage routes and at major ports;
- Strategic ports invest in storage tanks and logistics for renewable fueling, integrated with HVO/SAF production hubs;
- The first demonstrator ships with dual-fuel engines (bunker fuel + green methanol) enter long-haul routes.

Long Term (2040-2050):
Gradual replacement with biobunker

- Brazil uses and supplies green marine fuels;
- Green methanol begins fueling new large vessels, still in a complementary role.

Chart 10. **Consumption in Maritime Transportation (EJ)**



Role of public policymakers

1. Foster the advanced biofuel chain

a. Strengthen programs such as RenovaBio and Fuel of the Future by reviewing and gradually increasing mandates after 2030 (HVO, SAF, biogas, and 2G ethanol).

b. Implement the guidelines set out in the Fuel of the Future program.

c. Develop biodiesel testing and certification for ships, aligned with global standards and certifications.

d. Promote low-carbon hydrogen projects through actions within the Low-Emission Hydrogen Development Program (Law 14,990/2024) and expand port hubs in the Northeast and North regi**ons.**

2. Speed up vehicle electrification in key niches

a. Set progressive sales targets for low- and zero-emission vehicles — aligned with the Mover Program (industrial incentives and vehicle efficiency goals).

16. Alternative marine fuels include, for example, biobunker, biomethanol, eH2 fuels, methanol, biodiesel, and ethanol, as outlined in PTE1 and based on PTE2 premises.

b. Expand charging infrastructure, including a national plan for fast-charging stations along highway corridors and in urban areas.

3. Expand public transportation and the rail-waterway network

a. Speed up strategic rail projects and improve waterways, focusing on export corridors and inter-regional connections to reduce reliance on long-haul road transportation.

4. Fleet renewal and efficiency standards

a. Introduce consumption/CO_2 targets, in line with international best practices.

b. Resume environmental and safety vehicle inspection programs.

c. Implement a fleet renewal program for older trucks, replacing them with newer, more efficient models — including gas, hybrid or electric options.

Opportunities for the private sector

1. Biofuels and new fuels

a. Construction and expansion of HVO and SAF plants to meet growing demand.

b. Expansion of biomethane projects that offer dual benefits (energy production and waste management at landfills, farms and sugarcane fields) and can also generate carbon credits.

c. Construction of hydrogen hubs in ports or logistics corridors.

d. Reuse existing infrastructure by promoting the use of drop-in biofuels to reduce economic externalities — leveraging current logistics and minimizing adaptation costs.

2. Electromobility and automotive chain of the future

a. Local manufacture of components (modular chassis for electric buses, inverters, fast charging stations), vehicle assembly, or partnership with new EV manufacturers looking to establish themselves in Brazil to serve both the domestic and export markets.

b. Development of shared electric mobility startups and services.

3. Green infrastructure and logistics

a. Upgrade intermodal freight terminals by electrifying cranes and yard vehicles.

b. Rewards for major shippers that use clean logistics contracts to reduce the carbon footprint of their supply chains.

c. Higher green bond issue limits for airlines funding SAF or shipowners ordering next-generation dual-fuel vessels.

4. Digital services and new business models

a. Expansion of efficient routing platforms, load optimization (freight matching), and AI-powered fleet management.

b. Development of logtech and mobtech startups that improve logistics efficiency and reduce empty trips, delivering dual value-creating benefits: lower emissions and costs.

c. Growth of Mobility as a Service (MaaS) models in cities — apps that integrate multiple transportation modes with unified payment systems.

5. Competitive integration into the international market

a. Leverage Brazil's active participation in international regulatory bodies such as IMO/ICAO.

b. Harness Brazil's competitive advantages (biomass and renewable electricity) to drive the production of sustainable aviation and maritime fuels.

c. Align with international standards in alternative fuel production, promoting a diverse range of solutions to scale up production and lower costs.

4.5 Cities

The scenarios indicate that Brazilian cities[17] can significantly reduce their emissions by 2050 through the electrification of end uses and improved energy efficiency in buildings.

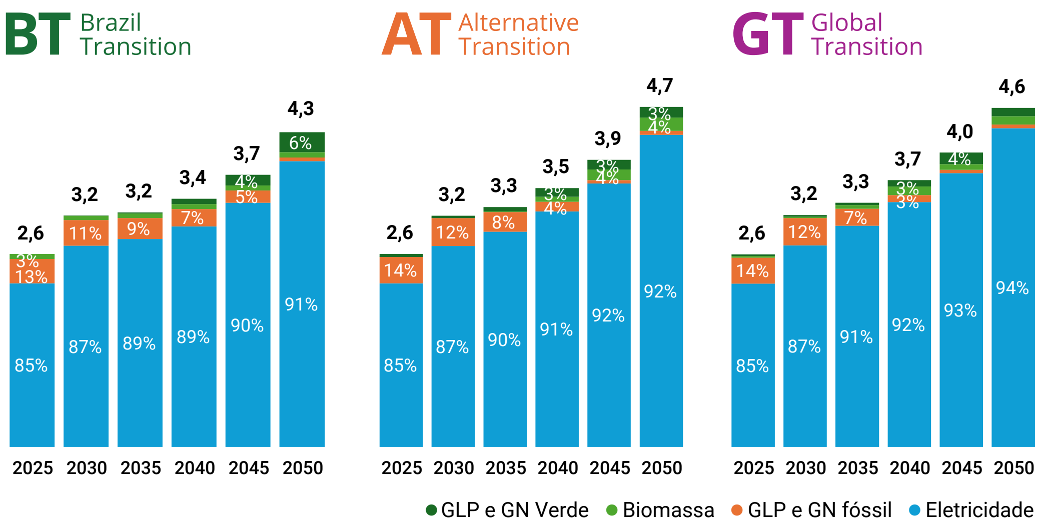
In the BT Scenario, residential and commercial electricity demand grows significantly and is met almost entirely by renewable sources. As a result, even with increased use of air conditioning and household appliances, direct urban emissions drop to ~3 $MtCO_2eq$ by 2050, compared to over 20 $MtCO_2eq$ today.

In the AT Scenario, water constraints and climate-driven increases in electricity demand boost energy consumption by around 7% relative to the BT Scenario (according to the premises established for the AT Scenario). Nevertheless, efficiency policies and electrification incentives help keep final emissions near 6 $MtCO_2eq$ by 2050. These results show that the urban energy transition is feasible and depends primarily on more efficient building standards, the replacement of gas-powered equipment with electric alternatives, and the expansion of distributed renewable generation.

The reductions are even more pronounced in the GT Scenario: by 2050, nearly all energy uses in buildings – such as water heating and cooking – are electrified and integrated with biogas by 2050, resulting in residual emissions close to zero.

17. Cities: urban buildings (residential, commercial and public) + stationary urban services (lighting, water/sewage). Urban vehicles are excluded — all fuel burned in cars, buses, taxis, etc. is accounted for in the Transportation sector.

Chart 11. **Consumption in Buildings (EJ)**



Short Term (2025-2030):

Enablers of Energy Efficiency and End-Use Electrification

- Mass adoption of energy-efficient equipment, such as LED lighting and inverter air conditioners, in homes and businesses encouraged through certification programs;
- Early-stage energy substitution (induction stoves and solar water heaters in homes, and heat pumps for water heating in hotels and high-end buildings);
- Exponential expansion of distributed solar generation.

Medium Term (2030-2040):

Accelerating energy transition and efficiency

- Introduction of energy performance standards for new buildings, along with a major retrofit effort for existing structures, especially large public buildings (schools, hospitals, etc.);
- Virtually no new LPG stoves and gas boilers for water heating;

- Significant expansion of subway, light rail (LRT) and bus rapid transit (BRT) systems, alongside the mass electrification of urban bus fleets and progressively tighter restrictions on individual urban transportation.

Long Term (2040-2050):

The road to carbon neutrality in urban uses

- The urban energy mix is mostly renewable, with widespread electrification of stationary uses (air conditioning, cooking and water heating), but some areas still rely on gas or LPG for specific applications;
- Smart grids integrate distributed energy resources, making urban energy consumption more efficient and resilient. Renewable electricity meets over 90% of total final urban energy demand;
- Sustainable neighborhoods with circular solutions for efficient management of energy, water and waste.

Role of public policymakers

1. Develop efficiency policies for buildings

a. Enhance labeling programs and implement mandatory standards for new buildings.

b. Develop policies (such as green taxes on services (IIS) and urban properties (IPTU)) and funding programs to support retrofitting of existing buildings.

c. Train and certify the workforce in green construction, so that construction companies and property managers have the knowledge to implement sustainable practices.

2. Promote energy-efficient appliances and residential electrification

a. Encourage the electrification of thermal uses (e.g., gradually phase out LPG subsidies and redirect them toward the purchase of electric stoves and solar water heaters).

b. Integrate social policies by expanding the Green housing program (Minha Casa Minha Vida) to include solar thermal systems and energy efficiency projects in low-income housing.

c. Ensure the reliability of the power industry in response to growing demand.

3. Waste management and urban bioenergy

a. Integrate waste management, sanitation and energy into urban master plans, creating synergies with distributed generation and reducing final disposal costs.

b. Promote distributed biodigestion units (organic waste from street markets, restaurants and grocery stores), as part of a circular economy approach.

c. Set targets to divert organic waste from landfills to composting facilities or waste-to-energy plants.

4. Smart cities and urban infrastructure

a. Develop pilot projects for smart grids featuring real-time energy management systems.

b. Regulate and promote time-of-use rates and demand response programs for urban consumers.

c. Facilitate the expansion of distributed generation and energy storage.

d. Leverage cross-sector synergies (e.g., biogas production at landfills).

Opportunities for the private sector

1. Distributed generation (DG) and storage

a. Provision of solar panel leasing services for those who prefer not to pay upfront.

b. Development of community solar projects (shared generation) and innovative solutions (solar roof tiles and photovoltaic façades).

c. Provision of batteries for homes or businesses, adding value through

d. backup power and energy savings associated with DG.

2. Urban infrastructure and electric mobility

e. Expansion of urban fast-charging networks (partnerships with malls, supermarkets and parking lots) and recharging solutions for residential buildings and fleets.

f. Provision of electric vehicle, e-bike and e-scooter sharing services.

g. Establishing joint ventures for local manufacture of vehicle components, (batteries and powertrains).

3. Competitiveness and market access

h. Establishing a competitive edge and enhancing market value for companies that comply with potential carbon barriers (such as Europe's CBAM).

i. Meeting global buyers' requirements to secure price premiums and preferred supplier status.

5 Macroeconomic and Regional Impacts

A well-managed energy transition can become a driver of economic and social development for Brazil. Our scenarios point to a potential win-win path: economic modernization paired with job creation and rising average incomes, while also achieving climate goals. However, despite the significant growth opportunities the energy transition presents for Brazil's less developed regions, particularly the Northeast and North, persistent regional and social inequalities are still expected to persist.

To turn the energy transition into a true driver of economic growth, Brazil must anticipate trends — by preparing its workforce, attracting investment, and adapting economic (and R&D) policies — so that green growth is not hindered by structural bottlenecks.

GDP Growth and Investments

In the BT Scenario, GDP is projected to grow at an average rate of around 3.0% p.a. between 2025 and 2050, a pace higher than the historical average of the past 28 years (2.3% p.a.[18]), driven by productivity gains and the expansion of new "green" industries. Investment plays a central role in sustaining this momentum, with average annual growth projected at 4.8% over the same period. A significant share of this investment is directed toward building infrastructure for clean energy, and low-carbon transportation and industry. This involves a major, yet feasible, capital effort: it would require raising Brazil's investment rate to between 20% and 25% of GDP over the coming decades, a substantial increase compared to the 16% average observed between 2015 and 2024. In terms of investment, two key aspects stand out:

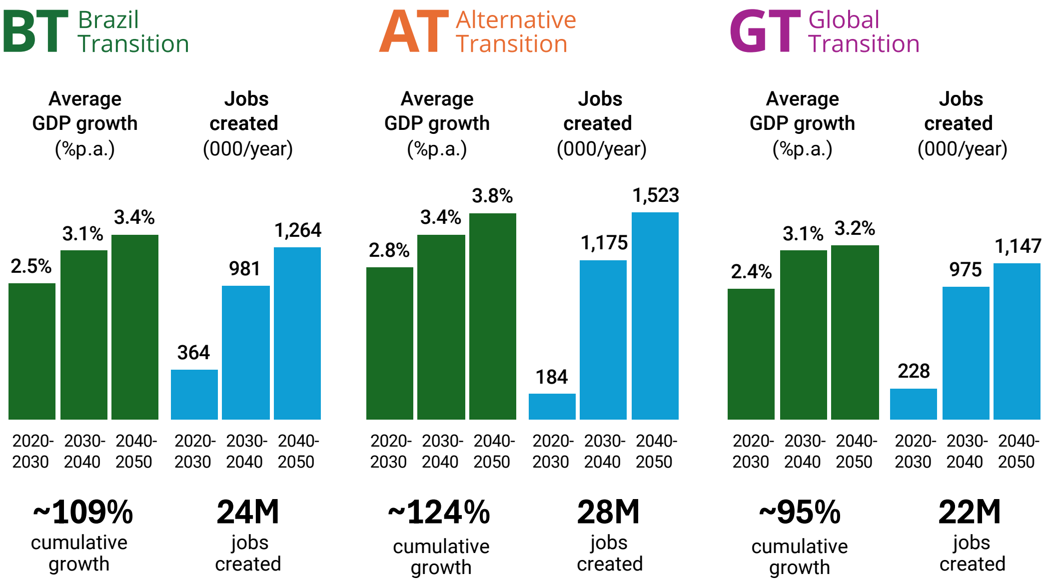
- While the broader adoption of electrification processes will also help drive investment, the most important levers are linked to the growing use of biomass and, consequently, the development of biofuel value chains.
- Since a large portion of these investments is directly tied to the development of energy infrastructure, "civil construction" is projected to experience robust growth, emerging as one of the fastest-growing industries, with strong potential for job creation.

Average economic growth is slightly higher (3.2% p.a.) in the AT scenario compared to the BT scenario (3.0% p.a.), while in the GT scenario, growth is lower (2.8% p.a.) than in the other two.

The stronger investment growth in the AT scenario is directly linked to the premise of an effective and successful industrial policy that fosters the development of local suppliers' productive capacity on competitive terms, across both traditional sectors and emerging "green" industries. The most significant aspect in this scenario is the development of the biofuels sector, which grows at nearly 5% annually, also driven by public policies promoting the substitution of fossil fuels.

18. According to the Brazilian Institute of Geography and Statistics (IBGE) System of National Accounts (SCN).

Chart 12. **GDP growth and job creation**

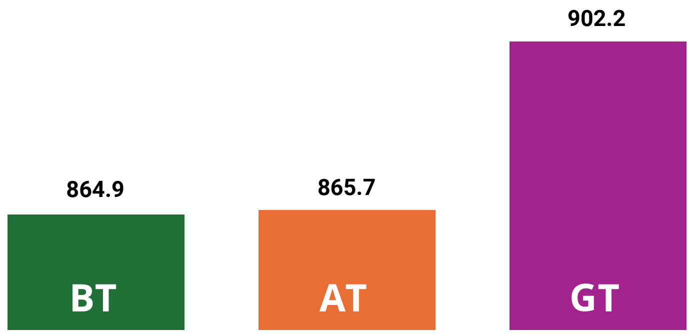


While the GT scenario, characterized by a sharp decline in the share of fossil fuels in the primary energy supply, unlocks new economic opportunities, such as the production of critical and strategic minerals, these major shifts in the energy landscape also entail significant additional economic costs. The transformation necessary to make this scenario feasible requires consistently higher OPEX and CAPEX expenditures, particularly from energy-intensive sectors, compared to the other scenarios.

These higher average costs are a major reason for the lower economic growth observed in the GT scenario. Considering the combined average OPEX and CAPEX of energy-intensive sectors and land use, annual costs in the GT scenario are approximately 4.3% higher (between 2025 and 2050) compared to the same sectors in the BT scenario; when compared to the AT scenario, these average costs in GT are 4.2% p.a. higher.

Finally, it is important to note that the model used in this study did not incorporate significant macroeconomic factors, such as monetary and credit policy variables (including the benchmark interest rate), or fiscal indicators and public debt levels.

Chart 13. **OPEX + CAPEX of energy-intensive sectors and land use**
(annual average in US$ billion between 2025 and 2050, at 2023 prices)



Given these higher costs, we can be infer that the GT scenario is consistent with higher inflation compared to the other scenarios used in this study.

Job creation

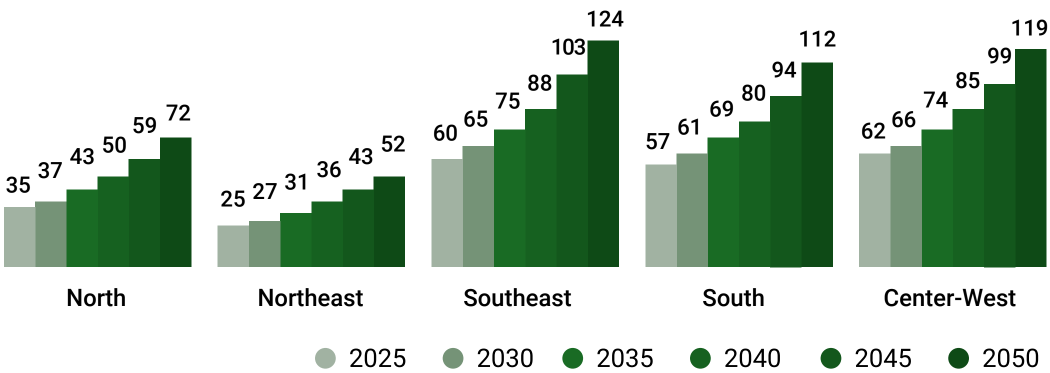
Net job creation is positive in all transition scenarios, but reskilling is required in some sectors. Labor-intensive activities, such as forest restoration, decentralized renewable energy (e.g., solar panel installation and wind turbine maintenance), and mass public transportation, create millions of new green jobs over the course of the period. For example, the goal of restoring 12 million hectares of forests alone can directly employ between 1 and 2.5 million people by 2030 — many of them in rural areas and in the North and Center-West regions, contributing to local development. The expansion of renewable energy across inland regions similarly creates jobs in power plant construction and operation.

Conversely, while declining fossil fuel sectors (oil and mineral coal production, traditional refining) may see job losses, the relatively gradual pace of this decline provides sufficient time to implement just transition policies (including job relocation, training, and early retirement) to mitigate said impacts. Active policies — such as training programs to reskill oil sector workers for offshore wind or industrial maintenance in biofuel plants — will be essential for regions that depend on fossil fuel income (e.g., Macaé in Rio de Janeiro, petrochemical hubs) to find new economic roles.

Regional Development

Given Brazil's diverse resource profile, the energy transition particularly benefits certain regions. Projections show the North and Center-West regions leading regional economic growth through 2050, boasting rates above the national average[19]. This is because these regions stand to benefit from: (a) the expansion of the bioeconomy and reforestation efforts (North), creating jobs and attracting investment in forest management, carbon credits, and sustainable agriculture; and (b) large-scale investments in renewable energy — for example, the strong solar potential in the Center-West, and wind energy in both the Northeast (already a leader) and the North (including well-planned Amazon-based wind and solar projects, potentially associated with green hydrogen production).

Chart 14. **Annual *per capita* income (In thousand reais at 2021 prices)**

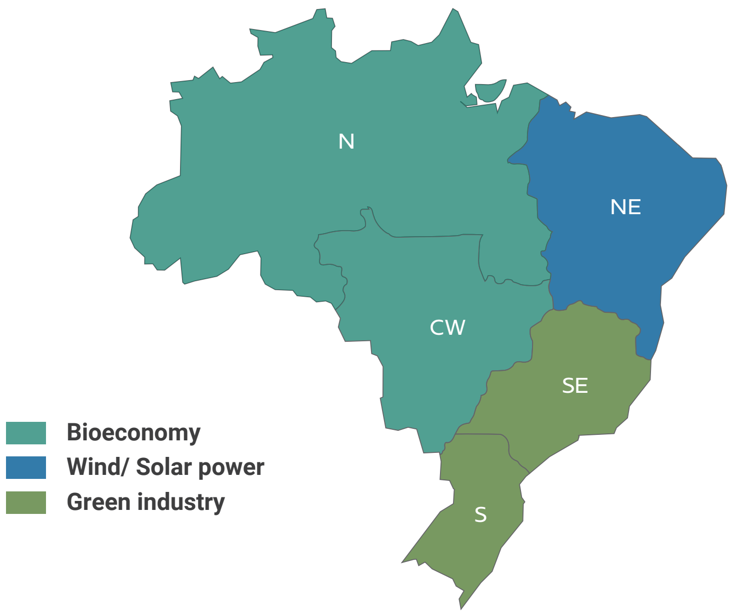


The Northeast region will remain a hub for renewable energy (wind and solar) and biofuels (sugarcane, biodiesel), sustaining strong economic growth. The Southeast and South regions will also benefit, but as their traditional sectors (heavy industry, refining) undergo transition, they will have to innovate. Nonetheless, they are expected to maintain stable growth by diversifying into green industries (e.g., energy equipment and electric vehicles manufacturing, and green chemicals).

19. This trend has been in place for the past 20 years and while the energy transition may not alter it, the shift toward a low-carbon economy is likely to reinforce it.

In short, from a regional perspective, differences in GDP growth rates between 2025 and 2050 are only marginal, with the North and Center-West regions growing slightly faster at 3.2% p.a., while the Northeast and South regions grow at 3.0% p.a., and the Southeast, at 2.9% p.a. Despite a certain degree of interregional deconcentration of growth, as the Southeast region, which alone accounts for roughly 53% of Brazil's GDP, shows the lowest growth, regional inequalities remain at high levels. As shown in the previous chart, per capita income in the Center-South regions remains significantly higher than in the North and Northeast. As an indication of this inequality, the average per capita income projected for the Northeast region in 2050 (in constant prices) remains below the average per capita incomes of the Southeast, Center-West, and South regions in 2025.

Chart 15. **Key growth sectors by region**



Funding and Competitiveness

Funding the transition stands as a macro-level challenge, but there are signs that channeling capital into green sectors can boost productivity and modernize the economy. Instruments such as a green taxonomy — aligned with the Brazilian Sustainable Taxonomy coordinated by the Ministry of Finance — sustainable bonds (green bonds), a just transition fund, and international climate finance (via carbon markets) can help channel additional resources.

At the same time, by aligning with the global low-carbon economy, Brazil safeguards its export competitiveness — avoiding carbon-related trade barriers (such as tariffs on steel or high-carbon footprint goods) and seizing emerging market opportunities (hydrogen exports, carbon credits, etc.). Regarding external accounts, reduced long-term reliance on imported fossil fuels can lower Brazil's exposure to oil price shocks and support a stable trade balance through the export of both cleaner energy inputs and low-carbon industrial goods.

6 Conclusion

The PTE2 scenarios provide a clear direction: to accelerate its path toward climate neutrality, Brazil must implement public policies that foster a dynamic business environment that can attract sustainable investment. The study shows, however, that the viability of this pathway is subject to various uncertainties, risks and costs, all of which are influenced by political, technological, economic, geopolitical, social and other factors. Given these uncertainties, it is key to implement robust, low-regret actions.

1. Speed up infrastructure investment

The next 5 to 10 years will be critical in determining success by 2050. The government, the private sector and development banks must cooperate to attract investment in key projects: expanding the power transmission grid to integrate new large-scale wind and solar plants; upgrading the power industry to support the integration of variable power from renewables; expanding strategic railroads and waterways to enable a modal shift; universalizing sanitation and harnessing energy from waste; and fostering the infrastructure for electric vehicle charging and biofuel supply. Enhance coordination of various federal government sectoral plans to develop an infrastructure agenda that aligns and prioritizes projects, ensuring coherence with climate goals.

2. Align the energy transition with existing industrial policy to maximize regional opportunities and reduce inequalities

For the macroeconomic benefits of the energy transition to translate into balanced development, Brazil must integrate its existing industrial policy with a territorial strategy that leverages each region's comparative advantages while also addressing the persistent inequality in per capita income distribution. This approach would amplify the impact of the New Brazil Industry (NIB) policy. In the Northeast, for instance, the projected average income for 2050 is expected to remain significantly below that of Brazil's other regions. A modern, regionally tailored industrial policy could combine targeted incentives for strategic sectors with cost-effective investments in workforce training, technological innovation, and infrastructure to help develop new industries. This arrangement not only enhances national competitiveness but also harnesses the energy transition to help reduce Brazil's longstanding regional and social imbalances.

3. Foster partnerships and new business models

To turn the energy transition into a driver of economic dynamism, Brazil must advance in building institutional frameworks that combine public-private partnerships, bilateral cooperation, and multilateral initiatives. These instruments can enable new business models that integrate technological innovation, productive investments, and shared gains across value chains. Such a collaborative environment will not only accelerate the diffusion of clean technologies but also foster the development of more dynamic ecosystems that can drive competitiveness, industrial diversification, and the creation of skilled jobs, thereby more broadly sharing the benefits of the transition.

4. Leverage Brazil's natural leadership in low-carbon energy to maximize its global influence

Brazil's highly renewable energy and electricity mix, coupled with the expansion of solutions such as biofuels and carbon credits, bolsters its position as a global leader in the low-carbon economy. This scenario creates an opportunity for Brazil to boost its influence on the international stage — for example, by taking a leading role in the COP30 climate agenda by proposing more ambitious targets, and securing trade gains through the export of clean energy, technology and expertise. Brazil should, therefore, enhance its participation in international institutions and strengthen South-South partnerships focused on green hydrogen production, so as to mobilize resources and open new markets. These actions are likely to garner support from civil society, which will become increasingly engaged in the transition as it recognizes the emergence of a competitive and sustainable national project.

5. Upgrading the Brazilian carbon market

Establishing a carbon market that includes the AFOLU sector and buttresses the SBCE is essential to expand social and environmental benefits, such as biodiversity protection through forest conservation and water resource management, and to support community development. However, the current system creates loopholes that compromise the environmental integrity of the market and limit its effectiveness in achieving actual emissions reductions. To remedy this, the AFOLU sector must be integrated into the regulated carbon market under clear rules and robust monitoring, reporting and verification mechanisms. This will contribute to the effective reduction of GHG emissions, promote greater environmental integrity, and establish a carbon market that operates fairly and efficiently. By strengthening the SBCE, Brazil can simultaneously enhance its economic competitiveness and achieve cost-effective emissions reductions, in line with the country's climate targets.

6. Implement a Just Transition Plan for vulnerable sectors and regions

To prevent the perpetuation of social inequalities, robust action plans must be implemented in the most vulnerable regions, specifically focusing on workforce training, promoting inclusive policies, and combating energy poverty. Reskilling programs for workers in the oil, coal, and high-emission industries, with relocation into clean energy sectors, will be necessary to prevent structural unemployment. A Transition Fund, funded by temporary carbon revenues (such as credit auctions or a carbon tax), is recommended to support economic diversification in oil- and gas-dependent municipalities (e.g., Campos and Macaé), and to offer temporary social protection. These actions are essential to secure political and social support for the energy transition and to reduce resistance.

From Urgency to Opportunity

The climate challenge can become a driver of Brazil's prosperity, if there is coordination and ambition.

The central message is clear: Brazil can achieve development consistent with the energy transition only by establishing the concrete conditions necessary to attract investment and build competitiveness. This requires the government to promote a stable, transparent and attractive business environment that instills investor confidence and accelerates innovation. At the same time, it is important to acknowledge the scale of the challenge: **achieving climate neutrality by 2050 is far from guaranteed**.

If there is any real chance of achieving it, that chance hinges on creating enabling conditions: **intergovernmental coordination, cooperation between the government and non- government stakeholders, the engagement of civil society, and a long-term visio**n. Without these elements, Brazil risks squandering time and opportunities; with them, Brazil can turn the energy transition into a driver of prosperity, competitiveness and global leadership.

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