Country Report

Transition pathways for Brazil

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Key messages

- Due to population and economic growth and the population's rising standard of living, energy consumption in Brazil will continue to increase significantly in the future. Thus, the challenges of a climate-neutral economy and society are great and require a balance between sustainability and development.
- Brazil's greenhouse gas (GHG) emissions accounted for 2.4 Giga tons of CO_2e in 2021, per capita emissions were around 8 tons of CO_2e. Brazil's emissions come mainly from land use, agriculture and livestock.
- With the current Nationally Determined Contribution (NDC), Brazil has committed to reducing GHG emissions by over 53% by 2030 compared to 2005 and to achieving net zero emissions by 2050.
- Brazil is one of the world's main producers of biofuels with the industrial potential to increase this option as well as to produce large quantities of electricity-based hydrogen and synthetic fuels.
- Despite the great potential of renewable energy sources, the lack of infrastructure is a major obstacle to the implementation of decarbonization measures in the building, transport and industrial sectors.
- There is still no long-term strategy for achieving the targets that have been set; further and consistent efforts are required from politicians and the economy in order to implement available reduction options.
- Ambitious transformation scenarios focus primarily on reducing emissions by halting deforestation, reforestation and projects to reduce emissions from soils and agriculture. Renewable energies are to be expanded to cover the additional future energy demand. Today's emissions are to be offset partly by substituting fossil fuels and partly by negative emissions from the AFOLU sector.

Introduction and overview

Brazil is the seventh most populated country with an estimated population of 203 million in 2022; Brazil's GDP is expected to increase by around 70% between 2022 and 2050 (Federal Republic of Brazil, 2023). The AFOLU sector (Agriculture, Forestry and Other Land Use) is particularly important in Brazil, with deforestation and enteric fermentation accounting for almost 61% of total greenhouse gas (GHG) emissions in 2021 (SEEG, 2023). While energy and transport account for 76% of global emissions (Bello et al., 2023), these sectors are only responsible for 18% in Brazil (SEEG, 2023). More detailed information on the socio-economic situation and current emissions can be found in the Annex.

Key topics of the country

According to (MAPBIOMAS, 2022), 58% of Brazil's territory is covered by forests, 494 million hectares (Mha), an area larger than the European Union (423 Mha). 84% of Brazil's forest area is in the Amazon region. 87.6 Mha were deforested since 1985, a decrease of 15% of the total area. From 2007 to 2018, deforestation in Brazil decreased compared to previous years, however, it began to rise again in the following years.

Most of the land use change was driven by agriculture and livestock, whose total area expanded from 187 Mha in 1985 to 282 Mha in 2022, an increase of over 50% (MAPBIOMAS, 2023). While pasture land grew by over 60% during this period, the area of land used for agriculture has increased 3.2-fold. This expansion did not correlate with socio-economic figures, as the share of agriculture and livestock in Brazil's GDP per capita decreased during the last decades (Ribeiro et al., 2023).

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More than 47% of Brazil's primary energy demand in 2022 was covered by renewable energies, which is factor 3 higher than the global average (EPE, 2023). The use of fossil fuels is clearly dominated by the consumption of oil and oil products with a share of over 35% of total primary energy consumption, gas is at around 10% and coal at 5%. Transportation and industry are by far the main energy consumers in Brazil, accounting for 33% and 32% of the final consumption in 2022 respectively.

In 2022, the share of renewable energies in electricity generation was around 85%. Hydropower dominates with a 60% share of the country's installed capacity, but the expansion of solar and wind energy as well as electricity generation from biomass has already reached a share of 24% of the country's electricity mix. However, meeting the additional demand expected in the future through the further expansion of renewables will pose a major challenge.

National targets (NDC) and programs/policies

With the latest update of the Nationally Determined Contribution (NDC) submitted to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) by October 2023, the Brazilian government has committed

- to reduce its GHG emissions by 48.4% by 2025 to 1.32 $GtCO_2e$ (Federal Republic of Brazil, 2023) compared to 2005 levels of around 2.56 $GtCO_2e$, a reduction by 1.24 $GtCO_2e$,
- to reduce GHG emissions by 53.1% by 2030 compared to 2005 to a net emission level of 1.20 $GtCO_2e$ and
- to achieve emission neutrality (net zero) by 2050.

The updated NDC envisages to reduce deforestation in Brazil to zero by 2030 and to actively invest in the recovery of degraded lands, nitrogen fixation and soil organic matter (carbon) accumulation projects, the integration of forestry, arable and livestock farming, agroforestry and reforestation. The revised document also emphasizes the development of a new Climate Change Plan, which encompasses eight sectoral mitigation plans and fourteen sectoral adaptation plans. It also highlights the importance of AdaptaBrasil, a system created to improve the understanding of the impacts of climate change in the country.

According to the guidelines for a National Strategy for Climate Neutrality, Brazil wants to achieve up to 50% of renewable energy in the national energy mix by 2030. Other important policy developments in recent years include the 2023-2025 Working Plan of the National Hydrogen Program, the Action Plan 'Zero deforestation by 2030' (5th phase) and the Energy Efficiency Program (IEA, 2023).

Key decarbonization pathways & related transformations

Comparison of policy relevant scenarios

There are several scenario studies for Brazil that have developed ambitious transformation paths. The study by La Rovere et al. (2021) includes two 2050 GHG emissions pathways. The Current Policies Scenario (CPS) continues the trends of today's mitigation measures, while the Deep Decarbonisation Scenario (DDS) goes beyond the 2021 NDC target and achieves net-zero emissions by 2050. This results in remaining emissions in 2050 of 17 $MtCO_2e$ in the DDS versus 1889 $MtCO_2e$ in the CPS, mainly from the AFOLU sectors. DDS envisages robust deforestation control, achieving more than 1000 $MtCO_2e$ removals in 2050. The total avoided emissions, when comparing both scenarios between today and 2050, are approximately 29.8 $GtCO_2e$. Carbon pricing contributes 30% to avoided emissions,

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set at 25-65 USD/t of CO_2e by 2030-2050. Regulatory and control measures and limited farmer access to public credits drive 59% of GHG reductions. The study emphasizes forest protection, reforestation, sustainable farming, and electric vehicles as main strategies toward net-zero emissions by 2050.

The 2019 study by Schaeffer et al. (2019) analyzed three long-term scenarios for Brazil. In the scenario that follows current policies (NCP), energy-related emissions increase by 42% by 2050 compared to today due to incentives for fossil fuels, and Brazil cumulatively emits 34 $GtCO_2e$ between 2010 and 2050. The 2°C target scenario (N2D) aims for a 44% reduction by 2050, mainly through land use change, resulting in an emission budget of 24 $GtCO_2e$. The 1.5°C target scenario (N1.5D) envisages an 85% reduction by 2050, relying on carbon capture and storage (CCS) and negative land use emissions, and achieving an emission budget of 17 $GtCO_2e$. The target scenario assumes huge efforts to achieve negative emissions, e.g. through the use of bioenergy with CCS (BECCS), so that positive emissions from fossil fuels and industry can remain, albeit to a lesser extent than today. Renewable energy sources are projected to dominate Brazil's energy mix (82% to 94%) by 2050. The scenarios show that forestry measures, such as ending illegal deforestation in the Amazon region, and agricultural measures, such as restoring degraded pastures, make a significant contribution to mitigate emissions. In the transport sector, the switch to electric vehicles is seen as crucial in order to reduce transport emissions to almost zero by 2050 in the N1.5D scenario; biofuels from BECCS plants are used to complement electric mobility.

Cruz et al. 2022 (Cruz et al., 2022), in collaboration with the Carbon Disclosure Project, investigated the impacts of climate change on Brazilian cities and strategies to mitigate them. Vulnerabilities were identified in coastal cities and cities dependent on agriculture, particularly in soy cultivation areas. Using the BLUES model, two scenarios were outlined - Baseline and Net-Zero with the aim of avoiding 21 $GtCO_2e$ emissions by 2050. In the Net-Zero scenario, it was projected that the AFOLU sector could offset 79.5% of GHG emissions by 2050 via pasture and forest recovery, afforestation, conservation of natural areas, and expanded integrated farming systems. Key steps include increasing forest areas for biofuel production by 3.6 Mha and expanding integrated crop-livestock and agroforestry systems by 18.3 Mha. In transportation, the strategies envisage gradual electrification of light vehicles and the use of biofuels for heavy vehicles, with the aim of reducing emissions by 36% by 2050. The report emphasizes necessary structural changes in energy, transport, AFOLU, and waste sectors, with AFOLU playing a crucial role.

Bello et al. (2023) examine three decarbonization scenarios with the BT scenario aiming for carbon neutrality in 2050 with a carbon budget of 24.3 $GtCO_2e$, while the AT scenario (24.9 $GtCO_2e$) pursues more stringent technical pathways, and the GT scenario (15.2 $GtCO_2e$) focuses on limiting global warming to 1.5°C by 2100. All scenarios anticipate that primary energy demand will exceed 400 million tons of oil equivalent by 2050 due to economic growth. Fossil fuel usage drops from 56.7% in 2022 (EPE, 2023) to a share of 13% to 27%, depending on the scenario, with over 70% of primary energy coming from renewables such as biomass, wind, and solar energy. The production of biofuels by the Brazilian industry and their use in transportation play a major role in BT and GT, despite the global trend towards electric vehicles. Similarly, the generation of negative emissions through BECCS is a key strategy, while wind and solar energy drive the growth of the power sector. GT cumulatively avoids 40 $GtCO_2e$ emissions, while BT and AT target 30 $GtCO_2e$. If deforestation is not curbed by 2028, achieving negative CO_2e emissions by 2035-2040 will hardly be possible and this will also hinder the zero emissions target even with annual negative emissions of almost 0.5 $GtCO_2e$. The study emphasizes nature-based solutions, such as the conversion of degraded pastures into forests and sustainable agriculture (61-85 Mha). Land-use change, reforestation and the expansion of forests for biofuel production are crucial, as is ending deforestation.

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Figure A compares the sectoral emissions structure in the various transformation scenarios considered. Further information can be found in the Annex: Table ATable A: Economic figures of transformation scenarios for Brazil shows the main economic figures of the scenarios regarding GDP per capita growth percentage and Table B main sectoral measures and actions of scenarios. Figure D illustrates the development of the primary energy consumption in different scenarios.

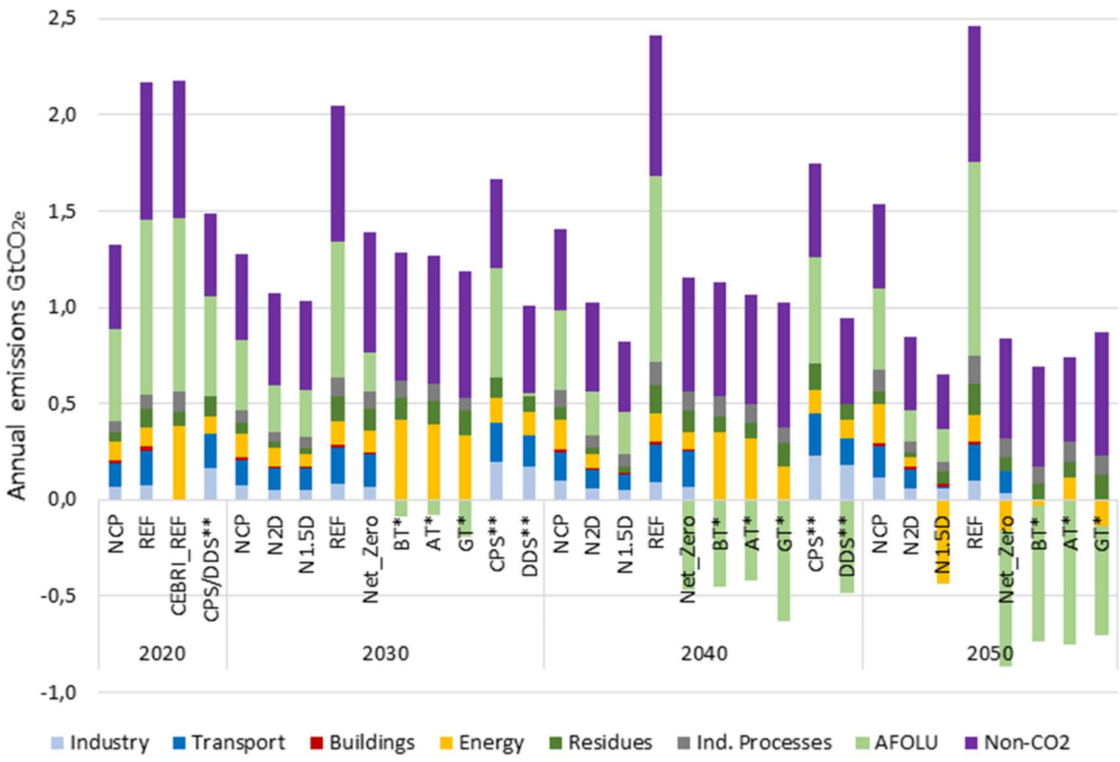

Figure A: Sectoral emissions structure in different transformation scenarios

2020 data for REF and CEBRI_REF is based on statistical values; the data for NCP and CPS/DDS are model projections and therefore deviate. * For BT, AT and GT, industry, transport and buildings sector emissions are included in the total energy emissions. ** For CPS/DDS scenarios, the building sector is included in energy, industry processes are included in industry, and non-CO_2 is considered as livestock emissions.

Key strategies of target-oriented scenarios

The transformation scenarios differ in terms of specific targets and the focus of technological solutions, but all pursue the target of zero emissions by 2050. Some studies focus on electric vehicles, biofuels and renewable energy sources, while others see an important role for carbon capture and storage. The studies make different policy recommendations to reduce emissions, ranging from carbon pricing to infrastructure investments, from technological innovations to changes in agricultural practices. The AFOLU sector plays a crucial role in all studies, be it through reforestation, sustainable agriculture or carbon sequestration in natural ecosystems. Reducing deforestation and investing in nature-based solutions for decarbonization are measures mentioned in the pathways. A common denominator is also the transition to low- or zero-emission transportation, such as electric or biofuel vehicles. All studies emphasize the complexity of reducing emissions in Brazil and the need for a multidimensional approach that includes policy changes, technological innovations and strategic changes in different sectors to achieve the ambitious goal of net zero emissions. Fossil fuels continue to be used in all scenarios,

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albeit at a low percentage. This is partly due to the major challenges involved in decarbonizing current energy consumption, particularly in the transport sector, and partly due to the huge potential for reducing emissions identified in the AFOLU sector. Nevertheless, there is a massive expansion of renewable energies in all scenarios, which cover the further increase in demand and supplement the hydropower already used on a large scale in the energy mix. However, the strategies reveal considerable risks that have received little attention in the debate to date. In particular, there is no sustainable and practicable implementation strategy for CCS and the strong focus on natural carbon sinks in the AFOLU sector carries the risk of reversibility and overestimation of emission reductions as the complex and fragile nature of the ecosystems involved and their vulnerability to the long-term effects of climate change are not adequately represented (Günther et al., 2024).

Sectoral system transformations

In the following we summarize key sectoral mitigation options that are discussed by researchers and in the public debate as ambitious and feasible for the transformation pathways in Brazil.

Industry

The sector's emissions are difficult to reduce from Brazil's perspective, and it requires major investments in new energy-efficient processes, recycling routes and conversion to alternative fuels. In the study by Cruz et al. (2022), the replacement of fossil fuels with biofuels or electricity from renewable sources and the use of CCS are mentioned in particular. The use of biomass in steel production, which is a sector that was responsible for almost 20% of total energy consumption of Brazilian industry in 2022 (EPE, 2023), is discussed e.g. by Wang et al. (2022) and Mandova et al. (2018). The use of CCS in the Brazilian industry is highlighted by Pinto et al. (2018). Other options for the steel sector include processes such as oxygen converters and electric arc furnaces, as well as technologies such as waste heat recovery and carbon capture. Furthermore, cross-sector solutions, such as integrating Industry 4.0 technologies and the use of renewable energy, are proving to be crucial strategies for reducing emissions (MCTIC, 2017b). In cement production, the second largest industrial emitter in Brazil, technologies such as the chemical recirculation system offer potential for capturing CO_2 during the production process (MCTIC, 2017a). Mitigation options were also analyzed by Thorstensen et al. (2024) for the industry sectors aluminum, chemicals, steel, cement, and oil and gas as those with the highest carbon emissions in Brazil. The report focuses on voluntary measures and targets of actors such as 'passive or renewable energy-based heating and cooling systems, improving energy efficiency and addressing issues such as methane leaks'. The report reveals significant lock-ins and path dependencies with 'pressure coming not only from public policies but also the internal market and from abroad'.

Transportation

There are several obstacles to the deep decarbonization of the Brazilian transport sector. Important aspects include general infrastructure constraints, a lack of public transportation and a cultural dependence on cars, as well as the currently limited role of electric mobility and the need to build charging infrastructure (MCTIC, 2017c).

Transport in Brazil is very much dominated by road transport. As long-distance transport is of great importance for the country, there is considerable potential for a modal shift to the far more energy-efficient rail and water transport. Already in 2017, the Brazilian Ministry of Science and Technology presented a modal shift scenario in which it is assumed that rail and waterways could compete with freight transport by heavy goods vehicles and are

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more flexible in terms of delivery times (MCTIC, 2017c). Products such as soybeans, iron ore and various minerals are considered as suitable goods for a shift to both rail (up to 60%) and waterways (up to 30%).

In 2021, around 76% of energy consumption in road transport was covered by fossil fuels, while biofuels accounted for 24%. Lightweight construction and better engines can achieve efficiency improvements of up to 35% (MCTIC, 2017c). Direct electrification would be especially feasible for private cars, light duty vehicles and public transportation in cities, while achieving also significant health co-benefits due to reduced air pollution. In July 2023, the fleet of electric and hybrid cars in Brazil comprised almost 159,000 vehicles (EPBR, 2023), but have not yet gained widespread acceptance although there was significant market growth in recent years. One of the main reasons are the still high costs compared to conventional vehicles, although the government offers incentives such as tax reduction or tax exemption on purchases. In addition, some hundreds electric buses exist, mostly being used for public transportation in the city of São Paulo. For last-mile delivery, several companies have initiated the transition of their fleets to electric vehicles. However, the lack of charging infrastructure is a major obstacle. The goal of the Brazilian authorities is to largely electrify the vehicle fleet in the medium to long term, particularly in São Paulo, Minas Gerais and Pernambuco, which plan to have a 100% electric fleet by 2050 (PNME, 2022). Efficient light electric vehicles (LEVs), including e-scooters, e-mopeds and e-microcars, can play a major role here in the relatively high motorized country. Microcars have greenhouse gas emissions of 50 g/km compared to average battery electric vehicles with 100 g/km and gasoline vehicles with 228 g/km on a life cycle basis (Ehrenberger et al., 2022). As a supplement to the expansion of an electrified local transportation system, they can be countered by political support measures to the trend in recent years towards larger vehicles such as SUVs.

There is political consensus that heavy duty, rail, air, and maritime transport will largely use biofuels or green synthetic fuels in the future (Bello et al., 2023). Due to the large availability of biomass and expertise in biofuel production (Tagomori et al., 2019), it is expected that the Brazilian industry will be able to realize the future supply of green fuels. Incentives to implement biofuels and targets to achieve carbon neutrality already exist in air and maritime transportation (Müller-Casseres et al., 2022). Advanced biofuels such as Hydrotreated Vegetable Oil (HVO) are more likely to be used as a “premium” fuel in aviation or road sector due to its higher price (Winnes et al., 2019). For maritime transportation, e.g. natural and synthetic gases, biodiesel, ammonia and methanol are discussed (Wei et al., 2023). For the Brazilian railroad sector, increasing the biodiesel share in the diesel mix is seen as a short term measure (Cruz et al., 2022). The electrification of railroad lines in the long-term requires high initial investments, but these can be refinanced over time through lower operating costs (Lovegrove & Morrison, 2012). Hydrogen fuel cells are also being discussed as alternative for long-distance transportation (Gray et al., 2021).

A policy that aims to reduce the use of private cars while promoting and incentivizing public transport requires in-depth planning to improve public transport infrastructure in combination with regulatory measures (Jamison & Bocca, 2021) such as the introduction of bus lanes, higher parking fees in high demand locations and intermodal integration projects (MCTIC, 2017c).

Buildings

The building sector has a rather small share of GHG emissions in Brazil and tends to be less in the focus of discussions on climate measures, so there are only a few laws and policy measures in the database Climate Change Laws of the World (climate-laws.org). According to IEA (2023), the following key aspects are to be addressed for the transition of the building sector. Heating and cooking needs currently are met by bioenergy (40%) and oil (36%). Higher access to clean cooking and electrification can reduce significantly the traditional use of biomass. Electricity demand for

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cooling almost triples by 2050 in the scenario STEPS of the IEA. In the scenario APS, minimum energy performance standards and more efficient buildings cut this growth by 35%. The main activity drivers are seen as the increase of air conditioner stocks and the increase in floorspace.

Energy supply system

In Brazil, stable investment conditions and a competitive auction system have enabled a significant expansion of wind and solar power plants since 2004, making Brazil a major producer of wind power. Electricity generation is currently dominated by hydropower with a total generation capacity of 110 GW and an additional capacity of 30 GW from pumped hydro plants. This provides a good basis for balancing future electricity demand with fluctuating solar and wind power generation. Political goals for the electricity supply in 2030 include a further increase in the share of renewable electricity generation beyond hydropower (wind, solar, biomass) to 33% and a 10% improvement in the efficiency of the electricity system. The Brazilian electricity grid currently still has high electricity losses of 16% of generation and requires high grid investments, particularly to connect rural regions with high generation potential. The following are seen as further development priorities (World Economic Forum, 2022):

- Expansion of distributed power generation with solar PV (target: over 37 GW in 2031),
- Modernization of hydropower to increase output, reserve capacity, efficiency and availability, and to reduce outages and negative socio-environmental impacts,
- Transformation of the numerous isolated electricity systems (outside the National Interconnected System) from a largely diesel-based supply to renewable generation technologies.

AFOLU

While the global average share of AFOLU emissions is 21% (Riahi et al., 2022), nearly three-quarters of Brazil's emissions come from the AFOLU sector. As stated before, deforestation accounts for most of the emissions in this sector. Soterroni et al. (2023) have evaluated the potential of Nature Based Solutions for land use change for Brazil:

- Reducing deforestation is the most effective strategy; without action, an area of native ecosystems the size of France would disappear in the next 30 years. The implementation of the Forest Code is crucial to stop illegal and legal deforestation and can help to reduce up to 0.6 $GtCO_2e$ per year between 2020 and 2050.
- Afforestation of areas that were previously non-forested results in negative emissions by sequestering CO_2 from the atmosphere. Afforestation could cover an area of 16 Mha by 2050 and has the potential to reduce a total of more than 3 $GtCO_2e$ between 2020 and 2050.
- Reforestation has a greater impact than afforestation in Brazil. For the most ambitious scenario of Soterroni et al. (2023), reforestation can reduce the GHG emissions between 2020 and 2050 about 5.7 $GtCO_2e$.

The following measures for sustainability in agriculture have been described in detail by (Angelkorte, 2023):

- Integrated farms as systems that combine forests, crops and livestock to achieve common benefits such as better soil quality and reduced chemical use (Polidoro et al., 2020; Rede ILPF, 2021).
- Vertical farms with high productivity through optimized soil and climate conditions (Banerjee & Adenaeuer, 2014; Harris & Kountouris, 2020).
- Urban farms and gardens offer proximity to consumers and low implementation costs, helping to reduce food losses in the production, processing and distribution chain (Csortan et al., 2020; Harris & Kountouris, 2020).
- Plant-based meats from soya beans, beans, peas, potatoes, rice and wheat as well as other agricultural raw materials (Bomkamp et al., 2022).

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- Cultured meat production using a renewable energy supply (Stonestrom et al., 2009).
- Closed intensive livestock farming with methane-inhibiting enzymes and algae to promote digestion and reduce methane production in the stomachs of cattle (Alves et al., 2022).
- Use of enzymes that inhibit methanogenesis in flooded rice cultivation (CONAB, 2023).

Global conditions

Although Brazil has set itself the net-zero emissions target, it has not yet formulated a long-term strategy for achieving the target and has therefore not sent any concrete information to the UNFCCC (Climate Action Tracker, 2023). In this respect, the climate policy in Brazil to date does not yet have a robust roadmap for achieving the target and, in particular, compliance with the interim targets formulated for 2025 and 2030 is uncertain. The following points are seen as key global factors that can support the progress of policy implementation:

- International pressure and attention with regard to the implementation of concrete measures, for example via supply chain regulations and international agreements and controls on strict standards in the production of agricultural products for export.
- Implementation of an effective (global) carbon pricing scheme, and initiation and support of further domestic value chains in the area of renewable energy expansion.
- International financing of mitigation measures through innovative, targeted investment projects.
- Efforts to end the largely illegal deforestation of Brazil's forests and reforestation efforts should more emphasize the enormous worldwide importance for the global environment, biodiversity and carbon sequestration and recognize this through financial support and compensation.

Key messages for next NDCs

Improvements since 2015

Since the signing of the Paris Agreement in 2015, there has been a troubling trend of increasing emissions of 2.8% per year. Notably, emissions experienced a significant surge in 2019 (increase of 18.4%) and 2021 (18.5%), primarily due to changes in land use (Observatório do Clima, 2023c) incentivized by the policy of the previous government. The current Brazilian government has begun implementing significant improvements in deforestation control. As of September 2023, deforestation levels have decreased by 50% compared to the previous year (Almeida, 2023). Current mitigation efforts in the transportation sector focus especially on green fuels. The “Combustíveis do Futuro” (Future Fuels) bill, announced in 2023, encompasses a range of actions aimed at increasing ethanol and biodiesel in gasoline and diesel blends, respectively, regulating synthetic fuels, gradually introducing green diesel, implementing the carbon dioxide capture and geological storage (CCS), and progressively integrating biokerosene into aviation fuel blends (Assessoria Especial de Comunicação Social, 2023).

The Brazilian government has also established an updated version of its Growth Acceleration Program, which envisions the economic growth alongside environmental protection, rather than pitting them against each other (Observatório do Clima, 2023b). The investment will be made towards the enhancement of energy efficiency and increase of the share of renewable energy usage.

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In January 2024, the Brazilian government launched the New Industry Brazil (Nova Indústria Brasil). The policy encompasses sustainable issues, not only for the industry production itself, but also for the raw material utilized, such as agricultural products. The main goal is to reduce CO_2 emissions per value added in industry by 30% until 2033 (Ministério das Cidades, 2024). However, no further regulations have been stipulated for the sector to meet this target, such as imposing a certain percentage of zero-emission fuels or enhancing energy-efficient activities.

Failures and lessons learned

The approach to reducing emissions in Brazil in recent years can be considered a failure. The introduction of the National Climate Change Policies (PNMC) (Brazilian National Policy on Climate Change, 2009) for the period from 2009 to 2020 failed to achieve the targets for emissions and deforestation. Deforestation rates increased to 180% above the PNMC target. In addition, 82% of investments in expanding energy supply until 2031 are focused on fossil fuels, contradicting decarbonization efforts (Observatório do Clima, 2023a). The updated NDC is the first response of the current Brazilian government: the short-term emission targets are more ambitious than the previous update, and are in line with the original NDC of 2015.

The major failure was the intensification of deforestation by the former government. The extent in the Amazon reached a deforested area of 13,038 km² in 2021, the highest in the last 15 years and an area larger than countries such as Lebanon or Jamaica. The destruction of Brazil's biomes was responsible for emissions of almost 1.2 $GtCO_2e$ (Observatório do Clima, 2023a). Illegal deforestation accounts for 95% of the deforested area, which highlights the lack of control by the Brazilian authorities. It's important to recognize the link between agriculture, livestock farming and deforestation. In 2022, 96% of deforestation in Brazil was attributed to the expansion of agriculture and livestock (Valdiones et al., 2023). Minimizing deforestation requires that any deforestation is detected, reported and well punished, so that perpetrators do not benefit from the illegally deforested area (Valdiones et al., 2023).

In the transport sector, potentials for sustainability and efficiency has only been exploited to a limited extent in recent years and decades. The Brazilian railroad network, for example, has not been expanded since the 1960s, but was reduced in size and a large part of the 30,000 km long rail network is not in operation today, mainly due to the high costs of maintenance. Instead, the growth of road transport was driven forward (Rádio Câmara, 2005), which was responsible for 59% of freight transport in 2021 (EPE, 2021). Brazil's National Railway Plan now has the vision of increasing rail's share of traffic from the current 17.7% to 34.6% and reviving passenger transport, which has largely disappeared. In contrast, maritime transport has seen an increase in the volume of goods transported over the last ten years (ANTAQ, 2023), but also has considerable potential for further expansion.

In the case of biofuels in transportation, ethanol production and local consumption decreased in 2022, leading to a rise in gasoline demand. In addition, the production and consumption of biodiesel decreased (Observatório do Clima, 2023a), primarily due to the reduction of the biodiesel blending quota from 13% to 10% in 2021. This adjustment, justified by authorities with the rapid inflation of soybean prices (the main biomass for biodiesel), was a response to the devaluation of the Brazilian currency against the dollar during that period (Verdélio, 2021).

Emissions from the energy sector rose by 12.5% between 2020 and 2021, the largest increase in 50 years. This was primarily due to the resumption of activities after the COVID pandemic, exacerbated by a drought that limited hydro power generation and thus increased the use of gas power plants. In 2021, a law was passed to expand thermal power plants, which stipulates a capacity utilization of at least 70% (Observatório do Clima, 2023a), which contradicts the sustainability goals.

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Annex

Key socio-economic figures and outlook

Brazil is the seventh most populated country in the world (Worldometer, 2023) with an estimated population of ca. 203 million in 2022. Between 2010 and 2022 population grew by 0.5% per year, a trend that is expected to continue until 2034. Afterwards, population growth is expected to gradually decline until a stabilization is achieved in 2046. Regarding the Human Development Index (HDI), Brazil ranks 87th in the world with a slow increase by around 5% between 2010 and 2020. The Brazilian GDP projection shows continuous long-term growth with a growth rate that is below the development of recent years starting from around 1.100 billion USD_{2010} to more than 5.600 billion USD_{2010} in 2050. GPD per capita was around 5.000 USD_{2010} in 2010 and around 15.000 USD_{2010} in 2020 and is expected to increase by 19% from 2020 to 2025, and by about 7.5% in each of the following 5-year episodes.

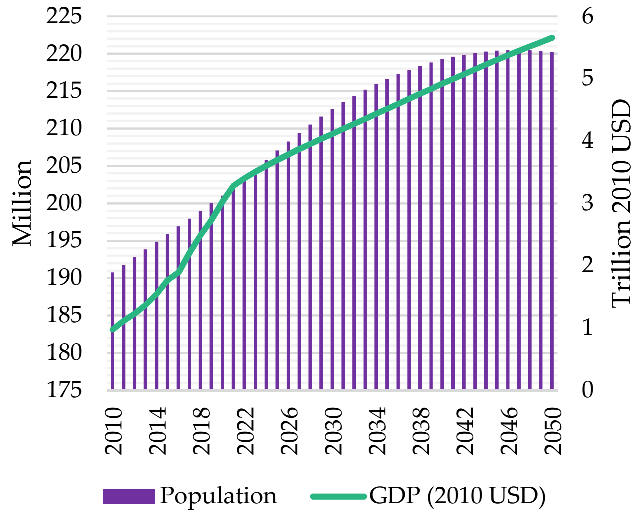

Figure B: Brazil's expected population and GDP development. Sources: IBGE, 2023, 2018; IPEA, 2022; OECD, 2023.

Current emission situation

Brazil's GHG emissions accounted for 2.4 Giga tons of CO_2e (GtCO2e) in 2021, a decrease of 8.3% compared to 2005 (SEEG, 2023). Almost 74% are associated with agriculture, forestry and other land use (AFOLU). Changes in land cover and livestock farming were responsible for 49 % and 25 % of these emissions respectively (Figure C).

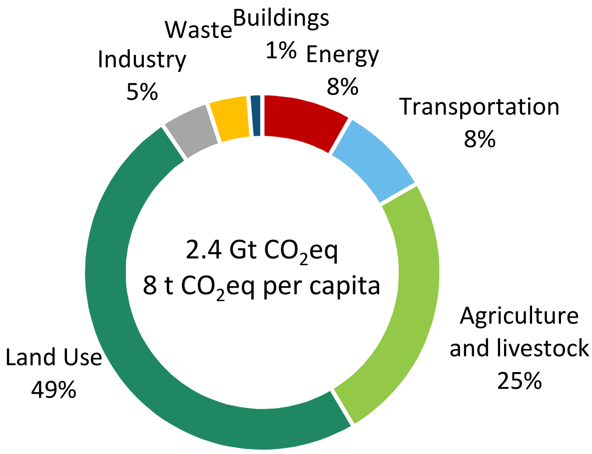

Figure C: Brazil's CO_2eq emissions by sector in 2021. Source: SEEG, 2023.

Brazil's per capita GHG emissions in 2021 were around 8 tCO_2e. In comparison, countries such as Belgium, Germany and the Netherlands have higher per capita emissions of 9 to 10 tCO_2e (OECD, 2023a). Brazilian emissions per GDP in 2021 amount to around 0.74 tCO_2e per 1000 USD of GDP. This value is relatively high compared to countries such as Germany (0.19 tCO_2e per 1000 USD GPD) or France (0.14 tCO_2e per 1000 USD GPD) (OECD, 2023a). Transportation accounts for the largest share of energy-related emissions (47 % in 2021) followed by the electricity and fuel production (26 %) and industry (16 %). Emissions from the industrial sector have notably increased during the last decades, most of them coming from the production of pig iron and steel as well as cement. In 2022, 36% of final energy

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consumption in Brazilian industry was covered by fossil fuels. Overall, this is divided into 35% coal and other solid fuels, 28% oil products and 37% gases (EPE, 2023).

Table A: Economic figures of transformation scenarios for Brazil

Study	Scenario	GDP/capita 2030 % growth	GDP/capita 2040 % growth	GDP/capita 2050 % growth	Reference
Unit	-	in relation to 2020	in relation to 2020	in relation to 2020	-
DDP	CPS	21.5%	43.9%	74.3%	(La Rovere et al., 2021)
	DDS	21.5%	43.9%	74.3%	
iCS	NCP	Not informed			(Schaeffer et al., 2019)
	N2D	Not informed			
	N1.5D	Not informed			
CDP	REF	24.3%	50.7%	86.1%	(Cruz et al., 2022)
	NetZero	24.4%	51.3%	90.3%	
CEBRI	BT	21.6%	41.3%	63.2%	(Bello et al., 2023)
	AT	21.6%	41.3%	63.2%	
	GT	21.6%	41.3%	63.2%	

Figure D shows primary energy usage per source of scenarios. Data for NCP, N2D and N1.5D primary energy were not available, therefore these scenarios are not shown.

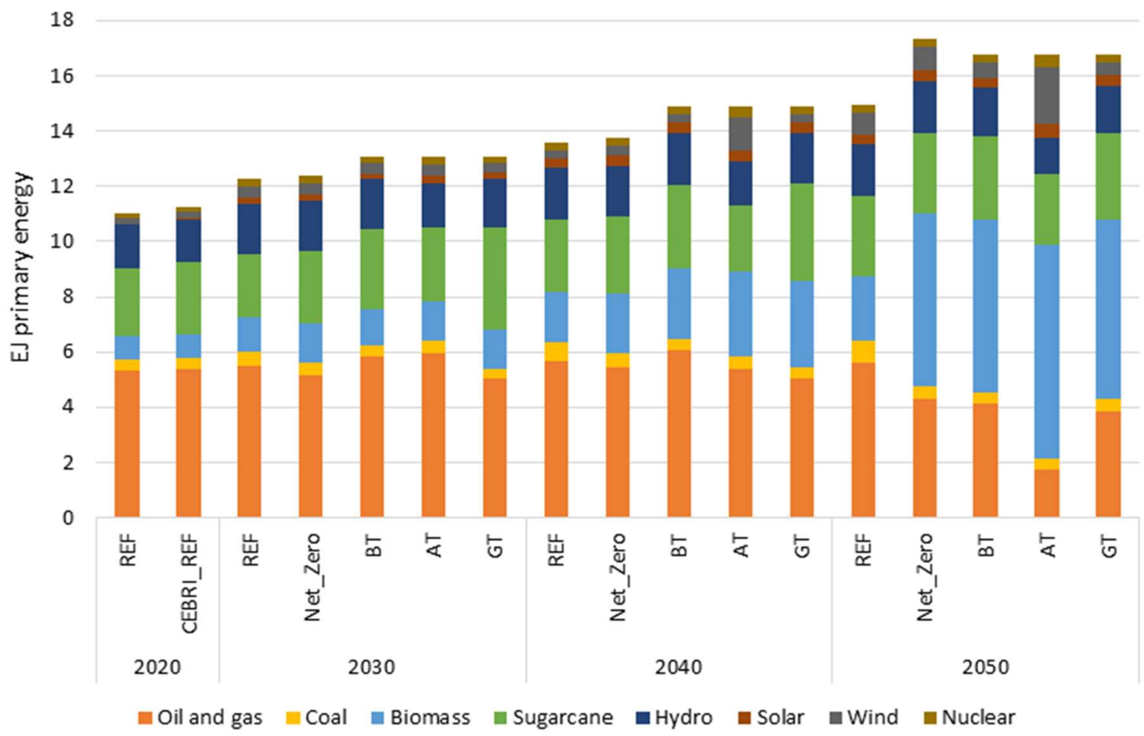

Figure D: Primary energy use per source for each transformation scenario

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Table B: Main sectoral measures in transformation scenarios for Brazil

Study	Agriculture	FOLU	Energy	Transportation	Industry
DDP	High-productivity agricultural areas; Cattle ranching intensification; Mixed crops	Zero illegal deforestation by 2050; Reforestation and restoration of 30 Mha; Fast-growing planted forests	Biomass reaching 31 GW in 2050; Wind reaching 53 GW in 2050; 85% increase in electricity power demand from 2020 to 2050	Zeroing ICE vehicle sells by 2045; Biofuel usage expansion; 20% of energy demand of cabotage supplied by bio-oil in 2050; Modal shift; Electrification of freight railways	New processes to sustainability of industry
iCS	Strengthen Low-Carbon Agriculture Plan; Restore 15 million hectares of degraded pastures by 2030; 5Mha of integrated cropland-livestock-forestry systems by 2030	Strengthen Forest Code; Zero illegal deforestation in Amazonia by 2030, with sequestrations compensating for emissions from legal suppression of vegetation; Enhancing sustainable forest management practices; Restoring and reforesting 12 Mha of forests by 2030	45% renewables by 2030; Non-hydro renewables to 28-33% by 2030; Non-hydro renewables at least 23% by 2030; Biomass reaching 30.2 GW in 2050; Wind reaching 13 GW in 2050	10% efficiency gains up to 2030; Promote efficiency measures; Improve public transport infrastructure; 18% biofuels in primary energy mix by 2030; Electrification of vehicles, especially light-duty	Promote new standards of clean technology
CDP	Reduction of degraded pasture areas; Crop rotation; 18.3 Mha of integrated cropland-livestock-forestry in 2050	Zero illegal deforestation by 2030; Growing of 3.6 Mha of eucalyptus and pine forests	Decrease hydro power share to 38% of installed capacity in 2050; Wind power share at 27% and solar energy share at 10% in 2050; Biofuel process using BECCS; Biomass reaching 200 GW in 2050 (total energy supply); Wind reaching 27.3 GW in 2050	Heavy vehicles gradual shift to biofuels; Light vehicles gradual electrification;	Vegetal coal increased usage; biomass usage; Technologies to increase efficiency of processes
CEBRI	Restoration of degraded pasture: 27 to 51 Mha until 2050; Up to 25 Mha of integrated cropland-livestock-forestry until 2050	Zeo illegal deforestation by 2028; Growing of 3 to 6 Mha of eucalyptus and pine forests; Reforestation of 40 Mha until 2050	Reduction in hydro power dependency to electric generation; up to 93% of renewable energy for electric sector; Biomass reaching 246 GW in 2050 (total energy supply); Wind reaching 43 GW in 2050; solar power expansion; oil usage reaching 5% of total energy demand in 2050; up to 5000 PJ of biofuels usage in 2050; Biofuel process using BECCS; up to 1 Mt of hydrogen produced by 2050	40% of pkm done by electric buses in 2050; Fuel cell vehicles responsible for 12% of cargo movement in 2050; reduction of energy demand due to electrification; biofuel, hydrogen and electrification spread	Electrification of energy demand; Vegetal coal increased usage; Technologies to increase efficiency of processes

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COUNTRY REPORT

Transition pathways for Brazil

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