LATIN AMERICA
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COUNTRY CLIMATE AND DEVELOPMENT REPORT

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Acronyms and abbreviations

ABC	Low-Carbon Agriculture Plan
ABEMA	Brazilian Association of State Environmental Entities
AFOLU	Agriculture, Forestry, and Other Land Use
ALMP	Active Labor Market Program
AMI	Advanced metering infrastructure
ANA	Water Regulatory Agency
ANP	National Agency of Petroleum, Natural Gas and Biofuels
ASP	Adaptive Social Protection
BAU	Business as usual
BLUM	Brazil Land Use Model
BNDES	Brazilian Development Bank
BRT	Bus rapid transit
CAR	Rural Environmental Registry
CBAM	Carbon Border Adjustment Mechanism
CCC	Fuel Consumption Account (Conta de Consumo de Combustíveis)
CCDR	Country Climate and Development Report
CDE	Energy Development Account (Conta de Desenvolvimento Energético)
CDM	Clean Development Mechanism
CEPAC	Certificate of Potential Additional Construction
CER	Certified Emission Reductions
CNJ	National Council of Justice
CNPE	National Council for Energy Policies
CO_2	Carbon dioxide
CPAT	Carbon Pricing Assessment Tool
CRA	Forest certificate
DDES	Deep decarbonization of the energy system
DRM	Disaster Risk Management
DSM	Demand-side management
EM	Environmental management
ETS	Emissions trading system
EU	EU - European Union
EV	Electric vehicle
FEBRABAN	Brazilian Federation of Banks
FNP	National Mayors Front
FU	Federation Unit
FUNCAP	National Calamity Fund
GDP	Gross domestic product
GHG	Greenhouse gas
GNI	Gross national income
$GtCO_2e$	Gigatonnes (billion metric tons) of carbon dioxide equivalent
GW	Gigawatts
IBAMA	Brazilian Institute of Environment and Renewable Natural Resources
IBGE	System of National Accounts
IDB	Inter-American Development Bank
IEA	International Energy Agency
ITR	Rural land tax
LEZ	Low Emission Zone
LULUCF	Land use, land use change and forestry
LVC	Land Value Capture
MCTI	Ministry of Science, Technology, and Innovation
MDB	Multilateral development bank
MDR	Ministry of Regional Development

MME	Ministry of Mines and Energy
MRV	Measurement, reporting and verification
$MtCO_2e$	Million tonnes (metric tons) of carbon dioxide equivalent
NAP	National Adaptation Plan
NBS	Nature-based solutions
NDB	National Development Bank
NDC	Nationally Determined Contribution
NOx	Nitrogen oxide
NPBP	National Program of Biodiesel Production and Use
NTM	Non-tariff measure
OECD	Organisation for Economic Co-operation and Development
PAC	Growth Accelerator Program
PBMC	Brazilian Panel on Climate Change
PDE	10-year Energy Expansion Plan (Plano Decenal de Expansão de Energia)
PES	Payments for Environmental Services
PNL	National Logistics Plan
PMR	Partnership for Market Readiness
PNH_2	National Hydrogen Program
PNMC	National Climate Change Policy
PPCDAm	Plan for the Prevention and Control of Deforestation in the Legal Amazon
PPP	Purchasing power parity
PV	Solar photovoltaics
R&D	Research and development
REDD+	Reducing emissions from deforestation and forest degradation
SDGs	Sustainable Development Goals
SMDU	São Paulo Municipal Office for Urban Development
SME	Small and medium-sized enterprise
SOE	State-owned companies
STF	Federal Supreme Court
TCFD	Task Force on Climate-related Financial Disclosures
tCO_2e	Tonnes (metric tons) of carbon dioxide equivalent
TDM	Travel demand management
TWh	Terawatt-hour
VRE	Variable renewable electricity
VTN	Bare land value
ZPS	Zero-emission power system

Monetary amounts are in US dollars (US$) and Brazilian reais (R$).

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Introduction

The Brazil Country Climate and Development Report (CCDR) examines the implications of climate change and climate action for Brazil's development objectives and priorities. It identifies opportunities for Brazil to achieve both its development goals and its climate commitments. It lays out a combination of sectoral and economy-wide policy reforms, as well as targeted investments in near- and medium-term mitigation and adaptation measures to achieve more rapid and inclusive development with lower greenhouse gas (GHG) emissions (hereafter referred to as low-carbon development). The idea is to maximize synergies between climate and development objectives, while addressing trade-offs among policy objectives and key transition challenges. The CCDR is structured in five sections:

» Section 1 focuses on Brazil's development context, including its priorities, main economic challenges (e.g., slow growth of productivity), and the risks and opportunities created by climate change and disasters, as well as national and global decarbonization efforts. It also outlines Brazil's existing climate commitments and policies, including Brazil's updated nationally determined contribution (NDC) and other environmental commitments made at the subnational level.

» Section 2 examines the interplay between Brazil's development path, including its pace and structure, and climate resilience and GHG emissions. It proposes a set of specific productivity-enhancing reforms to achieve inclusive growth while also improving efficiency and resilience.

» Section 3 explores the role of economy-wide policies—from fiscal reforms and financial sector regulations to social protection and labor policies—in enabling a transition toward more resilient, decarbonized growth.

» Section 4 presents three deep dives into sectoral actions selected for their potential impact on GHG emissions reductions, climate risk exposure, and development. They address i) curbing deforestation and scaling up climate-informed landscape management and resilience in agriculture; ii) transitioning to greener and more resilient energy and transport infrastructure; and iii) enabling resilient, low-carbon, and productive cities.

» Section 5 concludes with recommendations for multi-sectoral policy packages and investment interventions that should be prioritized over the next five years, and examines potential ways to finance the additional required investments.

The CCDR was informed by existing and new analyses on development and climate action in Brazil conducted by the World Bank, development partners, national and subnational research institutions, universities, think tanks, and civil society organizations (CSOs).

1. The Climate and Development Opportunity in Brazil

Main messages

- Brazil is highly exposed to climate change risks. The impacts of global climate change risks and local practices on the Amazon and Cerrado biomes are of particular concern, as they provide vital ecosystem services to Brazil, the South American region, and the world.

- Brazil is in an exceptional position to benefit from climate action, as it has several competitive advantages—most notably a relatively low-carbon energy supply, with large additional renewable energy potential. Its GHG emissions are dominated by land use change and agriculture, not energy. This creates specific opportunities and different costs than in other countries.

- Brazil's climate objectives and commitments are ambitious. Brazil has various subnational and sectoral plans and programs in place to deliver on its climate action commitments, but no centralized and consolidated strategy. Weak governance, political influence, and financing challenges result in weak implementation and in illegal activities that undermine growth and climate action.

1.1. Brazil's aspiration to reach high-income status will require shifts

Brazil aims to raise productivity and diversify its economy to become a high-income country, but its current growth model is unlikely to deliver the rapid growth needed. Brazil is an upper-middle-income country, with a gross national income (GNI) per capita of $15,600 in 2021 (in purchasing power parity terms).[1] It aspires to become a high-income country and join the Organisation for Economic Co-operation and Development (OECD). Brazilian growth has stagnated as demographic trends turned less favorable and the commodity supercycle came to an end. To attain high-income levels, Brazil needs to shift from a growth model based on factor accumulation (expanding labor, capital, and land) to productivity-led growth.[2] Key constraints include a low human capital foundation, which was further weakened by the COVID-19 pandemic,[3] and product market distortions due to low competition and the structure of Brazil's tax system among other factors. Distortions also exist in land markets, capital markets, (e.g., credit earmarking) and in labor markets (including labor taxes and regulations).[4] Infrastructure is undersupplied, and investments barely suffice to make up for depreciation.[5] All of this results in an inefficient, high-cost economy. Climate change further compounds these challenges, but also creates opportunities.

Shifting towards a growth model with greater productivity

Economic growth in Brazil over the past two decades has been driven mainly by the agriculture and extractive sectors, while manufacturing performance has been lackluster. Agriculture grew by nearly 97 percent since 2000, with agriculture, forestry and fisheries combined making up 6.9 percent of

[1] See World Bank data for GNI per capita, PPP (current international $): https://data.worldbank.org/indicator/NY.GNP.PCAP.PP.CD?locations=BR. Using the Atlas method, which is used for the Bank's income classifications, Brazil's per capita GNI in 2021 was $7,720. See World Bank data for GNI per capita, Atlas method (current US$): https://data.worldbank.org/indicator/NY.GNP.PCAP.CD?locations=BR.

[2] Dutz, M.A. 2018. *Jobs and Growth: Brazil's Productivity Agenda*. International Development in Focus. Washington, DC: World Bank. http://hdl.handle.net/10986/29808.

[3] Brazil's Human Capital Index was 0.55 in 2018; see World Bank data (scale of 0–1): https://data.worldbank.org/indicator/HD.HCI.OVRL?locations=BR, and the forthcoming Human Capital Review. The Human Capital Index is a summary measure of the amount of human capital that a child born today can expect to acquire by age 18, given the risks of poor health and poor education that prevail in the country where they live. Almost all developed countries have scores of 0.7 or higher.

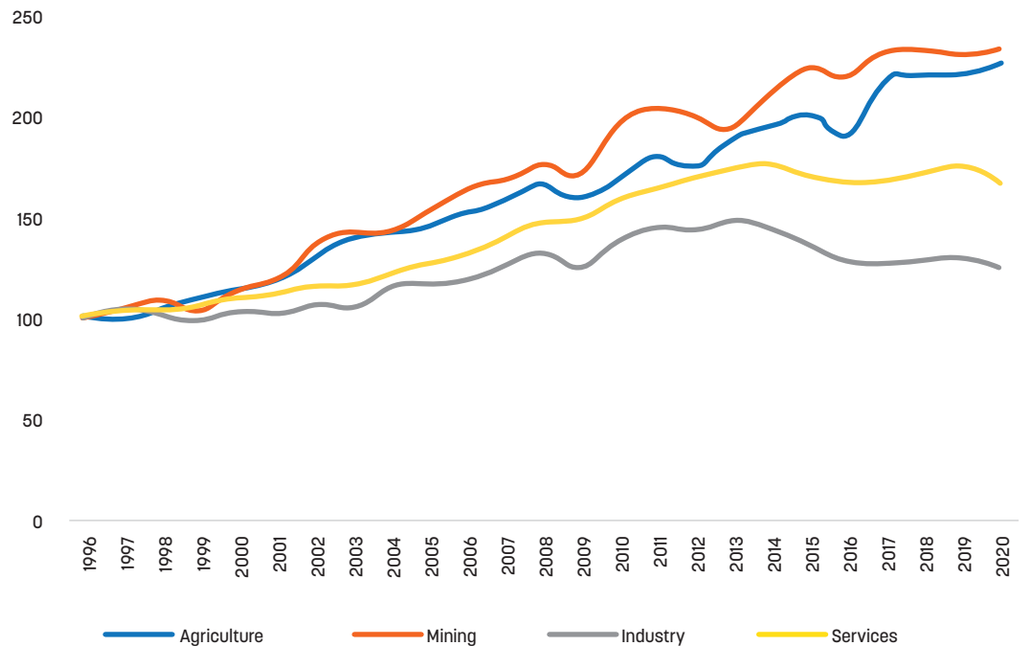
[4] Dutz, M.A. 2018.

[5] World Bank (2022), forthcoming Infrastructure Assessment.

gross domestic product (GDP) in 2021.[6] Agribusiness as a whole contributed about 27.6 percent of GDP in 2021[7] and 20.1 percent of total employment.[8] Similarly, the extractive industry (i.e., oil, gas, and mining) has grown by 87.9 percent since 2000. The share of agriculture and extractives in total exports grew from 9.1 and 7.1 percent in 2000 to 39.3 and 35.7 percent in 2021, respectively.[9] In contrast, manufacturing has grown less rapidly (Figure 1). This pattern reflects the large role of commodity exports and the legacy of import-substitution industrialization—a highly inefficient manufacturing sector protected by high import barriers.

Reforms to accelerate productivity growth have been implemented recently in areas such as the business climate (such as the new bankruptcy regime), investment promotion (opening new sectors to private investment), capital market efficiency (flexibilization of interest rates and a new law on credit bureaus), sector regulations (e.g., on sanitation, railways, and cabotage), and trade promotion. But there is still scope for more to be done. A recent OECD study finds that further reforms in areas such as competition, foreign trade, and economic governance could increase Brazilian growth by an average annual 0.9 percentage points over 15 years.[10]

FIGURE 1. Sectoral GDP Growth (2000=100)



Source: Brazilian Institute of Geography and Statistics - IBGE

[6] See https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=BR.

[7] See https://www.cepea.esalq.usp.br/en/brazilian-agribusiness-gdp.aspx. The definition of agribusiness GDP is sum of inputs, farming (agriculture and livestock), processing and agro-services.

[8] Castro, N.R., Barros, G.S.A.D.C., Almeida, A.N., Gilio, L. and Morais, A.C.D.P., 2020. The Brazilian agribusiness labor market: measurement, characterization and analysis of income differentials. *Revista de Economia e Sociologia Rural*, 58

[9] Atlas of Economic Complexity, Harvard. https://atlas.cid.harvard.edu/explore?country=32&product=undefined&year=2020&productClass=HS&target=Product&partner=undefined&startYear=1995.

[10] OECD. 2020. Brazil: Reforms to spur competitiveness, productivity and trade would strengthen COVID-19 recovery https://www.oecd.org/brazil/brazil-reforms-to-spur-competitiveness-productivity-and-trade-would-strengthen-covid-19-recovery.htm.

Reducing large spatial and social inequalities

Brazil remains one of the most unequal countries in Latin America and around the world. Gains made in reducing inequality and lifting people out of extreme poverty (US$2.15 2017 PPP) during the commodity boom were largely reversed between 2015 and 2018, when the Gini coefficient increased from 51.9 to 53.9.[11] The share of the population living in extreme poverty in 2019 was 5.9 percent, close to 2011 levels,[12] while about 26.2 percent of the population was living on less than US$6.85 per day (PPP).[13] In response to the most recent crisis, the government put in place ambitious social protection measures that have buffered the economy and temporarily protected households' income, albeit at a high fiscal cost. This has resulted in large near-term reductions in inequality and extreme poverty, with Brazil's Gini index having dropped to 48.9, and the extreme poverty rate dropped to 1.9 percent by 2020. Nonetheless, these drops, supported mostly by the government's COVID-19 response efforts, have been short-lived, with poverty and inequality projected to have bounced back in 2021 close to pre-pandemic levels of 28.4 percent and a Gini index of 52.9, respectively.[14]

Brazil also displays notable regional, racial, and gender disparities. The North lags behind the South on many fronts. Poverty rates in the northern states are 3 times higher than in the South; the income per capita is about 50 percent lower on average; the adult population has 1.5 fewer years of education; and people's access to sanitation and water are both 8 percentage points lower. Brazilian women are more educated and have longer life expectancies than men, but their income per capita is estimated at three-fifths that of men.[15] In 2019, roughly 3 in 10 poor individuals were Afro-descendant women living in urban areas.[16] The poverty rate among children in urban areas was 42.2 percent.[17] Post-pandemic estimates are unavailable, but projections suggest that the distribution of the poor population barely changed between 2019–2021.

Addressing serious infrastructure gaps

Access to infrastructure and basic services has expanded significantly in some sectors, but it remains deficient and cost-prohibitive in others. Brazil has made substantial progress in closing the electricity gap, including achieving near-universal access even in rural areas.[18] Similarly, almost 100 percent of urban and rural populations alike now have access to at least basic drinking water. By comparison, Brazil has significant gaps in sanitation, with only half the urban population connected to a sewage system.[19] The government goal is to reach 92 percent of sewage treatment by 2033, though this target may only be met in 2050. Despite ambitious housing programs, significant housing deficits remain. Most social housing developments in Brazil are still lagging in equipping affordable housing with access to basic services such as public transport, education, health, and social protection. Many of the government-supported programs (e.g., Minha Casa, Minha Vida) have delivered housing located at a considerable distance from city centers, making provision of services challenging and expensive.[20] Dispersed development patterns, combined with low-quality public transit, have resulted in traffic congestion, reduced access to jobs, and a high incidence of road accidents and deaths.

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[11] See Brazil data for Gini index: https://pip.worldbank.org/country-profiles/BRA.

[12] Brazil data for Gini index: https://pip.worldbank.org/country-profiles/BRA.

[13] See World Bank data for poverty headcount ratio at $6.85 a day (2017 PPP) (% of population): https://data.worldbank.org/indicator/SI.POV.UMIC?locations=BR. This is considered the poverty line for upper-middle-income countries.

[14] World Bank. Macro and Poverty Outlook – Brazil. October 2022.

[15] UNDP. 2020. "Human Development Report 2020 – The Next Frontier: Human Development and the Anthropocene." New York: United Nations Development Programme. http://hdr.undp.org/en/2020-report. The Gender Development Index (Table 4) shows the expected GNI per capita (PPP) for women was $10,535 in 2017, while for men it was $18,120. Also, see table 2.3 and Figure 2.4 here: https://openknowledge.worldbank.org/bitstream/handle/10986/37657/P1746910e33a8407d0b0850b8f0f5bcf18c.pdf?sequence=1&isAllowed=y

[16] World Bank. 2022. Brazil Poverty and Equity Assessment: Looking Ahead of Two Crises. Washington, DC: World Bank.

[17] Ibid. Poverty here is based on a R$499 poverty line. This is equivalent to half of the minimum wage. There is no national poverty standard in Brazil.

[18] See Sustainable Development Report data dashboard for Brazil: https://dashboards.sdgindex.org/profiles/brazil.

[19] For detailed city-by-city data on key Sustainable Development Goals indicators in Brazil, see ICS, and SDSN. 2021. "Índice de Desenvolvimento Sustentável das Cidades – Brasil." São Paulo and Paris: Instituto Cidades Sustentáveis and Sustainable Development Solutions Network. https://www.sustainabledevelopment.report.

[20] https://www.urbanet.info/brazil-social-housing-shortcomings/ (viewed November 2022).

Brazil has limited fiscal space and faces increasingly challenging demographic trends. The country has made progress towards rebalancing its budget, liquidating much of the pandemic's emergency spending package. But debt levels remain high (73.5 percent of GDP as of December 2022) and budget rigidity is also high (over 90 percent of expenditure is mandatory). Improving the efficiency and effectiveness of fiscal policy will be critical for Brazil to address these challenges and make progress in achieving its development goals. Action is needed to help reconcile fiscal discipline with Brazil's development needs and keep fiscal space to finance investments and programs geared towards climate change. These challenges will be magnified by demographic change and rapid aging of the population, which will increase pressures on the pension system and public services.

1.2. Integrating climate change considerations into reforms and plans for stimulating growth can help manage shocks and create opportunities

Brazil has important reforms and sectoral plans to address climate change. Various reforms in recent years have strengthened market flexibility (especially land, capital, and product markets), making the economy more adaptable to shocks while strengthening productivity growth.[21] The agricultural policy uses rural credit as its main agricultural policy tool, including through its Low-Carbon Agriculture Plan (ABC plan). Energy planning is critical for national development and the National Energy Plan (PNE 2050)[22] recognizes the need to expand energy supply to meet the growing demand, even after considering the projected energy efficiency gains for the next decades. The National Logistics Plan (PNL)[23] aims to tackle the inefficiency and, in some regions, the large environmental footprint of road-based transport infrastructure and low connectivity for a large portion of the national territory. The goal is to support integration of spaces and markets where it is important, enabling regional development. The PNL projects investments in transportation infrastructure between R$730 billion and R$1.2 trillion by 2035, with efficient growth of the transportation system; economic, social, and regional development; and environmental sustainability as guidelines.

Climate change could undermine the expected gains from the reforms and plans

Like all countries, Brazil will experience rapid change in climate conditions and the impact will be spatially varied. By the end of the century, the average temperature in Brazil is expected to rise, depending on the trajectory of global GHG emissions, by 1.7 °C to 5.3 °C from the 1986–2005 average.[24] All of Brazil's biomes are vulnerable to the impact of changes in temperature and rainfall, though with significant regional differences.[25] Severe climate events are likely to intensify, causing major impacts in cities and vulnerable areas. The agricultural sector will be significantly impacted by climate change. Impacts will be concentrated in the poorest regions of the country such as the Northeast, where population groups have worse conditions of income, education, and housing. The projected warmer climate of the future could also convert the semiarid Northeast into an arid region, and impact subsistence agriculture, water availability, and population health, forcing people to migrate to other regions.

Climate change impacts on freshwater availability have significant implications for agriculture and for other water-intensive economic sectors, such as industry, mining, and hydropower. Brazil holds about 20 percent of all global freshwater,[26] but it is facing increasingly frequent and intense water crises.

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[21] The reforms focus on improving the efficient allocation of credit, labor market efficiency, reducing the cost of doing business, attracting investment (for example in sanitation), and opening the economy to trade, among others.

[22] See https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/Plano-Nacional-de-Energia-2050.

[23] See https://www.epl.gov.br/plano-nacional-de-logistica-pnl.

[24] World Bank. 2021. "Climate Risk Country Profile: Brazil." Washington, DC: World Bank Group. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-07/15915-WB_Brazil%20Country%20Profile-WEB.pdf.

[25] PBMC. 2013. "Executive Summary." In *Impactos, Vulnerabilidades e Adaptação: Contribuição do Grupo de Trabalho 2 ao Primeiro Relatório de Avaliação Nacional do Painel Brasileiro de Mudanças Climáticas [Impacts, Vulnerabilities and Adaptation: Contribution of Working Group 2 to the First Assessment Report of the Brazilian Panel on Climate Change]*, edited by E.D. Assad and A.R. Magalhães. Rio de Janeiro: Universidade Federal do Rio de Janeiro. http://pbmc.coppe.ufrj.br/index.php/pt/publicacoes/relatorios-pbmc/item/impacrtos-vulnerabilidade-e-adaptacao?category_id=18.

[26] Getirana, A. 2016. "Extreme Water Deficit in Brazil Detected from Space." Journal of Hydrometeorology 17 (2): 591–99. doi:10.1175/JHM-D-15-0096.1.

This is due to growing demand for water in the country,[27] combined with the impacts of both climate change and land degradation. Deforestation in the Amazon is negatively affecting rainfall patterns in large parts of Brazil,[28] and the loss of native vegetation in the Cerrado, where the country's main aquifers are situated, is increasing aridity and leaving water bodies unprotected. [29] In the Paraná River Basin, there are more than 50 large dams and reservoirs, which help produce a huge volume of electricity and store massive amounts of water. In 2021, however, the worst drought conditions in decades led water levels in several reservoirs to drop below 20 percent of capacity.[30]

Brazil faces exceptional environmental risks, including tipping points

Deforestation and other human activities compound the risks resulting from climate change, especially in the ecologically vital Amazon and Cerrado biomes. Evapotranspiration in the Amazon basin transfers 20 billion tonnes (Gt) of water daily from the soil to the atmosphere.[31] This is more water than the Amazon River discharges daily into the ocean (17 Gt). This water vapor forms the aerial rivers that spread humidity and rain to large areas of Brazil and the South American continent, from the Andean mountains to the La Plata Basin. This water cycle depends on forests returning up to 75 percent of precipitation to the air, resulting in future precipitation. Deforestation in the Amazon basin disrupts this cycle by reducing evapotranspiration, increasing land surface temperature, increasing rainfall runoff, and decreasing overall rainfall.[32, 33] Deforestation also reduces the natural erosion control functions of native forests, resulting in increased sediment loads in hydropower dams.

Feedbacks between continued deforestation and climate change could lead to a tipping point beyond which large areas of the Amazon basin (within and outside Brazil) no longer have sufficient rainfall to support the native ecosystems and forests. Reaching a tipping point in the Amazon biome would mean irreversible damage to the structure of the biome and its ecosystem services. This includes the loss of vital carbon storage functions, resulting in the release of a colossal quantity of carbon dioxide (CO_2) into the atmosphere. The Inter-American Development Bank (IDB) estimated that the economic impacts of reaching such a tipping point on Brazil alone could amount to US$184.1 billion (R$920.5 billion or 9.7 percent of 2022 GDP) through 2050.[34]

Adaptation will be crucial to maintaining agricultural productivity

Brazilian agriculture is exposed to climate variability, affecting the sector's productivity. Climate change impacts on agriculture are expected to reduce yields and income. These impacts, however, differ across crops and geographic regions, and depend on how the agricultural sector adapts. Recent modeling studies indicate that the average temperature and the number of dry days are expected to increase, especially in the central parts of Brazil.[35] Climate change is thus expected to reduce pasture and grain productivity by 2050 and change the areas most suited for livestock and agricultural production. With

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[27] Naspolini et al. (2020)." Brazilian Environmental-Economic Accounting for Water: A structural decomposition analysis." *Journal of Environmental Management*, Vol 265, July 2020, 110508. URL: https://www.sciencedirect.com/science/article/pii/S0301479720304424

[28] Khanna, J. et al. 2017. "Regional Dry-Season Climate Changes Due to Three Decades of Amazonian Deforestation." *Nature Climate Change* 7 (3): 200–204. doi:10.1038/nclimate3226.

[29] Anache, J.A.A. et al. 2019. "Hydrological Trade-Offs Due to Different Land Covers and Land Uses in the Brazilian Cerrado." *Hydrology and Earth System Sciences* 23 (3): 1263–79. doi:10.5194/hess-23-1263-2019.

[30] Getirana, A., R. Libonati, and M. Cataldi. 2021. "Brazil Is in Water Crisis — It Needs a Drought Plan." *Nature* 600 (7888): 218–20. doi:10.1038/d41586-021-03625-w.

[31] Nobre. (2014). "O Futuro Climático da Amazônia: Relatório de Avaliação Científica." Articulación Regional Amazónica, 1, 42. Retrieved from http://www.pbmc.coppe.ufrj.br/documentos/futuro-climatico-da-amazonia.pdf.

[32] For an overview of the science and the economic implications of disrupting these critical processes, see Banerjee, O. et al. 2021. "An Amazon Tipping Point: The Economic and Environmental Fallout." IDB Working Paper Series, No. IDB-WP-01259. Inter-American Development Bank. doi:10.18235/0003385.

[33] Khanna et al., 2017, "Regional Dry-Season Climate Changes Due to Three Decades of Amazonian Deforestation."

[34] Banerjee et al., 2021, "An Amazon Tipping Point: The Economic and Environmental Fallout."

[35] Zilli, M. et al. 2020. "The Impact of Climate Change on Brazil's Agriculture." *Science of The Total Environment* 740 (October): 139384. doi:10.1016/j.scitotenv.2020.139384.

increasing average temperatures and heat waves, agriculture in the North and Midwest regions is expected to be under the highest climate stress. However, historically, the Northeast has experienced the most severe impacts of droughts, as the region's small-scale agriculture is rainfed.[36]

Climate change is expected to change the areas that are suitable for several crops. Many staple crops in Brazil, such as wheat and maize, have limited heat tolerance, while soy and cotton are more moderately impacted by climate stress. Livestock productivity is also sensitive to rising temperatures and heat waves, negatively impacting dairy production. In recent decades, irrigation has played a key role in the growth of Brazilian agriculture. Currently 13 percent of Brazil's cropland is equipped for irrigation, and as of 2017, 68 percent of water consumption in Brazil was for irrigation.[37] There is significant inefficiency and water losses in these systems and no systematic recharge or other sustainability measures. The decline in precipitation, longer dry periods, and warmer temperatures resulting from climate change are expected to increase water evaporation rates, reducing both surface water and groundwater availability. The expected increase in use of irrigation will likely result in growing competition over water for agriculture and for hydropower, posing threats to all water-dependent sectors, such as power and mining, and exposing Brazil's growth to climate risks.[38]

With adaptation measures, Brazil could significantly reduce the impact of climate change on agricultural production, though impacts will vary regionally. With an optimal adaptation process and the ability to reallocate resources and change crop spatial distribution (e.g., if soybean areas can move south and pasture areas move south and east[39]), models suggest that the overall impact for Brazil would be a small loss at the national level, equivalent to 0.15 percent of GDP by 2042. However, the economies of Brazil's largest soy-producing states, Mato Grosso and Mato Grosso do Sul, would be the most adversely affected, and this adaptation process will face multiple barriers and constraints.[40] The different economic impacts across states could result in internal migration, with states such as Mato Grosso do Sul and Bahia experiencing out-migration and São Paulo and Rio Grande do Sul experiencing in-migration. Such adaptation processes could reduce aggregate costs significantly, but with significant social disruption and household impacts, and would require support for a just transition for agricultural workers.

Climate risks will increase for cities, infrastructure, and informal settlements

Losses from climate-related events in Brazil are recurring and large, calling for urgent action. A World Bank assessment of national, state, and municipal level civil defenses and protection found that between 1995 and 2019, reported nationwide losses from climate-related events cost an average of more than R$13.33 billion per year.[41] Overall, drought is the costliest climate-related hazard in the country (R$199.8 billion between 1995 and 2019), followed by flash floods (R$55 billion) and riverine floods (R$32.2 billion). Extreme heat is more frequent and intense in urban areas, due to the urban heat

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[36] Because of this, during the 2012–2016 period, the *Garantia Safra* program disbursement exceeded U$2.1 bi in agricultural insurance payments to farmers in the Northeast region. Marengo, J.A., Galdos, M.V., Challinor, A., Cunha, A.P., Marin, F.R., Vianna, M.D.S., Alvala, R.C., Alves, L.M., Moraes, O.L. and Bender, F., 2022. "Drought in Northeast Brazil: A review of agricultural and policy adaptation options for food security." *Climate Resilience and Sustainability*, 1(1), p.e17.

[37] ANA. 2019. "Manual de Usos Consuntivos da Água no Brasil." Brasilia: Agência Nacional de Águas e Saneamento Básico (National Water and Basic Sanitation Agency). http://www.snirh.gov.br/portal/snirh/centrais-de-conteudos/central-de-publicacoes/ana_manual_de_usos_consuntivos_da_agua_no_brasil.pdf/view.

[38] World Bank (2021). Climate Risk Country Profile – Brazil. URL: https://climateknowledgeportal.worldbank.org/country/brazil.

[39] Zilli et al., 2020, "The Impact of Climate Change on Brazil's Agriculture."

[40] Using computable general equilibrium (CGE) simulations, building on forthcoming work by the World Bank and dos Santos et al. (2022), it becomes possible to explore the implications of different climate change scenarios (expressed in Representative Concentration Pathways, or RCPs) for the Brazilian economy through their impacts on agricultural production. To this end, the modelling uses information on weather patterns (notably changing temperatures and precipitation) and CO_2 concentrations associated with different RCPs at a spatially disaggregated level. This climate information, drawn from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), was then turned into agricultural suitability measures at the municipal level, using models provided by EMBRAPA (reference: dos Santos, W.P., Avanzi, J.C., Viola, M.R., Chou, S.C., Acuña-Guzman, S.F., Pontes, L.M. and Curi, N., 2022. "Projections of rainfall erosivity in climate change scenarios for the largest watershed within Brazilian territory." *Catena*, 213, p.106225.)

[41] World Bank. 2020. *Report of material damages and losses due to natural disasters in Brazil - 1995–2019: Relatório de danos materiais e prejuízos decorrentes de desastres naturais no Brasil – 1995–2019 (Portuguese)*. Washington, DC: World Bank Group.
Data collected within that report comes from incident reports submitted by municipalities to access federal funds for response and recovery. Therefore, the cost of disasters in Brazilian cities is estimated to be much larger. Some cities, such as São Paulo, have not submitted many reports, but this may indicate not that they are not experiencing disasters, but that these cities (usually the most financially sound ones) are covering most of the costs without reaching out for federal support.

island effect. The states of Rio Grande do Sul, Minas Gerais, Bahia, Pernambuco, and Santa Catarina have reported the greatest losses, accounting for half of the total R$333.36 billion in reported losses between 1995 and 2019. Nearly every municipality reported some losses and damages during the period, and 85 percent of 5,570 municipalities reported climate-related disaster losses.

The concentration of people, infrastructure, and economic activity in Brazil's cities means that inadequate urban adaptation would result in large overall economic costs. Floods and landslides pose significant risks to all cities, requiring increased investments to mitigate these risks. Despite concerted government efforts to build housing, the significant housing deficit has led people to continue to build informal dwellings, often in unsafe areas such as floodplains and steep slopes. Although droughts affect far more people nationwide, floods caused 88 percent of deaths from disasters between 2000 and 2018—2,435 altogether, mainly in urban areas.[42]

Natural hazards significantly disrupt infrastructure, negatively impacting the competitiveness of Brazil's economy. Brazilian firms lose amounts equivalent to about 0.23 percent of GDP every year due to infrastructure disruptions. The majority (55 percent) are caused by failures to transport infrastructure, followed by power (44 percent) and water (2 percent).[43] More than 5 percent (120,000 km) of Brazil's road and railway infrastructure is exposed to flood risks. The projected reduction in precipitation and changes in seasonal rainfall patterns are also likely to create risks for Brazil's hydropower-dominated electricity supply, potentially resulting in periodic energy crises. The current hydropower assets are aging, with large-scale hydropower assets averaging 55 years, leading to reduced efficiency and capacity—due both to their age and to inadequate maintenance.

1.3. Brazil is in an exceptional position to benefit from climate action

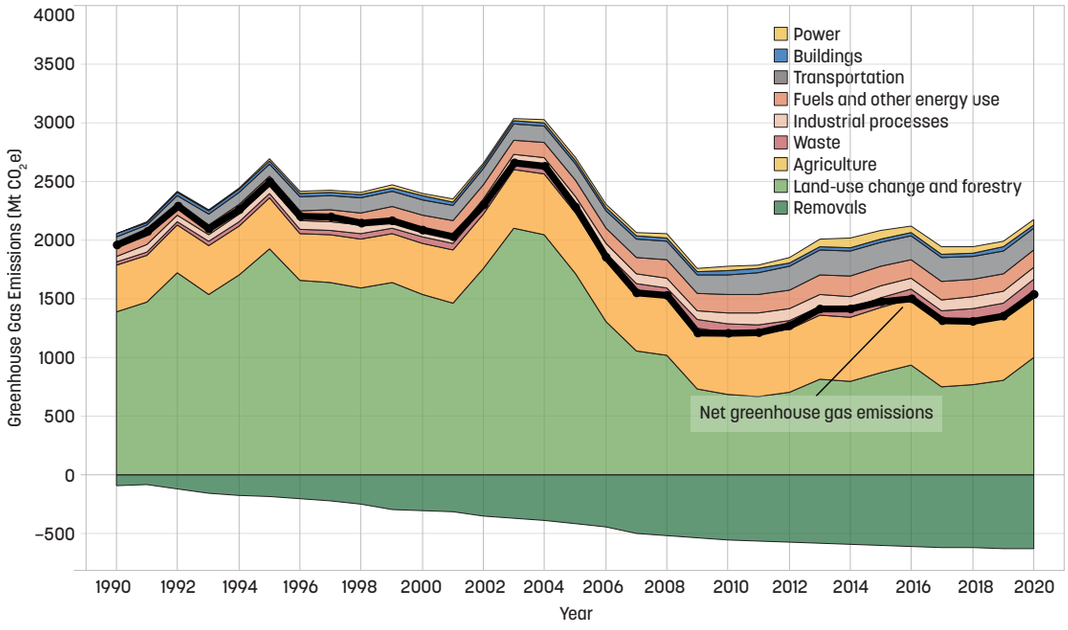
Brazil's GHG emissions are primarily due to land use change (primarily deforestation) and agriculture, rather than energy like in most countries. Land use change and agriculture accounted for 52 percent and 24 percent, respectively, of Brazil's total GHG emissions between 2000 and 2020. Electricity and transport accounted for 12.5 percent and 45 percent of GHG emissions from the energy sector in 2000 (as shown in Figure 2). This is very different from global averages: energy use (for electricity, heating and cooling, transport, industry, and other uses) accounts for about three-quarters of global emissions, while agriculture, forestry, and land use combined contribute only about 18 percent.[44] The unusual structure of Brazil's emissions creates a different set of opportunities and cost structures for decarbonization than in other countries.

[42] See EM-DAT dashboard for Brazil: https://www.emdat.be/emdat_atlas/sub_html_pages/sub_html_BRA.html.

[43] World Bank analysis using data from Hallegatte, Stephane; Rentschler, Jun; Rozenberg, Julie. 2019. Lifelines : The Resilient Infrastructure Opportunity. Sustainable Infrastructure. Washington, DC: World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/31805 License: CC BY 3.0 IGO.

[44] Climate Watch. 2022. "Global Historical Emissions." Washington, DC: World Resources Institute. https://www.climatewatchdata.org/ghg-emissions.

FIGURE 2. Sectoral breakdown of GHG emissions in Brazil



Source: World Bank staff calculations, based on SEEG data[45]

Reducing land use change and boosting agricultural productivity could mitigate climate risks and reduce GHG emissions

Brazil has made remarkable progress in fostering agricultural growth and reducing deforestation in the past decades. The agricultural sector transformation was driven by economic reforms, including openness to foreign trade, sustained public and private investments in technological innovation, and rural credit investments. From 2000–2013, agricultural productivity increased by 105.6 percent, compared to 11.7 percent and −5.5 percent in the services and in the manufacturing sectors, respectively. Forest conservation policies, associated with other economic factors, contributed to a reduction of 80 percent in deforestation rates in the Amazon from 2004 to 2012. Deforestation has however recently trended upward, posing a challenge to achieve long-term sustainability goals.

In recent years, government agricultural low-carbon policies and industry initiatives have contributed to lower the sector's emissions intensity, but further efforts are required. Sectoral emissions have grown at a slower pace than agricultural production. To date, Brazil has applied 17.4 million hectares of different combinations of integrated crop-livestock-forest systems, contributing to the sequestration of 21.8 million tons of CO_2 equivalent ($MtCO_2e$) and surpassing by 21 percent the original NDC targets by 2020. Also, around 50 percent of total croplands in Brazil are under permanent no-till technology systems. However, in the longer run, stronger economic incentives to scale up the adoption of low-carbon practices are required to further curb agriculture and livestock emissions, such as improved provision of technology transfer, reforms to the rural credit system to increase green finance, and innovative Payment for Environmental Services incentives.

[45] See https://plataforma.seeg.eco.br/total_emission.

Further preserving Brazil's natural landscapes, and curbing deforestation, would contribute to more resilient agriculture and land use. Augmenting agricultural and livestock productivity, while enforcing forest protection and management, would help reduce conversion of native vegetation. That, along with additional efforts to curb deforestation, as noted earlier, would positively influence precipitation and temperature at a regional scale, and help reduce soil erosion and the associated nutrient loss.

Landscape measures could remove large amounts of CO_2 from the atmosphere. In 2020, gross GHG emissions in Brazil amounted to 2.16 billion tonnes of carbon dioxide equivalent ($GtCO_2e$), but, after approximately 600 million tonnes (Mt) of removals by Brazil's natural ecosystems, net GHG emissions were 1.52 $GtCO_2e$.[46] Sections 3 and 4 delve deeper into how tackling the main sources of GHG emissions in Brazil would involve addressing underlying drivers of land use change, including agriculture and extensive cattle pastures.

Maintaining a decarbonized energy sector could provide Brazil with a competitive lead in manufacturing

Brazil could stay ahead on emissions reductions by continuing to decarbonize its energy sector. In 2019, the country got 46.2 percent of its total energy supply from renewables, including hydropower and biomass, and it generated 82.3 percent of its electricity from renewables. The corresponding shares for the world were 14.1 percent and 28.8 percent, respectively.[47] In a detailed government analysis, conducted as part of the latest 10-Year Energy Expansion Plan, hydropower and sugarcane products such as biomass and ethanol stand out—accounting, jointly, for 30 percent of the total energy supply.[48] The analysis also shows that hydropower is the main source of electricity, accounting for 83 percent of power generation in 2021, followed by wind and biomass, with roughly 10 percent each.[49] In 2021, electricity accounted for 18.5 percent of total energy consumption. Brazil has successfully implemented policies to support solar and wind integration, including variable renewable electricity (VRE) auctions, tax breaks, and incentives such as reduced interconnection costs. Recent laws and regulations enacted in 2021 are expected to facilitate further scaling up of distributed generation and offshore wind.[50] This share is expected to increase significantly in the coming decade. The analysis projects that distributed generation (mainly renewable) will more than double, so that by 2031, it will account for 15 percent of total generation.

However, concerns about the reliability of hydropower amid growing water scarcity have led the government to seek to expand gas-fired power production, potentially increasing the carbon intensity of the Brazilian economy. In June 2021, as part of a new law to privatize Eletrobras, the largest generation and transmission utility in Brazil, the National Congress required that 8 gigawatts (GW) of new thermal capacity be installed by 2030. These plants are required under the law to be at least 70 percent inflexible, resulting in a substantial increase in thermal power in Brazil's baseload power supply.

In parallel, Brazil plans to increase its oil production from its large reserves of offshore oil and associated gas (pre-salt) by about 80 percent from 2021 levels.[51] Brazil's offshore oil and gas reserves are among the largest in the world. Currently they are globally competitive and an important source of

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[46] Data from the Greenhouse Gas Emission and Removal Estimating System (SEEG); see http://seeg.eco.br.

[47] See data for total energy supply (TES) by source and electricity generation (by source) on the International Energy Agency (IEA) Data Browser: https://www.iea.org/data-and-statistics/data-browser. Percentages were calculated by the authors. Data for 2019 for Brazil and the world, as reported by the IEA, are used to ensure comparability. The latest national energy balance shows that in 2021, renewables made up 44.7 percent of Brazil's energy supply and 78.1 percent of domestic electricity generation. The report notes that water shortages affected the electricity mix. See EPE. 2022. "Balanço Energético Nacional 2022: Relatório Síntese 2022 [National Energy Balance 2022: Synthesis Report 2022]." Energy Research Company (Empresa de Pesquisa Energética). https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/balanco-energetico-nacional-2022.

[48] See Figure 11–3 in EPE, and MME. 2022. "Plano Decenal de Expansão de Energia 2031 [Ten-Year Energy Expansion Plan 2031]." Brasilia: Energy Research Company (Empresa de Pesquisa Energética) and Ministry of Mines and Energy (Ministério de Minas e Energia). https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/plano-decenal-de-expansao-de-energia-2031. Hydropower made up 12 percent of the energy supply, and sugarcane products, 18 percent.

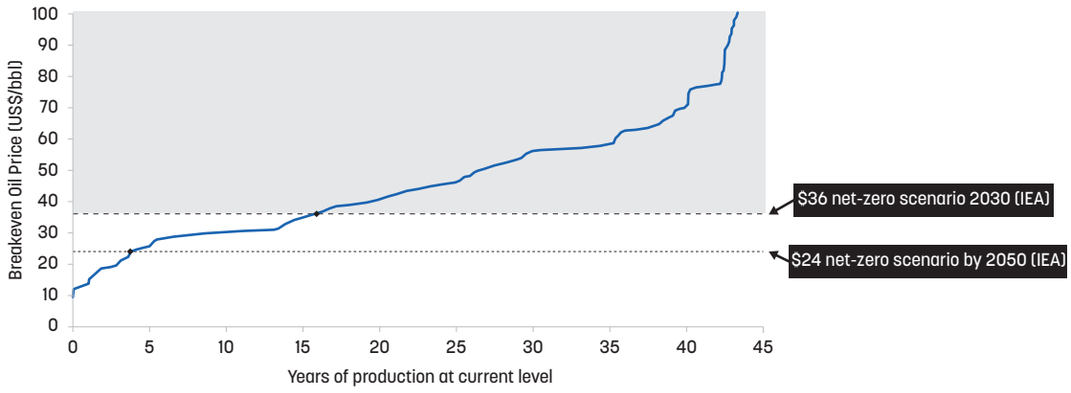
[49] See Table 11–3 in EPE and MME, 2022.
Note that almost half the biomass generation is self-generation or off-grid; biomass fueled 36 TWh of grid-connected power in 2021, and 30 TWh off-grid. Almost all the wind power is grid-connected.

[50] EPE and MME, 2022, "Plano Decenal de Expansão de Energia 2031 [Ten-Year Energy Expansion Plan 2031]."

[51] Ibid.

national income (Figure 3). Projections of future decreases in global demand for oil and gas resulting from the global trend toward net-zero emissions by mid-century could pose a risk to those revenue flows. Brazil's reserves are estimated to have a break-even oil price of about US$40 per barrel,[52] and the International Energy Agency (IEA) net-zero scenario assumes a price of $36 in 2030 and $24 by 2050.[53] The Inter-American Development Bank (IDB) has estimated that Brazil's future production could be nearly half or nearly double its 2016 oil production, depending on the pace of global decarbonization, highlighting the large uncertainty of Brazilian oil's future competitiveness.[54] Fuel production represented 5 percent of total national emissions in 2019, the third largest share in the energy sector (behind transport and industry).[55] Petrobras, the major public national petroleum company, has reduced its carbon intensity of oil production to 15.9 $kgCO_2e$ per barrel of oil in 2021, below the global average, and aims to eliminate gas flaring.[56]

FIGURE 3. Estimated break-even price for remaining economical oil resources in Brazil



Source: Rystad Energy

Modal shift, mass transit and e-mobility could augment resilience and boost productivity

Transport emissions are roughly equally distributed between cargo and passenger transport. Road transport accounts for 91 percent of GHG emissions from transport.[57] Transport activity represented 45 percent of total emissions in the energy sector in 2020[58]—roughly equally distributed between cargo and passenger transport. The Brazilian cargo modal split is classified as 66.2 percent road, 17.7 percent rail, 14.8 percent waterway, 1.2 percent pipeline, and 0.1 percent airway.[59] Brazil has about 1.7 million kilometers of roads,[60] but only 12.4 percent of the network is paved, and

[52] Goldman Sachs. 2021. "Top Projects 2021: A Tale of Shrinking Reserves and Rising Profits." Equity Research.

[53] IEA. 2021. "Net Zero by 2050: A Roadmap for the Global Energy Sector." Paris: International Energy Agency. https://www.iea.org/reports/net-zero-by-2050.

[54] Solano-Rodriguez, B. et al. 2019. "Implications of Climate Targets on Oil Production and Fiscal Revenues in Latin America and the Caribbean." Washington, DC: Inter-American Development Bank. doi:10.18235/0001802.

[55] https://plataforma.seeg.eco.br/sankey. 2018 data was selected to be more representative (pre-COVID).

[56] https://www.ogci.com/case-study/petrobras-applying-carbon-capture-and-eor-at-scale-in-ultra-deep-waters-case-study/.

[57] Analysis of Brazilian Greenhouse Gas Emissions and Their Implications For Goals of Climate of Brazil 1970-2019. Greenhouse Gas Emission and Removal Estimation System - SEEG 8: Climate Observatory, 2020. Available at: https://Seeg-Br.S3.Amazonaws.Com/Documentos%20analiticos/Seeg_8/Seeg8_Doc_Analitico_Sintese_1990-2019.pdf.

[58] 2019 data from Analysis of Brazilian Greenhouse Gas Emissions And Their Implications For Goals of Climate of Brazil 1970-2019. Greenhouse Gas Emission and Removal Estimation System - SEEG 8: Climate Observatory, 2020. Available at: https://Seeg-Br.S3.Amazonaws.Com/Documentos%20analiticos/Seeg_8/Seeg8_Doc_Analitico_Sintese_1990-2019.pdf.

[59] EPL. 2021. "National Logistics Plan 2035: Executive Report (English Version)." Brasilia: Planning and Logistics Company (Empresa de Planejamento e Logística). https://ontl.epl.gov.br/planejamento/relatorios/.
See also EPL. 2021. "Anuário Estatístico de Transportes 2010–2020 [Transport Statistical Yearbook 2010–2020]." Brasilia: Planning and Logistics Company (Empresa de Planejamento e Logística). https://www.gov.br/infraestrutura/pt-br/assuntos/dados-de-transportes/AnuarioEstatisticodeTransportes2020QRcode21.06.2020.pdf.

[60] CNT - Confederação Nacional do Transporte (2017). Boletim Estatístico CNT – Feb. 2017. Available in: http://www.cnt.org.br/Boletim/boletim-estatistico-cnt.

another 9.1 percent is slated to be paved. The poor quality of roads increases travel time, maintenance costs, and fuel consumption. Only 71 Brazilian cities concentrated in 11 states have commuter rail services; 23 cities have bus rapid transit (BRT) systems;[61] and only 64 cities have registered electric vehicles.[62] Inadequate public transit service in most of the country, combined with urban sprawl, has increased dependence on cars and motorcycles, with large economic and welfare costs.[63] In 2010, traffic congestion cost Brazil an estimated 2.6 percent of its GDP,[64] and traffic accidents generate annual losses of R$56 billion in sacrificed production, hospital costs, and property losses.[65] Air pollution, much of it from transport, was linked to about 44,000 deaths in Brazil in 2016.[66]

Brazil's cities vary greatly in their GHG emissions profiles, resources, and key opportunities for decarbonization. Solid waste management contributes a significant share of emissions from Brazil's urban areas, ranging from 22 percent (0.5 tCO_2e per capita) to about 8 percent (0.2 tCO_2e per capita) of total emissions from the city.[67] Waste generation in Brazil is expected to increase from 81.9 million tonnes (Mt) in 2020 to 122.3 Mt in 2050, still below the projected global increase of 73 percent during the same period. Given the relatively large proportion of waste that is dumped, total emissions from solid waste in 2020 in Brazil are estimated at 63.8 $MtCO_2e$, and are expected to increase to 94.1 $MtCO_2e$ by 2035 in a business-as-usual (BAU) scenario.[68]

The low carbon intensity of Brazil's industrial exports is a competitive advantage

As advanced economies decarbonize, their standards will trickle through global trade, creating new expectations for Brazil's exports, as well as new opportunities. Brazil will see changes in output and trade, especially in high-emission sectors. For Brazil to remain competitive in global markets, resources and investments will need to shift towards relatively low-emission sectors. This creates an opportunity to drive the diversification of exports and the economy beyond agriculture and extractive industries. Brazil has an important advantage for building a low-emission industrial sector: its relatively clean and renewable energy matrix and the low carbon intensity of its production compared with its peers (Figure 4).

Although Brazil's exports are relatively low carbon, the GHG intensity of the Brazilian export basket increased by 28.1 percent from 2010 to 2018, from 967 tCO_2e per million reais exported, to 1,239.6 tCO_2e.[69] This is due to beef and soybeans, the production of both of which is associated with large amounts of emissions from land use change and deforestation. As a large agricultural producer and exporter, Brazil should proactively adapt beef and soy production to low-carbon agriculture while avoiding food security problems, food-driven inflation, loss of external competitiveness, and external imbalances.

Under current plans, climate policies by Brazil's trade partners are expected to have relatively small impacts on Brazil's aggregate real income, output, and trade; but larger effects are likely over the longer term. With global policies consistent with its trade partners' NDCs and the introduction of the European Union (EU)'s Carbon Border Adjustment Mechanism (CBAM), Brazil could see real income decrease by 0.1 percent in 2030 relative to the baseline. The effect of the CBAM is negligible, because it

[61] https://brtdata.org/.

[62] https://brtdata.org/.

[63] SEEG 8: Climate Observatory, 2020. Available at: https://Seeg-Br.S3.Amazonaws.Com/Documentos%20analiticos/Seeg_8/Seeg8_Doc_Analitico_Sintese_1990-2019.Pdf.

[64] Vianna, G.S.B., and C.E.F. Young. 2015. "Em busca do tempo perdido: Uma estimativa do produto perdido em trânsito no Brasil [In search of lost time: An estimate of production losses in traffic congestion in Brazil]." *Revista de Economia Contemporânea* 19 (3): 403–16. doi:10.1590/198055271933.

[65] Carvalho, S.C.P., F.D. Santos, and M. Pulquério. 2017. "Climate Change Scenarios for Angola: An Analysis of Precipitation and Temperature Projections Using Four RCMs." *International Journal of Climatology* 37 (8): 3398–3412. doi:10.1002/joc.4925.

[66] Ministério da Saúde. 2019. "Saúde Brasil 2018: Uma Análise da Situação de Saúde e das Doenças e Agravos Crônicos: Desafios e Perspectivas." Brasilia: Health Surveillance Secretariat, Ministry of Health. http://bvsms.saude.gov.br/bvs/publicacoes/saude_brasil_2018_analise_situacao_saude_doencas_agravos_cronicos_desafios_perspectivas.pdf.

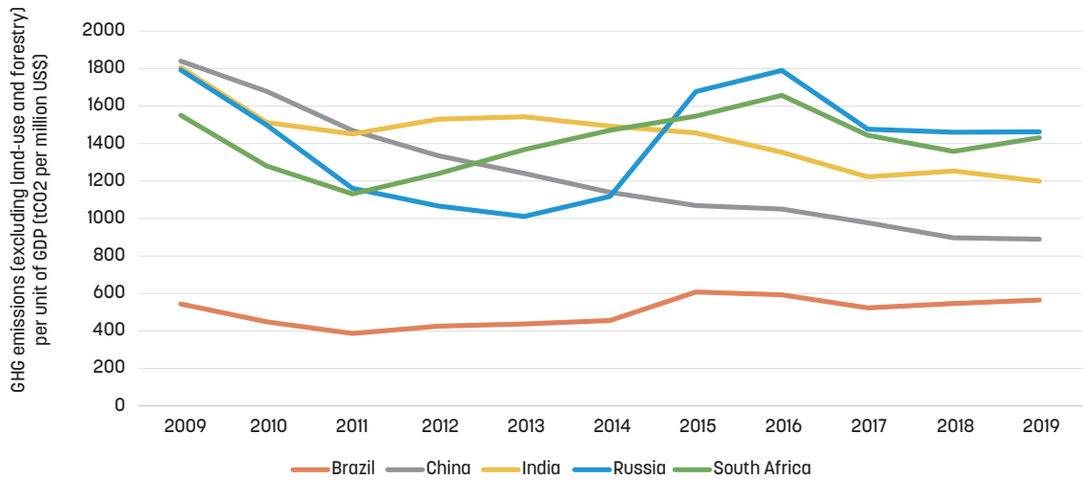
[67] See the C40 Cities Knowledge Hub: https://www.c40knowledgehub.org/s/article/C40-cities-greenhouse-gas-emissions-interactive-dashboard?language=en_US. The dashboard includes data for the four Brazilian cities that are C40 members: São Paulo, Rio de Janeiro, Curitiba, and Salvador. Note that each city's GHG emissions inventory is from a different year, ranging from 2016 to 2018.

[68] Ibid.

[69] Alvarenga Jr. et al. (2021). "Structural Change and Climate Change in Brazil: A Structural Decomposition Analysis of the Brazilian GHG emissions from 2000–2018." Working Paper, Environmental Economics and Sustainable Development Research Group (GEMA).

applies to fossil fuels, while Brazil's emissions are from agriculture and land use changes.[70] Extensions of the CBAM or other trade-climate policies that target these emissions—especially with regard to deforestation—and changes in technologies and global value chains, could however have a much larger impact on Brazilian trade and competitiveness over the medium term.

FIGURE 4. Carbon intensity of Brazilian economy (excluding land-use and forestry emissions)



Source: ClimateWatch

1.4. Brazil has ambitious climate commitments

Brazil has an ambitious goal of net zero by 2050

Brazil's nationally determined contribution (NDC), submitted in 2015 and most recently updated in 2022, commits to an economy-wide approach to emission reductions consistent with the 2°C global goal.[71] It also calls for strengthening and enforcing the Forest Code; reaching zero illegal deforestation; restoring and reforesting 12 million hectares (ha) of forests by 2030; and enhancing sustainable forest management systems. In the energy sector, proposed actions are to increase the share of sustainable biofuels to about 18 percent, and the share of renewables (beyond hydropower) in the energy mix to about 45 percent by 2030. Brazil also proposes to improve efficiency in the electricity sector by 10 percent by 2030. In agriculture, the proposed actions are strengthening the Low-Carbon Agriculture Program (ABC Plan), restoring an additional 15 million ha of degraded pasturelands by 2030, and enhancing 5 million ha of integrated cropland-livestock-forestry systems by 2030. In industry, new standards for clean technology, energy efficiency measures, and low-carbon infrastructure are proposed. In the transportation sector, the NDC calls for efficiency measures, improved infrastructure, and better public transit service in urban areas.

[70] CCDR Background Paper. June 2022. Brazil Trade and Climate Change Diagnostic. World Bank.

[71] Brazil has made three submissions, but its commitments have not changed; the updates reaffirmed the initial commitments and/or answered questions about those commitments. See Federative Republic of Brazil. 2015. "Intended Nationally Determined Contribution." Brasilia. https://unfccc.int/sites/default/files/BRAZIL%20iNDC%20english%20FINAL.pdf; 2020. "Brazil's Nationally Determined Contribution (NDC) – Update." Brasilia. https://unfccc.int/sites/default/files/BRAZIL%20iNDC%20english%20FINAL.pdf; 2022. "Nationally Determined Contribution (NDC) – Annex: Information to Facilitate Clarity, Transparency and Understanding of Brazil's NDC." Brasilia. https://unfccc.int/sites/default/files/NDC/2022-06/Updated%20-%20First%20NDC%20-%20%20FINAL%20-%20PDF.pdf.

Brazil's NDC identifies several priorities for adaptation as well. They include developing an agricultural risk and vulnerability monitoring system; promoting ecosystems-based adaptation in areas at risk of extreme events; expanding the scope of the National Drinking Water Surveillance Program; and assessing the climate change vulnerability of Indigenous populations and their lands. However, the NDC does not set quantitative targets for adaptation, and the listed measures are not associated with an action plan.

In the most recent (2022) NDC update, Brazil commits to halve its emissions by 2030 (from 2005 levels) and achieve net-zero GHG emissions by 2050. Under the "guidelines for a national strategy for climate neutrality," a key share of Brazil's emission reductions would come from achieving "zero illegal deforestation" by 2028. Brazil has also joined the Global Methane Pledge, to reduce global methane emissions by 30 percent by 2030.[72] For Brazil, reducing methane emissions will require addressing emissions from cattle ranching and curbing the increase in methane emissions from waste.

Climate change in Brazil's policies and plans

The framework policies that shape the climate agenda in Brazil began with the first National Climate Change Policy (Plano Clima, or PNMC) in 2007 by the Inter-ministerial Committee on Climate Change and the publication of the PNMC in 2009. The PNMC, instituted by law, is the main cornerstone and legal framework for climate change mitigation and adaptation in Brazil. It establishes the basic principles, objectives, guidelines, and instruments for mitigation and adaptation. Key PNMC objectives include reducing anthropogenic GHG emissions by 36.1–38.9 percent below projected emissions in 2020, strengthening the reduction of GHGs from various sources, and the stimulation and development of the Brazilian Market for Emission Reduction.

The PNMC states that Brazilian public policies and government programs should be compatible with the PNMC. It requires the preparation of specific plans for the mitigation of and adaptation to climate change in key sectors. There are several sectoral policies and measures that either enable (e.g., the Forest Code and ABC and ABC+ plan) or hinder decarbonization and resilience to climate change. There are also subnational measures that aim to advance climate action (e.g., Rio de Janeiro and Belo Horizonte have already adopted goals to decouple economic development from the increase in GHG emissions).

Brazil's National Adaptation Plan (NAP) recognizes 11 sectors that climate change will affect considerably.[73] It does not, however, set out a clear roadmap or targets. At the sectoral level, independent of the NAP, the consideration of adaptation and resilience is mixed. For example, the water sector's targets do not reflect the importance of augmenting resilience through efficient mechanisms for enabling sustainable water use, watershed restoration, increased water storage capacity and water recharge, and economic pricing. In the agriculture sector, the NAP does not include information on local climate change impacts, resilience, adaptive capacity, or specific policy measures to scale up adaptation implementation and improve agricultural risk management instruments. Furthermore, the much-needed broader landscape and value-chain approaches are still nascent in the NAP.[74]

[72] See https://www.globalmethanepledge.org.

[73] MMA. 2016. "National Adaptation Plan to Climate Change." Volume I: General Strategy. Brasilia: Ministry of Environment (Ministério do Meio Ambiente). https://www.gov.br/mma/pt-br/assuntos/climaozoniodesertificacao/clima/arquivos/pna_volume-i_en.pdf. The sectors include agriculture, biodiversity and ecosystems, cities, disaster risk management, industry and mining, infrastructure, vulnerable populations, water resources, health, food and nutritional security, and strategy for coastal zones.

[74] Di Gregorio, M. et al. 2016. "Integrating Mitigation and Adaptation in Climate and Land Use Policies in Brazil: A Policy Document Analysis." CIFOR Working Paper No. 194. Centre for Climate Change Economics and Policy. https://www.cifor.org/knowledge/publication/5997/.

Government capacity and institutional arrangements for climate action

The governance structure of the National Climate Change Policy (PNMC) includes a decision-making body at the federal level, with federal and state government representatives, researchers, and others. Implementation of the PNMC is via sectoral programs and activities. There has been a recent weakening of this structure,[75] creating a lack of domestic and international confidence in the political will and managerial capacity of the Federal Government.

State governors have tried to fill the coordination void at the federal level through the Coalition of Governors for Climate, operating at the subnational level.[76] Brazil's 26 states and the Federal District (together known as Federation Units or FUs) have secretariats and agencies dedicated to environmental policies and are focal points for conducting plans and policies on climate change. The FUs coordinate through the Brazilian Association of State Environmental Entities (ABEMA),[77] which brings together the secretariats and agencies for environmental policies, and dialogue with the Federal Government.

Implementation progress varies among FUs. Among the 27 FUs, 21 have a policy on climate change, 16 have established a state forum with stakeholder representation, 10 have a climate action plan, and four are preparing their plans.[78] Seven FUs have adaptation plans, five report GHG emission inventories, and five have GHG reduction targets. Many FUs have gaps in technical and managerial capacities, including in mobilizing financing for actions. They also struggle to harmonize with the federal regulatory framework. At the municipal level, there are technical initiatives such as the CB27,[79] which brings together 26 Brazilian state capitals and the federal government to strengthen and coordinate climate action. In the political sphere, the National Mayors Front (FNP)[80] promotes the "Meeting of Municipalities with Sustainable Development" every two years to discuss urban sustainability in Brazil. Even higher-capacity metropolises and regional capitals struggle with promoting climate-oriented planning, regulation, access to financing, and investments. Exceptions include São Paulo and Belo Horizonte, which have promoted intensive land use and densification of strategic areas coupled with land value capture (LVC) instruments.[81] As a result, these cities have increased own-source revenues and used them to support inclusive, compact, and transit-oriented development.

State-owned companies (SOEs) play an important role in the Brazilian economy, delivering essential services such as water, energy, financial services, and transport infrastructure. Legislation covering public and mixed capital companies, and their subsidiaries, obliges them to adopt practices that lead to sustainable environmental development, including in the contracting of works and services. While these do not necessarily link to climate change, the main SOEs already disclose their GHG emissions.

Brazil's judiciary has increased its ambition and performance in issues related to climate change, with the highest courts having structures to implement the climate agenda. In 2019, the National Council of Justice (CNJ) launched the National Observatory on Environmental, Economic and Social Issues of High Complexity and Great Impact and Repercussion. Its objective is to conduct analysis and use evidence for the policy formulation and initiatives that protect the natural environment of the Legal Amazon (an area of over 5 million square kilometers comprising all nine Brazilian states in the Amazon basin). The Panel on Environmental Actions for the Amazon Region monitors lawsuits in the Legal Amazon and has an institutional partnership with the Brazilian Institute of Environment and Renewable Natural Resources

[75] The Government has removed several bodies by decrees or lower normative acts, including the steering and technical-scientific committees that defined the guidelines for use of resources for reducing deforestation and validation of results achieved.

[76] The coalition is a nonpartisan alliance that has increased its political prominence since 2020, including through the participation by governors in international meetings and a close relationship with other governments.

[77] See https://www.abema.org.br.

[78] See https://www.globalcovenantofmayors.org/our-cities/.

[79] See https://forumcb27.com.br.

[80] The FNP brings together all 412 municipalities with a population of more than 80,000 inhabitants, which together represent 61 percent of the population and 70 percent of the Brazilian GDP.

[81] Monteiro, Emanuela et al. 2022. "Urbanization and Climate: Enabling Resilient, Low-Carbon and Productive Cities." Background paper for the Brazil CCDR.

(IBAMA) for technical advice and data sharing on deforestation and illegal exploitation of environmental reserves. In 2021, a national interactive panel of environmental and inter-institutional data (SireneJud), was created, but it still lacks capacity or knowledge of climate litigation at the international level.

Civil society has been increasingly using litigation to promote the goals of the PNMC and the NDC in Brazil. There are several climate-related appeals on the Federal Supreme Court's (STF) agenda for judgment, including ensuring that the Forest Code and resolutions related to environmental licensing and sanctions are not weakened or in conflict with other laws, and resuming implementation of the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm), one of the plans in the PNMC. In July 2022, the STF issued its first judgement in a climate lawsuit requiring the Federal Government to fully reactivate the Climate Fund which was set up as part of the National Climate Policy Plan and has been inoperative since 2019.

The political economy of climate change

As in many countries, subsidies and taxes in Brazil are benefiting specific groups that wield political influence while having a negative economic impact on society. This is evident, for example, in two key sectors for climate action—the power sector and agriculture/land use—where political support for deep decarbonization and resilience-building interventions is limited. In the power sector, the fossil fuel subsidies and tax benefits in Law 14.299 and the gas capacity requirements set out in Law 14.182 create barriers to decarbonization. With regard to gas, mandated demand from the power sector is currently an anchor for the offtake of gas production from the pre-salt reserves, consuming about 30 percent of total domestic gas supply. Thus, a reduction in demand for gas from the power sector would disrupt the current strategy for gas sector development to supply residences in Brazil. Considering the powerful vested interests focused on promoting gas distribution network expansion in Brazil, adjustments to the current law will require extensive stakeholder engagement, robust evidence on the economic benefits of such changes, and mechanisms for compensating affected constituencies. Coal mining, meanwhile, generated roughly 20,000 direct and indirect jobs as of 2018.[82] A robust just-transition strategy for communities affected by the retirement of coal mines and thermal power plants will be imperative for changes in this subsector.

Weak governance and financing challenges constrain implementation and create space for illegal activities that undermine climate action. Governance challenges stem from the overlapping functions of government agencies and inconsistent regulations. An example is in the land sector, in which five different federal entities handle the registration of different land tenure categories. They do not coordinate with the multiple state and municipal agencies that have overlapping mandates and manage separate and disconnected databases.[83] These complexities facilitate illegal land grabbing, a key driver of deforestation. In terms of financing challenges, at the city level, there is a strong imbalance between cities' multiple mandates and their limited revenue capacities. Municipalities/cities have only 18 percent of the total public budget,[84] and their investment capacity is strongly dependent on own-source revenues, such as property taxes and service fees, and direct federal investments.

The weakening of institutions responsible for environmental protection has involved budget cuts, regulatory changes, and interference by special interest groups. Such "capture" results in regulations that are not aligned with the public interest, but instead favor the interests of the regulated industry. For example, currently, some agricultural interest groups (including some cattle ranchers and those affiliated with the livestock industry) have notable influence at both subnational and federal levels. Furthermore, the low risk of serious penalties and the possibility of amnesty for illegal deforestation embolden these

[82] IBGE. 2021. "Anuário Estatístico do Brasil 2020." Rio de Janeiro: Instituto Brasileiro de Geografia e Estatística. https://biblioteca.ibge.gov.br/biblioteca-catalogo?id=720&view=detalhes.

[83] Hanusch, ed. (forthcoming). *A Balancing Act for Brazil's Amazonian States: An Economic Memorandum*. International Development in Focus. Washington, DC: World Bank.

[84] Blanco Junior, C et al., 2018. O desafio do planejamento metropolitano no pacto federativo brasileiro In: *Governança multinível e desenvolvimento regional sustentável: Experiências do Brasil e Alemanha*. 1 ed. São Paulo: Oficina Municipal; Fundação Konrad Adenauer, 2018, v.1, p. 91-110.

and other special interest groups (see Section 4.1). The weakening of monitoring and enforcement (due to budget cuts, freezes in employment, and obstructions to decision making) constrains the feasibility of much-needed reforms related to land titling, and to taxes, subsidies, and credit schemes that now promote extensive agriculture and carbon-intensive practices.

Countervailing the power of such special interest groups is difficult and requires multiple instruments. These include ensuring that autonomous institutions (e.g., the General Accounting Office, the Judiciary) hold public and private entities accountable when they do not comply with the law. It is also important to forge partnerships focused on greater transparency and access to data and information, and to strengthen private sector initiatives (from companies, financial agents, and investors) focused on traceability and preference for sustainable production and purchasing.[85] Making forest protection compatible with economic development requires a recognition of the public-goods nature of natural forests, where the value of ecosystem services considerably exceeds the private exploitation values.

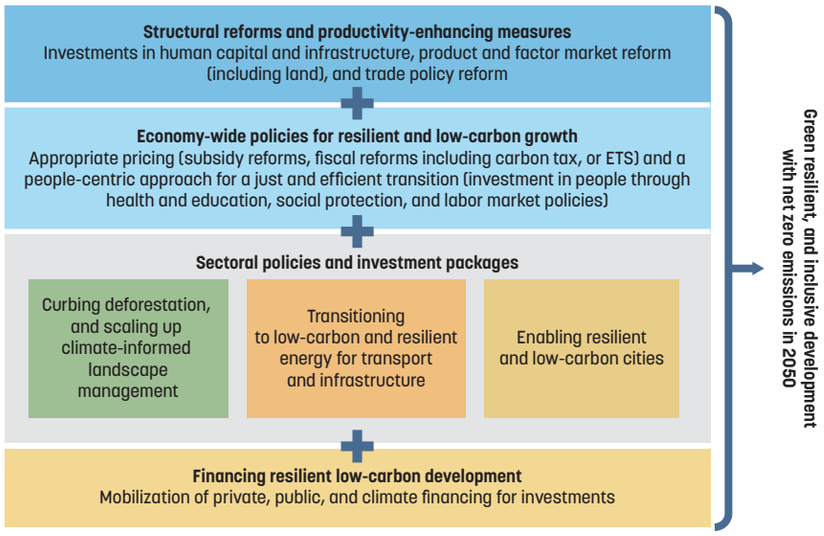
Policy thus needs to be attuned to political economy challenges. For example, performance-based financing can help generate a political economy more conducive to forest protection. The forthcoming World Bank report on the Amazonia and Section 4.1 of this CCDR suggest how climate finance and carbon trading can be leveraged to incentivize governments and individuals to protect forests by linking financing to verifiable reductions in deforestation.

1.5. This CCDR's recommendations and structure

How can Brazil reduce its exposure and vulnerability to climate change risks and capture the opportunities offered by resilient and low-carbon development? This CCDR emphasize actions in four dimensions that reinforce and build on each other: structural reforms and productivity-enhancing measures, economy-wide policies for resilient and low-carbon growth, sectoral policies and investment packages, and action to ensure the required investments can be financed (Figure 5). Structural reforms can boost productivity and efficiency and help Brazil transition to a productivity-led growth path that would reduce pressures on the environment. But not every growth path leads to the same resilience and GHG emissions, and structural change takes time. Hence, structural reforms need to be complemented with economywide interventions to align the incentives of households and the private sector and improve their ability to transition to a cleaner and more resilient development path. Even with these interventions, capturing opportunities at the sectoral level—for instance linked to land use or the power sector—requires dedicated interventions, and the right sectoral regulations, policies, and investments. And these investments can be carried out only if public and private capital can be mobilized and directed toward the most pressing needs.

[85] Hanusch, ed. (forthcoming). *A Balancing Act for Brazil's Amazonian States: An Economic Memorandum*. International Development in Focus. Washington, DC: World Bank.

FIGURE 5. This CCDR's recommendations: a combination of structural reforms, economy-wide climate policies, targeted sectoral measures, and financing



2. Productivity-Enhancing Reforms for Faster, More Resilient and Efficient Growth

Main messages

- By making productivity the main engine of growth, Brazil can achieve stronger and inclusive growth. It can also make its economy more resilient, by preserving natural wealth, preventing possible tipping points in ecosystem services, reducing carbon emissions, and diversifying growth and exports.
- Policies reforms that enhance flexibility and facilitate the reallocation of labor and capital across firms, sectors and regions can reduce adjustment costs created by climate change impacts or policies to reduce emissions.
- Trade policy can help Brazil generate opportunities to participate in global value chains beyond primary commodities, leveraging its latent advantages in green and higher value-added products.

2.1. Inclusive development and higher productivity would enhance climate resilience and reduce GHG emissions

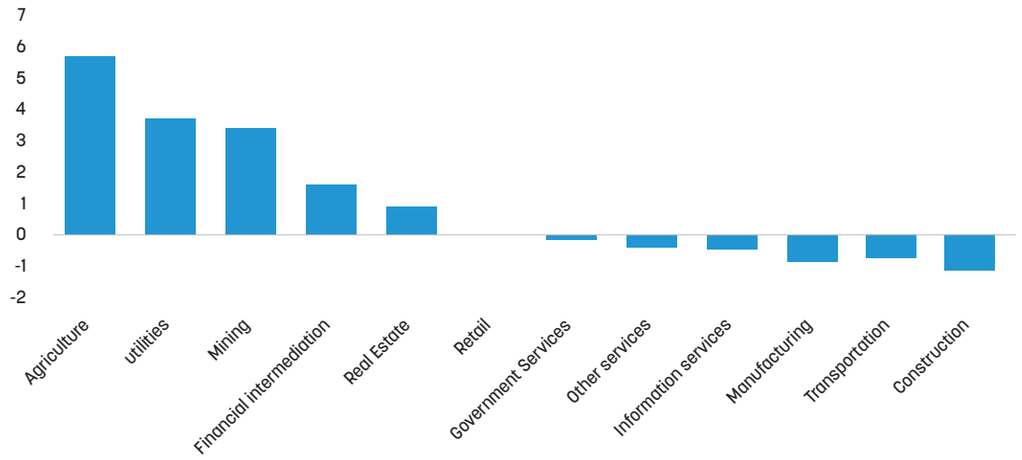
People living in poverty are particularly vulnerable to climate change impacts and other natural hazards. Socioeconomic factors, such as access to infrastructure services, labor productivity, financial inclusion, and coverage by social protection, are among the most important predictors of how severely people will be affected by climate change impacts.[86]

A more efficient and sustainable growth model would make Brazil more resilient. It is crucial to ensure that all new investments and policy changes account for climate risks—a key dimension of adaptation and resilience. Amid growing water scarcity, it is crucial to avoid waste and minimize inefficiency. Similarly, if Brazil does not successfully curb deforestation and land conversion, the Amazon could reach a tipping point, resulting in permanent forest dieback and impacts on precipitation patterns across the country and South America. That would affect agricultural productivity, hydropower, and other economic activities, as well as people's water security. A growth model that combines forest protection and management with greater diversification would reduce those climate risks.

Brazil's productivity performance has been weak and uneven, contributing to lower resilience and high environmental impacts. Commodity sectors (agriculture and mining) have outperformed many other sectors, such as manufacturing (Figure 6). Commodity sectors account for less than 10 percent of GDP, but dominate exports, a reflection of the high productivity and competitiveness of those sectors.

[86] See, for example: IPCC. 2022. "Summary for Policymakers." In *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by H.-O. Pörtner et al. Cambridge, UK, and New York: Cambridge University Press (in press). https://www.ipcc.ch/report/ar6/wg2/; Global Commission on Adaptation. 2019. "Adapt Now: A Global Call for Leadership on Climate Resilience." Rotterdam and Washington, DC: Global Center on Adaptation and World Resources Institute. https://gca.org/global-commission-on-adaptation/report; Hallegatte, S. et al. 2016. *Shock Waves: Managing the Impacts of Climate Change on Poverty. Climate Change and Development*. Climate Change and Development. Washington, DC: World Bank. doi:10.1596/978-1-4648-0673-5_fm.

FIGURE 6. Sectoral labor productivity growth (average growth, 1996–2021)



Data source: World Bank, using data from Brazilian Institute of Economics at the Fundação Getulio Vargas (IBRE)

Different growth paths have different implications for GDP, deforestation, and GHG emissions. Drawing on a computable general equilibrium model, which maps regional economies within Brazil with an attached land use and emissions matrix,[87] Table 1 shows how annual growth in external agricultural demand or productivity[88] in various sectors would affect GDP, deforestation, emissions, and mining (including oil) exports. The table shows, for example, that an acceleration of growth in global food demand would raise Brazilian GDP—relative to the baseline—but come at a significant cost to natural forests and raise emissions. At the same time, mining exports would somewhat be displaced by agricultural exports, because productivity gains outside mining will reduce the relative competitiveness of extractive exports.

TABLE 1. Macroeconomic scenarios (cumulative percentage change compared with baseline after 12 years)

A permanent increase by 0.5 percentage points in annual growth…	**Brazilian GDP** (% change to the baseline)	**Forested land** (millions of hectares)	**GHG emissions** ($MtCO_2e$)	**Mining exports (incl. oil)** (% change to the baseline)
… of external agricultural demand	0.50	–1.0	29.2	–17.38
… of total factor productivity	17.89	3.62	–141.0	–58.52
… In agriculture	0.80	0.8	18.2	–6.22
… In agriculture in Amazônia	0.19	–0.1	15.0	–1.70
… In mining	0.30	0.2	–0.7	29.47
… In services	10.10	–0.1	3.1	–23.75
… In manufacturing	5.00	1.9	–67.8	–26.89

Note: Blue shading indicates values that are positive for the economy and beneficial for natural forests and the climate.

Source: World Bank analysis, based on Ferreira Filho and Hanusch 2022.

[87] See Ferreira-Filho, JBS., and M. Hanusch. 2022. "A Macroeconomic Perspective of Structural Deforestation in Brazil's Legal Amazon." Policy Research Working Paper 10162, Washington, DC: World Bank.

[88] Increasing demand/productivity growth by 6 percentage points over 12 years. 6 percent productivity growth is what agriculture has shown over recent years.

The impact of agricultural productivity growth on emissions depends on economic and institutional factors. Global food demand keeps increasing, and one substantial source of recent demand for beef and soy (as feed for livestock) has come from China's fast-growing meat consumption.[89] A rise in agricultural demand increases demand for land. In the absence of forest law enforcement and effective land governance, that pushes the "arc of deforestation" further into the Amazon (see Section 4). Emissions rise due to both land conversion and agricultural activities themselves.

Increased agricultural productivity leads to higher emissions unless the sector makes a substantial transition to less carbon-intensive agricultural practices and technologies, and forest protection is improved. In spite of improvements, with emissions growing slower than agricultural production, Brazilian agriculture remains emissions-intensive (especially livestock). This explains overall higher emissions when agricultural productivity improves (Table 1). In addition, there are indirect effects, especially in the "arc of deforestation": increases in productivity can indirectly worsen local deforestation, as more competitive farmers take market share from other farmers (the "Jevons effect").[90] Agricultural emissions could be reduced through higher adoption of low-carbon emission agricultural practices and technologies, and/or changes in consumption behavior (e.g., lower beef consumption). Section 4 discusses how to strengthen forest and land governance, which is critical to contain the "Jevons effect".

Productivity gains in manufacturing would reduce Brazil's emissions relative to the baseline, and this can be amplified when the energy supply becomes even greener. Higher manufacturing productivity reduces the relative competitiveness of more resource-intensive sectors—in this case, mining and agriculture—and accelerates the transition toward sectors with lower GHG emissions. Oil exports would fall, and so would deforestation (Table 1). Partly due to Brazil's green energy matrix, emissions from higher manufacturing output would remain limited and be more than offset by reduced emissions from agriculture and a lower rate of deforestation.

2.2. Reforms to trade policy can help capture opportunities in green value chains

Brazil's high trade barriers are hampering further productivity growth and expansion of its manufacturing sector. The average import tariff in Brazil was 13.6 percent in 2020[91]—little changed over the past two decades. Meanwhile, the average tariff in Mexico declined from 18 to 6.7 percent, and in China from 12.4 to 7.4 percent. Compared with other countries, Brazil levies relatively high taxes on imports of intermediate goods for industrial use and capital goods. This undermines the ability of Brazilian companies to compete on the global market and to integrate into global value chains. For example, the average tariff on processed industrial inputs is 12.1 percent in Brazil, compared with 6.8 percent in China and 4.5 percent in Turkey. In order to seize opportunities in the low-carbon transition, it is important for Brazil to reform its trade policies to enable its manufacturing sector to expand production for export.

Brazil also has high tariffs and numerous non-tariff measures on environmental goods.[92] Imports of environmental goods are a key mechanism for accessing new technologies that can drive carbon competitiveness throughout industry, whether it be equipment and parts related to renewable energy, machinery for managing waste, or instruments for measuring emissions. Brazil also imposes a relatively high number of non-tariff measures (NTMs) compared with other countries in the region. A total of 2,501 non-tariff measures are imposed on environmental goods entering Brazil.[93] The renewable energy plant (REP) category faces the largest number, with 817 NTMs.

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[89] Rising agricultural demand also emanates from within Brazil. Public health policies could be implemented to encourage a shift towards healthier and more plant-based diets, which would improve the population's health and have co-benefits in terms of emissions reductions.

[90] Hertel, Thomas. 2012. "Implications of Agricultural Productivity for Global Cropland Use and GHG Emissions: Borlaug vs. Jevons." GTAP Working Paper No. 69.

[91] World Development Indicators.

[92] Environmental goods are defined using the Asia-Pacific Economic Cooperation list: https://www.apec.org/meeting-papers/leaders-declarations/2012/2012_aelm/2012_aelm_annexc. It describes the environmental features of the agreed products, such as renewable energy production; control and removal of pollutants from the air; destruction of solid and hazardous waste; air and water purification; renewable and environmentally friendly products; and measurement activities to conduct research and development (R&D) for environmental protection.

[93] Pranidhi Sawney, Euijin Jung, Andre Jean Curtis, Maria Filipa Seara e Pereira, Jose E. Signoret, Maryla Maliszewska, Vicky Chemutai and Paul Brenton. 2022. Brazil Trade and Climate Change Diagnostic. A Background Paper to the Brazil CCDR.

Facilitating trade reforms in both environmental goods and services is critical to propel green production and trade, and subsequent growth. Trade reform can support decarbonization by helping to rebalance Brazil's growth model beyond commodities. Effective safeguards are needed to further reduce negative impacts of trade on Brazil's ecosystems. Brazil also needs to improve quality standards and lower the costs of certification to facilitate exports of sustainable goods to advanced markets such as the European Union (EU). In addition, it is important to liberalize environmental services, which are critical for the proper functioning and use of environmental goods.

2.3. Green value chains create major opportunities for growth in Brazil

Brazil has considerable potential in producing green goods and services, for which demand is expected to grow with decarbonization trends. According to the IEA's net-zero roadmap, annual capacity additions in solar photovoltaics (PV) are projected to increase almost fivefold over the next decade, while wind annual capacity additions are expected to triple.[94] Electric vehicles are set to see even larger scale-ups, increasing 18-fold from around 3 million car sales annually in 2020 to 56 million in 2030.[95] These growing global markets will generate major economic opportunities, especially if Brazil benefits from global measures that reward green production in global value chains. In some of the products required for decarbonization, Brazil has potential competitive advantages: because it already has a large market share in products that require similar skills and expertise, Brazil is likely able to produce them at a competitive cost and to capture a larger market share.[96] This includes products related to the wind turbine value chain, including alternating current (AC) generators, liquid dielectric transformers, and parts for electric motors and generators.

Brazil also is currently competitive in several critical materials used in EV batteries and electric and hydrogen-fueled buses. While the graphite market is largely dominated by China, Brazil has the third-largest graphite reserves in the world[97] and is the second-largest producer of natural flake graphite.[98] Brazil is also competitive in calcined petroleum coke, the anode material in lithium batteries. Brazil is increasingly competitive in electric buses and developing its competitiveness will position Brazil well in that growing global market.[99] For EVs, however, other competitive countries are aggressively driving down costs, and Brazil may be better off reducing tariffs and importing cheaper EVs from offshore.

Climate-smart mining practices will be crucial to a sustainable expansion of Brazil's green minerals sector. Brazil is the world's largest producer of niobium, the second largest producer of iron ore and manganese, and among the largest producers of bauxite and tin. Minerals, such as manganese and rare earths, are crucial for technologies that support global decarbonization, and demand for them is projected to increase in the coming decades.[100] Brazil's rich endowments of key minerals place it in an enviable position. However, growing demand for manganese, much of which has occurred in the state of Pará, has resulted in illegal mining, including on Indigenous territories in the state.[101] Evidence shows that mining activities have caused significant deforestation, both within and outside mining lease boundaries.[102] Climate-smart mining practices can reduce the footprint of mining activities. These practices include using renewable energy to power mining machinery and transportation, encouraging innovation to drive resource

[94] IEA, 2021, "Net Zero by 2050: A Roadmap for the Global Energy Sector."

[95] See https://www.iea.org/reports/net-zero-by-2050.

[96] Mealey, Penelope. 2022. "Capturing benefits of the green transition: Green competitiveness and jobs in Brazil." Background paper for CCDR.

[97] USGS. 2020. "Graphite." In Mineral Commodity Summaries 2020, 72–73. Reston, VA: U.S. Geological Survey. http://dx.doi.org/10.3133/mcs2020.

[98] INN. 2021. "Graphite Mining in Brazil: A Key Component in the Future of Energy Storage." Investing News Network. June 23, 2021. https://investingnews.com/innspired/graphite-mining-in-brazil/.

[99] Currently the supply of electric buses is constrained by the import of electrical components. Brazilian players are mostly focused on adapting the body of the vehicle to electric engines to assemble electric buses for pilot EV projects in Brazilian cities.

[100] Hund, K. et al. 2020. "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition." Climate-Smart Mining Facility report. Washington, DC: World Bank Group. https://www.worldbank.org/en/news/press-release/2020/05/11/mineral-production-to-soar-as-demand-for-clean-energy-increases.

[101] Gomes, Danielly. 2022. Manganese Is Exploited and Transported Illegally in Pará (Podcast Portuguese). https://pulitzercenter.org/id/node/22415.

[102] Sonter, L. J., Herrera, D., Barrett, D. J., Galford, G. L., Moran, C. J., & Soares-Filho, B. S. (2017). "Mining drives extensive deforestation in the Brazilian Amazon." *Nature Communications*, 8(1), 1–7.

and energy efficiency, adopting forest-smart mining practices to avoid and minimize negative impacts to forested areas, and robustly managing geological data and environmental impacts.[103] Recent work on climate-smart mining has also underscored the importance of managing social disruption created by new mining operations.[104]

Brazil has healthy prospects to produce, consume, and/or export green hydrogen, which can help accelerate the energy transition while diversifying exports and attracting investment. Given Brazil's ample supply of wind and solar energy, infrastructure, and proximity to regional markets, it could become an important producer of green hydrogen and its derivatives (ammonia and methanol). This is a major economic opportunity, as green hydrogen is considered crucial for decarbonizing industry and other energy uses that are difficult to electrify.[105] Building a competitive hydrogen economy requires the concurrent development of hydrogen supply, transportation infrastructure, and demand in a way that ensures low/net-zero lifecycle GHG emissions and minimizes material (mineral, water), land, environmental, and social impacts. Brazil could use green hydrogen to decarbonize industry (petroleum refining, petrochemicals, chemicals, steel, etc.) and transport (especially long-haul freight and heavy-duty mining trucks), and to contribute to the flexibility of the power system.

[103] Hund et al., 2020, "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition."

[104] Ibid.

[105] IEA. 2021. "Net Zero by 2050: A Roadmap for the Global Energy Sector." Paris: International Energy Agency. https://www.iea.org/reports/net-zero-by-2050.

3. Economy-wide Policies for Resilient and Low-carbon Growth

Main messages

- A set of economy-wide interventions is needed to provide the right incentives to households and the private sector, and to enable them to act on climate-related opportunities.
- Options include an emissions trading system (ETS) or broad tax reform that would price carbon emissions (with revenues possibly recycled through reductions in other taxes). Verified and high-quality forest offsets could bring sustainable land use into a broader carbon-pricing architecture.
- A people-centric approach is key, as the poor are disproportionately hurt by climate change and can also be harmed by poorly designed climate policies. Strengthened governance and appropriate education, training, and labor market policies can support Brazil's economic transition.

3.1. Carbon pricing could accelerate decarbonization and leverage global carbon markets

Brazil has established the foundations for an ETS

In May 2022, the issuance of an executive decree (No. 11.075) established the foundation for carbon markets in Brazil, and a bill to regulate a national emissions trading system (ETS) is before the National Congress.[106, 107] Analyses and extensive public consultations done under the Partnership for Market Readiness (PMR) Brazil Project determined that in Brazil, an ETS tends to draw more political support than a carbon tax.[108]

A required step towards the setting-up of an ETS is the implementation of a national mandatory GHG measurement, reporting, and verification (MRV) system for large emitters. Such a system is crucial for the implementation of an ETS, as it provides the data input for the operation of the ETS, allowing for the definition of emissions limits, enforcement of obligations, etc. The development of such systems is complex. In Brazil, however, a mandatory MRV for energy and large emitters in industry could be built on an existing voluntary initiative administered by the Ministry of Science, Technology, and Innovation (MCTI) that aims to structure a national corporate GHG MRV system.[109]

In the Brazilian context, the industrial sector is the best candidate for inclusion in an ETS. Drawing on international experience, early implementation would be relatively straightforward for the big industrial emitters. The energy sector is another contender. However, existing structural characteristics and policy instruments would make immediate implementation complex for the entire energy sector. Similarly,

[106] The Bill of Law (PL 528/2021, later attached to PL 2.148/2015) has yet to receive a vote. The decree is an important initial step towards establishing a carbon market and calls for relevant ministries to establish sectoral emissions reduction targets, while also providing for the creation of a centralized registry for corporate GHG emissions, GHG mitigation projects and resulting carbon credits. However, the decree does not imply any mandatory participation.

[107] See http://www.planalto.gov.br/ccivil_03/_ato2019-2022/2022/decreto/D11075.htm.

[108] The Partnership for Market Readiness Brazil Project, led jointly by the Ministry of Economy and the World Bank, analyzed alternative suites of climate policy instruments to identify which policy package would generate the best socioeconomic impacts while allowing for NDC compliance. The project was able to deliver a robust set of analytical results and recommendations by analyzing and tailoring the best international experience to the economic, institutional, regulatory and technological realities of the main Brazilian emitting sectors: agriculture (cattle ranching), energy (power generation and fuels), industry, and land use, land use change, and forestry (LULUCF). To learn more, see https://www.thepmr.org/country/brazil-0.

[109] https://www.gov.br/mcti/pt-br/acompanhe-o-mcti/sirene/central-de-conteudo/noti/mcti-prepara-modulo-para-relatar-emissoes-de-gases-de-efeito-estufa-do-setor-privado.

agriculture, forestry, and other land use sectors (AFOLU) are currently not good contenders for direct inclusion in an ETS, because of the technical challenges of regulating emissions from enteric fermentation and the illegal nature of deforestation. However, with appropriate methodologies to ensure their quality and integrity, verified forest-based offsets could be included and provide opportunities for low-cost emission reductions, while creating additional revenue to support reforestation and forest restoration.

Box 1. Carbon credits: International trading in the context of the Paris Agreement

Brazil has substantial experience with international carbon markets, mainly through a long involvement with the Clean Development Mechanism (CDM) established under the Kyoto Protocol. Brazil was the fourth-largest global seller of Certified Emission Reductions (CERs) and the third-largest host country for registered CDM project activities.[110] Brazil is also a main player in voluntary carbon markets, hosting the third-largest number of emissions reduction and removal projects.[111]

Article 6 of the Paris Agreement, which creates the overarching framework for international carbon trading, could play a crucial role in finance and investment flows in the coming decades. A 2021 study estimated that the market created by Article 6 mechanisms could reach up to US$300 billion in 2030 and $1 trillion in 2050, considering climate neutrality targets.[112] Voluntary carbon markets are also expected to experience significant growth in the coming decades, constituting yet another source of demand for carbon credits globally.[113, 114]

Given its history in carbon credit project development and carbon trading, Brazil is commonly placed among the countries with the highest selling potential in international carbon markets.[115] It has substantial potential for generating carbon credits from nature-based solutions (NBS) linked to the country's extensive forests (REDD+ and afforestation and reforestation), as well as other emission mitigation sources, such as bioenergy and various forms of renewable energy. If Brazil can leverage this potential, its natural competitive advantages would then materialize, attracting significant flows of foreign capital and boosting the country's development.

As part of a broad fiscal reform, a carbon tax could help reduce GHGs and boost efficiency

There is significant room to improve Brazil's tax system, simultaneously making it more productivity-enhancing and greener. The Brazilian tax system is overly complicated, with a multitude of federal and subnational taxes levied under different rationales.[116] Proposals for tax reforms in Brazil

[110] https://cdm.unfccc.int/Projects/projsearch.html (accessed in September 2022).

[111] Climate Focus Voluntary Carbon Market Dashboard (accessed in September 2022).

[112] Yu, S. et al. 2021. "The Potential Role of Article 6 Compatible Carbon Markets in Reaching Net-Zero." Working Paper. The International Emissions Trading Association and University of Maryland. https://www.ieta.org/The-Potential-Role-of-Article-6-Compatible-Carbon-Markets-in-Reaching-Net-Zero.

[113] TSVCM. 2021. "Taskforce on Scaling Voluntary Carbon Markets: Final Report." Institute of International Finance. https://www.iif.com/Portals/1/Files/TSVCM_Report.pdf.

[114] https://www.mckinsey.com/business-functions/sustainability/our-insights/a-blueprint-for-scaling-voluntary-carbon-markets-to-meet-the-climate-challenge.

[115] IETA. (2019). "The Economic Potential of Article 6 of the Paris Agreement and Implementation Challenges." Washington, D.C.: University of Maryland and CPLC.

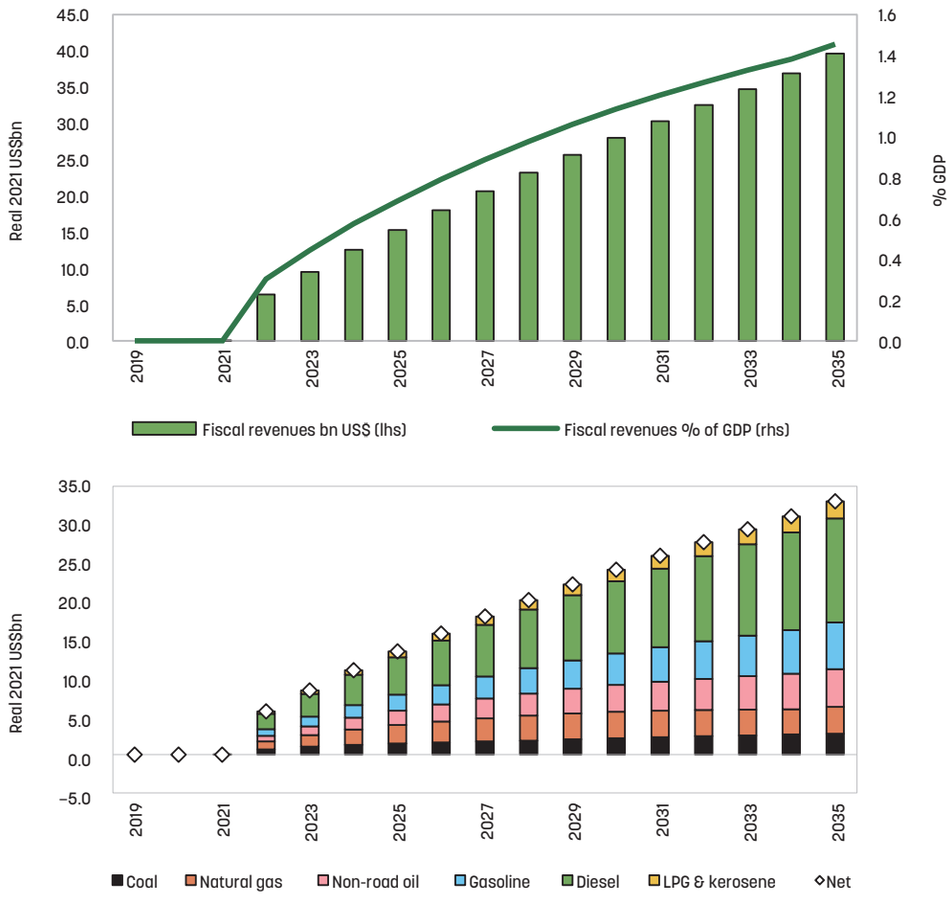
[116] World Bank Group. 2019. "Doing Business 2020: Comparing Business Regulation in 190 Economies – Economy Profile of Brazil." Washington, DC. https://www.doingbusiness.org/content/dam/doingBusiness/country/b/brazil/BRA.pdf.

have been debated for several years. Within the field of proposed changes, there could be an opportunity to pursue the implementation of a carbon tax, as well as to revise and eventually phase out subsidies to emission-intensive activities.

Carbon charges could incentivize low-carbon development and finance revenue-neutral tax shifts, which would enable Brazil to streamline and simplify its tax system without adding to the pressure on its public finances. To enable such a policy of revenue-neutral net stimulus, a carbon charge should be combined with a reduction in the taxes that most hinder economic and employment growth in Brazil, as well as in those that are least equitable. In the international literature on environmental tax reforms, the best-performing tax shift has often been found to be to reduce taxes on the wages of low-income workers.[117]

A relatively modest carbon tax with large coverage could be a substantial source of revenues for Brazil in the coming decade. To illustrate the potential of a carbon tax to simplify and streamline Brazil's tax system, an analysis was conducted for this CCDR of the impact of the introduction of an economy-wide upstream carbon charge on fossil fuels. The model started with a rate of R$75 (~US$14) per tCO_2 at the beginning of 2022, rising to R$350 (~US$67) in real terms by 2030. As shown in Figure 7, such a carbon tax would raise about R$140 billion (US$28 billion, or 1.2 percent of GDP) in additional revenues in 2030 from fossil fuels compared with maintaining the existing excise regime.

FIGURE 7. Increased public revenues from carbon tax



Source: World Bank analysis done for CCDR

[117] Heine, D., and S. Black. 2018. "Benefits beyond Climate: Environmental Tax Reform." In *Fiscal Policies for Development and Climate Action*, 1–63. International Development in Focus. The World Bank. doi:10.1596/978-1-4648-1358-0_ch1.

At the same time, a climate-informed tax reform could reduce implicit subsidies to carbon-intensive activities. These tend to be applied in the energy sector, granting direct subsidies or tax waivers to fossil-fuel related activities (upstream, midstream, and downstream). Schemes such as REPETRO, REIDI/REPENEC, and REPEX are the main programs that generate tax waivers for the fossil fuel industry. Subsidies for fossil fuels also include tax waivers for fossil-fuel imports, equipment, and investments, as well as subsidies for coal-fired power generation, which alone totaled almost R$1 billion (US$200 million) in 2020.[118, 119] Congress recently extended tax waivers and subsidies for coal up to 2040.[120] In the context of a tax reform that includes a carbon tax, the aim should be to phase out the tax waivers and subsidies promoted by REIDI/REPENEC, REPEX, and CDE-coal, decommissioning coal-fired power plants no later than 2040, unless they feature carbon capture technologies to neutralize emissions.

3.2. A people-centric approach to make climate action fairer and more efficient

Policies and interventions need to be designed with consideration for their efficiency and aggregate impacts, but also their distributional implications. Even shocks with a limited impact, such as short-term reductions in agricultural yields, can seriously affect individual regions, communities, or workers. The same is true of the green transition: even if it produces net job gains, it will still destroy jobs linked to coal and other high carbon-intensity activities. Irrespective of the magnitude of aggregate effects, both climate change impacts and climate policies can have very disparate impacts and affect people and communities through very different channels. Anticipating these impacts, avoiding or mitigating them to the extent possible, and assisting the people who are affected is critical to ensure a fair and sustainable transition.

Climate change is likely to increase poverty, at least in the near term

Climate change is likely to affect human capital and have persistent effects on welfare and productivity that can be transmitted across generations. The latest World Bank poverty and equity assessment for Brazil finds that about 19 percent of the population lives in municipalities considered to be at high environmental risk; about 8 percent in municipalities with high socioeconomic vulnerability; and 2 percent in municipalities with both types of risks.[121] The poor are less equipped to cope with the consequences of climate change, since they have relatively low levels of asset accumulation and lower savings, and they are also likelier to live in flood-prone areas and to depend on agriculture.

There is evidence that there is a relationship between formal employment and climate change.[122] After short wet periods, formal employment tends to shrink temporarily, then recover in subsequent quarters. In contrast, short dry periods lead to decreases in employment up to 12 months later. Longer periods of drier or wetter weather (six months or longer) show a smaller response. This may be because prolonged weather anomalies give agricultural and related industries time to adjust their employment needs. While these employment effects are relatively small, they probably underestimate the full impact, as they focus on formal employment, while a stronger response is likely for informal employment.

[118] REPETRO, REIDI/REPENEC, and REPEX are the main programs that generate tax waivers for the fossil fuel industry, acting on imports and exports of equipment and machinery, on the development of oil and gas infrastructure, including refineries, and even on the imports of crude oil and derivatives.

[119] INESC, 2021: "Subsídios aos combustíveis fósseis no Brasil: conhecer, avaliar, reformar". Brasília.

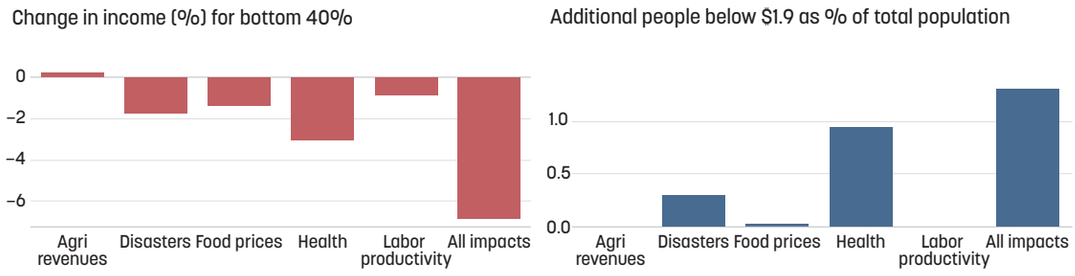
[120] Extension of coal subsidies falls under Law 14.299/2022 (https://www2.camara.leg.br/legin/fed/lei/2022/lei-14299-5-janeiro-2022-792216-publicacaooriginal-164327-pl.html); expansion and extension of tax benefits falls under the REPETRO program (MP 795/2017 - https://www.congressonacional.leg.br/materias/medidas-provisorias/-/mpv/130444).

[121] World Bank. 2022. "Brazil Poverty and Equity Assessment: Looking Ahead of Two Crises." Washington, DC. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099230007062256153/P1746910e33a8407d0b0850b8f0f5bcf18c.

[122] Patterson, D. et al. 2022. "Geospatial ESG: The Emerging Application of Geospatial Data for Gaining 'environmental' Insights on the Asset, Corporate and Sovereign Level." WWF, World Bank Group and Global Canopy. https://www.wwf.org.uk/sites/default/files/2022-01/Geospatial_ESG_Report.pdf.

The future impacts of climate change on poverty in Brazil are highly uncertain, but they could be significant, even over the short term. They depend on future climate shocks and natural variability of the climate system, socioeconomic conditions, and the effectiveness of adaptation measures taken by individuals, communities, and governments. Analysis shows that if socioeconomic conditions stagnate, climate shocks could increase the extreme poverty rate by 0.6–1.3 percentage points as early as 2030.[123] In a more optimistic development pathway, with more inclusive growth, structural change, and improved access to infrastructure services, the impact could be reduced, ranging from 0.4 to 1.0 percentage points. Figure 8 provides estimates for the impact of climate change on poverty and the income of the bottom 40 percent, in the most pessimistic scenario. Agricultural revenues are barely affected by 2030, as the effect of average climate change on yields and food prices (including through global food markets) cancel out. The impact through food price, however, affects real incomes, especially for people in the bottom 40 percent. Health, which include increases in the prevalence of vector- and water-borne disease, and damages from natural disasters (essentially floods and droughts) are the two main channels through which climate change could increase poverty over the very short term. These results highlight the importance of access to health services to mitigate climate change impacts, as well as the importance of proactive risk management (see Section 4.3).

FIGURE 8. Effects of different climate change impacts on household incomes (bottom 40%) and extreme poverty rate by 2030, in a high-impact scenario



Source: Results for Brazil, based on Jafino et al. 2020.[124]

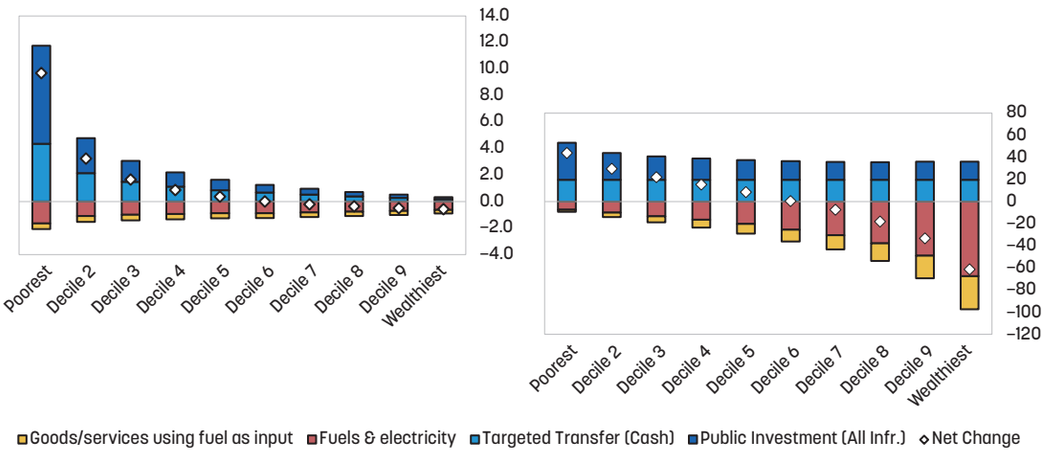
Climate policies can be designed to contribute to poverty reduction

Complementary interventions can mitigate negative socioeconomic effects of climate policies, particularly on lower-income people. For instance, carbon pricing could have detrimental impacts on equity, unless a share of the revenues is used to protect the bottom of the population most affected by price shocks. As an illustration, Figure 9 shows the results of modeling the effect of using about half the revenues collected by a carbon tax to fund a universal (untargeted) per capita cash transfer. Even such a simple approach would make the policy both pro-poor and pro-equity; it would also benefit rural households more than urban ones, because rural Brazilians tend to be poorer and consume less fossil fuels. Of course, implementing such recycling is not simple or costless, and a range of revenue recycling options could be considered. For example, net impacts for equity would be more progressive if, instead of an equal lump-sum transfer, the revenues from the carbon charge were used to boost or extend a means-tested social protection scheme.

[123] The analysis drew on prior work by the World Bank. See Jafino et al., 2020, "Revised Estimates of the Impact of Climate Change on Extreme Poverty by 2030." The analysis starts from the most recent household surveys to represent the demographic mix and socioeconomic structure. Baseline scenarios for possible evolutions of the population to 2030 were developed, considering demographic changes and economic growth, with a stable climate. Then, five types of climate change impacts were modeled: impacts of changing conditions on farmers' incomes (based on global climate and agro-economic models); impacts on household income of floods, droughts, and storms; impacts of changes in food prices on real income (assuming fixed food consumption in real terms); health-related impacts on income and health expenditures (water-borne diseases); and the labor productivity impact of higher temperature. Each reduces households' real income in different ways, depending on their sources of income, the share they spend on food, and their access to social protection and to infrastructure services.

[124] Ibid.

FIGURE 9. Cash transfers make the policy pro-poor and pro-equity: relative (left) and absolute (right) loss in consumption by direct and indirect price increases on income deciles in 2022



Source: Simulations performed by World Bank with the Carbon Pricing Assessment Tool (CPAT), a tool co-developed by the World Bank and the International Monetary Fund

Investments in human capital, enhanced social protection, and active labor policies can boost resilience and ensure a just transition

Successful strategies to help workers and communities transition can take many forms, but should go beyond simple financial compensation. For example, structural policies may be geared towards increasing resilience to shocks (e.g., improving access to financial instruments and borrowing), facilitating greater labor market flexibility and mobility, and creating new job opportunities by incentivizing economic innovation and diversification. More targeted policies, meanwhile, could be aimed at affected workers, such as early retirement packages or financial and re-employment support. They might be deployed alongside broader community- or regional-level initiatives, such as skills training and investments in human capital, local economic development programs, and environmental regeneration. What is critical for managing longer-term impacts is to go beyond simple compensation mechanisms and invest in human and economic development interventions, including investments in and measures to improve infrastructure; policies and regulations to attract new businesses, education and skills programs; support for research and development; and expansion of soft location factors (e.g., tertiary education institutions, culture and leisure, natural infrastructure) to attract inward—and prevent outward—migration of people, business, and investment.[125]

Labor transitions

Some workers who lose their jobs in high-emitting extractive sectors may be able to shift to greener jobs, but they will require support to manage skill, location, and wage mismatches.[126] Some green jobs may require similar skills as fossil fuel-related jobs. However, many "brown" sector workers (especially those in oil and gas extraction) are likely to require policy support to help them overcome barriers relating to differences in skill, wages, and geography. An important challenge is that wages in the oil and gas industry tend to be higher than alternative employment options for people with similar skills. While workers in extraction in the mineral coal industry could readily transition to other mineral sectors, differences in the spatial distribution of mining resources mean that they will need to relocate to access those jobs. Support

[125] Diluiso, F. et al. 2021. "Coal Transitions—Part 1: A Systematic Map and Review of Case Study Learnings from Regional, National, and Local Coal Phase-out Experiences." *Environmental Research Letters* 16 (11): 113003. doi:10.1088/1748-9326/ac1b58.

[126] Mealy P., 2022. "Capturing benefits of the green transition: Green competitiveness and jobs in Brazil." Background paper for the Brazil CCDR.

is also needed to ensure that places with high concentrations of brown jobs do not lose their economic viability, sense of community, and identity, and can develop alternative activities and livelihoods. Regional development strategies can help mitigate such impacts.

Sectors that are neither green nor brown could provide more feasible transition possibilities for displaced brown sector workers. For example, for oil and gas workers, employment in pipeline and maritime transportation could provide better-paid opportunities with minimal retraining requirements. While these sectors may not expand in response to global decarbonization, they provide more closely matched employment opportunities, in terms of wages, skills, and geography, for displaced brown-sector workers, pointing to the importance of considering all channels of labor redeployment.

Active labor market policies and unemployment protection

The transition away from "brown jobs" can lead to long-term impacts on certain groups of workers. Active labor market programs (ALMPs) and unemployment insurance can be important to mitigate the adverse impact on the poor and vulnerable.[127] They can help increase employability of those displaced by the green transition by adapting their skillset to "green jobs"[128] and closing their gap in skills. Brazil already has a number of skills training providers with institutional knowledge and capacity that could be leveraged to help workers through labor market transitions. When designed with features based on local demand and needs, training programs in Brazil have a positive impact on employment rates. The Government is seeking to increase the supply of green courses within the Sistema S, a national training provider funded by private sector contributions that offers free professional training in key areas of industry and commerce. The success of ALMPs varies by target group, program design, and how they are implemented. Women and the long-term unemployed often show greater benefits, but ALMPs are often less effective for youth and for older participants.[129] Retraining programs should be targeted to those who can benefit the most, such as women and people from minority groups, industry-switchers, laid-off manufacturing workers, or those with high tenure.[130]

To ensure quality training for workers affected by the green transition, spending needs to be increased to ensure the continuity of ALMP programs and positive outcomes. Since the 2014 crisis, budget cuts have defunded or discontinued most of the existing ALMP programs in Brazil. Instead of introducing new professional skills providers, the Government should leverage existing programs that already have the institutional knowledge and capacity to help build skills for the green transition. That said, training activities are not all that is needed to smooth the green transition for workers. It is also critical to invest in labor market information systems and employment services. To support workers during transitions, it will also be important to coordinate the existing unemployment insurance program with ALMPs, to ensure that workers have income support as well as training and labor intermediation support.[131]

Social protection and education

Adequate social protection policies can help Brazil's most vulnerable populations adapt to climate change, withstand shocks, and transition more smoothly to a low-carbon economy. An adaptive social protection (ASP) system combines different sectoral approaches, including social protection, disaster risk management (DRM), and climate change adaptation, to build the resilience of vulnerable people. The goal is to enhance their capacity to prepare for, cope with, and adapt to changes and shocks that may affect large swaths of the population.[132]

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[127] Rigolini, J. 2021. "Social Protection and Labor: A Key Enabler for Climate Change Adaptation and Mitigation." Social Protection and Jobs Discussion Paper No. 2108. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/36669.

[128] ILO. 2017. "Active Labour Market Policies." Green Initiative Policy Brief. Geneva: International Labour Organization. http://www.ilo.org/global/topics/green-jobs/publications/WCMS_614301/lang--en/index.htm.

[129] Card, D., J. Kluve, and A. Weber. 2018. "What Works? A Meta Analysis of Recent Active Labor Market Program Evaluations." *Journal of the European Economic Association* 16 (3): 894–931. doi:10.1093/jeea/jvx028.

[130] Cavaco, S., D. Fougère, and J. Pouget. 2013. "Estimating the Effect of a Retraining Program on the Re-Employment Rate of Displaced Workers." *Empirical Economics* 44 (1): 261–87. doi:10.1007/s00181-010-0391-6.

[131] See, for example, Morgandi, M. et al. 2020. "Enhancing Coverage and Cost-Effectiveness of Brazil's Unemployment Protection System: Insights from International Experience." Washington, DC: World Bank. http://hdl.handle.net/10986/35168.
The report lays out a set of recommendations on how to enhance the unemployment insurance system, including adapting the access conditions, benefit generosity and co-responsibilities to best practices, and implementing some complementary policies to extend protection to the excluded unemployed, such as savings instruments.

[132] Bowen, T. et al. 2020. *Adaptive Social Protection: Building Resilience to Shocks*. Washington, DC: World Bank. http://hdl.handle.net/10986/33785.

Brazil has a mature social protection system and high levels of coverage by social assistance, but there is room for improvement to create a true ASP system. Based on the SP Stress Test launched by the Bank in 2021,[133] the overall average score of Brazil shows that the country enjoys an "established" social protection system in terms of readiness and scalability to respond to the most recurrent and disruptive climate-induced natural disasters. The country has clear linkages between DRM and social protection, well-established early warning systems, and a social registry with high coverage. Given that low-income households are overrepresented in areas exposed to climate hazards, however, there is room to expand resources for social protection shock response and to further modernize the social registry with climate change vulnerability information.

Social protection can support the mitigation of climate change through programs focused on reducing deforestation or restoration of ecosystems. Social protection can support anti-deforestation efforts through payments for environmental services (PES) or through public works programs. PES programs such as the discontinued national Bolsa Verde program or the ongoing Bolsa Floresta program in the state of Amazonas can serve as important social protection interventions for forest communities.

Education also has the potential to play a critical role in responding to the climate crisis. The education sector can play a key role by shifting behaviors and social norms to favor more resilient or less wasteful behaviors.[134] This requires strengthening curricula and teacher training to include environmental knowledge and considerations, as well as basic information on hazards, risks, and behaviors. The education system also needs to take into account climate change adaptation and low-carbon development, which will require a workforce with strong foundational skills and expanded advanced skills.

[133] World Bank. 2021. "Stress Testing Social Protection: A Rapid Appraisal of the Adaptability of Social Protection Systems and Their Readiness to Scale-Up." A Guide for Practitioners, Version 1. Washington, DC: World Bank. https://blogs.worldbank.org/voices/preparing-today-tomorrow-stress-testing-social-protection-systems.
The test provides a rapid appraisal of the adaptive capacity of a social protection system in response to a shock. It examines policies, coordination arrangements, delivery systems and instruments, pre- and post-emergency.

[134] Emerging initiatives in municipalities such as São Paulo could be replicated.

4. Three Key Sectoral Policies and Investments to Align Development and Climate Action

Main Messages

- Relatively low-cost monitoring and enforcement measures to stop illegal deforestation (per the 2012 Forest Code) and boost land-based and forest carbon removals can significantly reduce emissions. Complementary efforts to promote climate-smart agriculture, boost crop and livestock productivity, and foster diversified and inclusive growth in rural areas through forest-based economic activities will also be necessary.

- Brazil is well positioned to create a resilient and zero-carbon power system that can support decarbonization of harder-to-abate sectors through electrification and a switch to zero-carbon fuels such as green hydrogen. In the transport sector, investments and regulations to boost energy efficiency and electrification, and to reduce car use by improving public transit, are key.

- Economic gains can be generated by increasing the resilience of new assets and investments, especially in infrastructure. Politically difficult reforms of subsidies, taxes, and policies in the agriculture/land and energy sectors are critical to avoid Brazil losing its head start in decarbonizing its economy.

To achieve its climate objectives and net zero emissions by 2050, Brazil cannot rely exclusively on structural change and economy-wide measures—it will also need targeted sector-level interventions. While Brazil stands to benefit from a resilient and low-carbon transition, several obstacles stand in the way. They include sectoral policies that skew incentives (e.g., in land, agriculture, and energy), the lack of important regulations (e.g., related to e-mobility), and the fact that some actions generate public goods, but not direct returns for those making the investments.

This section dives deeper into three areas in which interventions could have particularly large benefits in terms of GHG emissions, climate risk exposure, and inclusive growth. The first is curbing deforestation and scaling up climate-informed landscape management (Section 4.1). The second is transitioning to greener and resilient energy, infrastructure, and transport for industries and manufacturing (Section 4.2). The third is to enable resilient and low-carbon cities (Section 4.3). To create a common anchor for these three deep dives, the CCDR analysis includes an illustrative path to net zero emissions by 2050 (Figure 10). This is not the only path consistent with Brazil's long-term mitigation target, but it highlights the potential roles of different sectors and is used to discuss feasibility, challenges, costs, benefits, and policy options.

The illustrative pathway toward more resilient low-carbon development explored in the CCDR aims to achieve net-zero emission by 2050 through the combination of a few key changes:

» **Carbon removal from the atmosphere through various forms of land use change:** from plantations and integrated land management systems, no-till farming, degraded pasture recovery, protected areas and Indigenous lands, native forest restoration, and secondary forests.

» **Net-zero deforestation:** consistent with Brazil's pledge to achieve zero illegal deforestation by 2028 and net-zero deforestation by 2050. Legal deforestation is assumed to remain constant[135] and the designation of protected areas is assumed to increase until 2030, then remain constant. Between 2030 and 2050, the reduction in emissions from land use and forests follows the estimate for cost-effective mitigation potential.

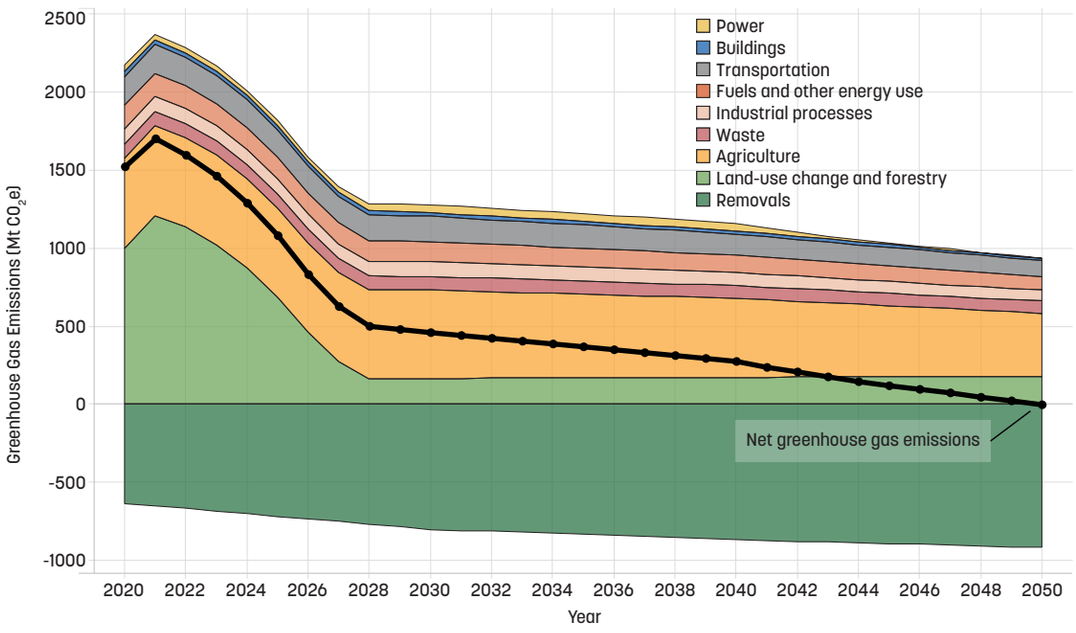
[135] While without illegal deforestation the search for legal ways to clear land should go up, the stock of legally clearable land will be getting closer to exhaustion. We assume that in the long run, the net effect is neutral.

» **More productive agriculture, with very limited land-clearing:** Growth in agricultural production after 2028 happens mostly through productivity gains on land that was already cleared and in areas available for legal deforestation under the 2012 Forest Code (i.e., private lands that are registered under the Rural Environmental Registry and are not designated as Permanent Preservation Areas or Legal Forest Reserves).

» **A fully decarbonized power sector, with 99 percent renewables and 1 percent nuclear,** plus a new green hydrogen supply enabling other sectors, such as transport and industry, to decarbonize through electrification and fuel-switching. The decarbonization of auto-generation and isolated power systems is assumed to generally follow the same path as the national grid.

» **Emission reductions across sectors, through electrification, fuel-switching, and modal shifts:** Modal shifts from road freight to rail and waterways, and from private vehicles to public transit in urban areas, help reduce transport emissions. Ministry of Science and Technology assumptions of emission reductions from 2020 to 2050 were used for waste (16 percent), energy use in industry and agriculture (10 to 20 percent), fuel production (23.5 percent), buildings (50 percent), and fugitive emissions (90 percent); emissions from bunker fuels are assumed to remain constant.

FIGURE 10. Brazil GHG emissions and removals by sector, 2020–2050



Source: World Bank analysis done for CCDR.

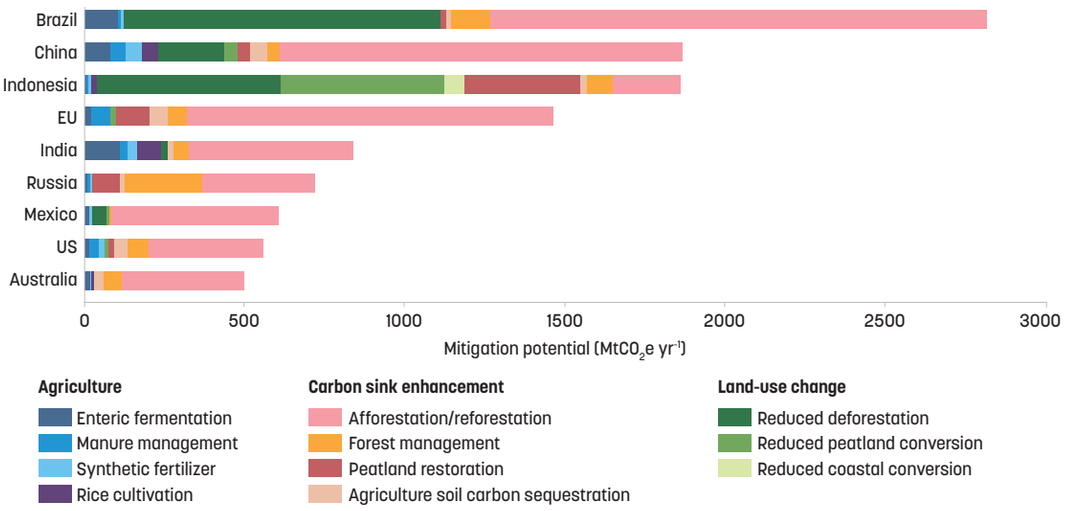
4.1. Curbing illegal deforestation and boosting agricultural productivity

Brazil can stop illegal deforestation by 2028, as it pledged at COP26, and reap large GHG emission reduction benefits at a manageable cost. A 2021 study found that Brazil has the highest total cost-effective mitigation potential from land-based measures of any country in the world, 1.7 ± 0.5 $GtCO_2e$ per year.[136] By far the largest share of that potential is in protecting forests (Figure 11). Already, the vast majority of deforestation in Brazil is considered illegal (as per the 2012 Forest Code), so meeting the 2028 commitment alone would make a major impact. Under the Plan for the Prevention and Control of Deforestation in

[136] Roe, S. et al. 2021. "Land-Based Measures to Mitigate Climate Change: Potential and Feasibility by Country." *Global Change Biology* 27 (23): 6025–58. doi:10.1111/gcb.15873.

the Legal Amazon (PPCDAm)[137] of 2004 and other environmental protection policies, and during the commodity boom from 2004 to 2012, Brazil reduced deforestation in the Amazon by about 80 percent.[138] This decreased Brazil's emissions from land use change by 65 percent. This trend has since reversed due to limited operationalization of the Forest Code, the undermining of institutions involved in forest monitoring and forest law enforcement, changes in the land law,[139] continuation of subsidies that motivate extensive cattle ranching, and a less favorable macroeconomic environment.

FIGURE 11. Potential to reduce emissions: a comparative sample



Source: Based on Roe et al. 2021.[140]

Illegal logging, agriculture (including cattle ranching), and land grabbing, responding to weak law enforcement, poor land governance, and macroeconomic drivers (commodity prices and demand, exchange rates), have all been identified as drivers of deforestation. Illegal land-grabbing—to expand cattle ranching and for land speculation, among other things—is a significant driver of deforestation in the Amazon[141] and Cerrado biomes.[142] Some of the underlying reasons for this activity include limited collection of issued fines,[143] weakening of monitoring and enforcement, and the possibility that revisions to the Forest Code could result in legitimizing illegal deforestation and providing formal land rights over the area. Under these conditions, expected benefits from use of the land[144] and short-term profits from selling timber exceeded the expected costs.

[137] The PPCDAm has been renewed several times, and a related plan has been developed for the Cerrado. For an overview of the key targets and links to the different versions of the plan, see https://climate-laws.org/geographies/brazil/policies/plan-to-control-illegal-deforestation-and-recovery-of-native-vegetation-ppcdam-and-ppcerrado.

[138] West, T.A.P., and P.M. Fearnside. 2021. "Brazil's Conservation Reform and the Reduction of Deforestation in Amazonia." *Land Use Policy* 100 (January): 105072. doi:10.1016/j.landusepol.2020.105072.

[139] Sant'Anna, A.A., and L. Costa. 2019. "Bailing out Environmental Liabilities: Moral Hazard and Deforestation in the Brazilian Amazon." LACEA Working Paper No. 0031. Latin American and Caribbean Economic Association. http://vox.lacea.org/?q=wps/bailing_environmental_liabilities.

[140] Roe et al., 2021, "Land-Based Measures to Mitigate Climate Change: Potential and Feasibility by Country."

[141] Brito, Brenda et al. 2019. "Stimulus for Land Grabbing and Deforestation in the Brazilian Amazon." *Environmental Research Letters* 14 (6): 064018. doi:10.1088/1748-9326/ab1e24.

[142] Schneider, M., A.A. Biedzicki de Marques, and C.A. Peres. 2021. "Brazil's Next Deforestation Frontiers." *Tropical Conservation Science* 14 (January): 19400829211020470. doi:10.1177/19400829211020472.

[143] West, T.A.P., and P.M. Fearnside. 2021. "Brazil's Conservation Reform and the Reduction of Deforestation in Amazonia." *Land Use Policy* 100 (January): 105072. doi:10.1016/j.landusepol.2020.105072.

[144] Assunção, J., C. Gandour, and R. Rocha. 2015. "Deforestation Slowdown in the Brazilian Amazon: Prices or Policies?" *Environment and Development Economics* 20 (6): 697–722. doi:10.1017/S1355770X15000078.

Deforestation is most prevalent in undesignated lands, where it is illegal.[145] In July 2017, the new land law (13.465) put in place a process whereby those occupying undesignated public lands prior to 2011 (which was a crime under a 1966 federal law) could be granted formal tenure. Under the law, the Government could approve their claim, and they had to pay the Government the bare land value (VTN). The VTN was often below market value in some areas by as much as 82 percent.[146] In 2019, there were 32,490 parcels of land, accounting for 8.6 million hectares in the Brazilian Amazon, that were being processed for land titles to the occupants.[147] The new law effectively encourages clearing native forests to acquire land rights, a historical practice. Further enabling land-grabbing is the slowdown in the demarcation of Indigenous lands and in the creation of conservation units—activities that help curb illegal deforestation and benefit Indigenous Peoples and local communities.

Additional incentives to deforest for agriculture come from subsidies, rural credit policies, and the structure of the rural land tax (Imposto sobre a Propriedade Territorial Rural, ITR). Plano Safra, the main subsidized credit program, supports cattle ranching in the Legal Amazon's less developed states and crop production in the more advanced states. Since 2008, accessing this source of subsidized credit requires a land title. In 2021–2022, of the R$244 billion (US$48.8 billion) budget of Plano Safra, only R$5 billion (US$1 billion) was allocated to the ABC program,[148] which partly explains why the credit is not resulting in agricultural intensification. Furthermore, tax breaks for agriculture increased from 8.93 percent of total tax breaks in 2006, to 12.01 percent in 2021. The Instituto Escolhas estimated that the beef industry received R$123 billion (US$24.6 billion) in subsidies between 2008 and 2017.[149] Concomitantly, the structure of the ITR,[150] a progressive land tax tied to the productivity of land that can legally be used for agriculture, made extensive cattle ranching consistent with a lower ITR tax bracket.[151] This is because the productivity tables used to determine the ITR have not been updated to promote greater productivity. Furthermore, the likelihood of being penalized for illegally deforesting is low.

Zero net deforestation can be achieved without compromising development

Brazil could achieve its commitment to zero illegal deforestation by 2028 and reach zero net deforestation by 2050 without compromising development. An analysis, done for this CCDR using the Integrated Economic-Environmental Modeling (IEEM) Platform, shows that Brazil can reach its climate commitments with positive impact on GDP, export revenue, wealth, and social gains. It would require a combination of effective forest law enforcement and forest governance (NZD scenario) with the development of diversified land-based economic activity, including forest-based economic activities and increased agricultural productivity in the Amazon (DEA scenario). Table 2 presents the modeling results, which internalize the contribution of ecosystem services to the economy.[152]

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[145] These are lands that are not designated as conservation units, Indigenous lands/territories, private land, or rural settlements at the federal, state, or municipal level.

[146] Brito, B. et al. 2021. "10 Essential Facts About Land Tenure Regularization in the Brazilian Amazon." Belém: Imazon. https://imazon.org.br/publicacoes/10-essential-facts-about-land-tenure-regularization-in-the-brazilian-amazon-2/.

[147] Brito et al. (2019) estimated, using an average land market price from 2016 per municipality and the four scenarios for paying the VTN, that, by using a VTN significantly lower than market price, the government missed earning between $5 billion to $8 billion. See Brenda Brito et al., 2019, "Stimulus for Land Grabbing and Deforestation in the Brazilian Amazon."

[148] The ABC program is part of a national strategy to reduce GHG emissions from the agricultural sector. At the core of the ABC Plan is a new line of low-interest rural credit to fund the implementation of agricultural practices or technologies that are likely to contribute to climate change mitigation and/or adaptation. The program is organized along six axes: i) recovery of degraded pastures; ii) crop-livestock-forest integration and agroforestry systems; iii) no-tillage system; iv) biological nitrogen fixation; v) planted forests; and vi) treatment of animal waste. In addition, the plan proposes specific actions to adapt to climate change.

[149] Leitão, S. et al. 2020. "Do Pasto ao Prato: Subsídios e Pegada Ambiental da Carne Bovina." São Paulo: Instituto Escolhas. https://www.escolhas.org/wp-content/uploads/2020/07/Do-pasto-ao-prato-subsidios-e-pegada-ambiental-da-cadeia-da-carne-SUM%C3%81RIO-EXECUTIVO2.pdf.

[150] The ITR aims to raise both revenue and land productivity. It is assessed progressively at rates ranging from 0.03 percent to 20 percent, and is based on the area and value of the land, as well as the productive area as a percentage of total area.

[151] Hanusch, ed. 2022. *A Balancing Act for Brazil's Amazonian States: An Economic Memorandum*. International Development in Focus. Washington, DC: World Bank. Citing IPAM 2016.

[152] The general equilibrium model used for the analysis was run using different scenarios. For some of the scenarios, it is assumed that deforestation is exogenous in order to achieve zero illegal deforestation in the timeframe committed to by the Government of Brazil.

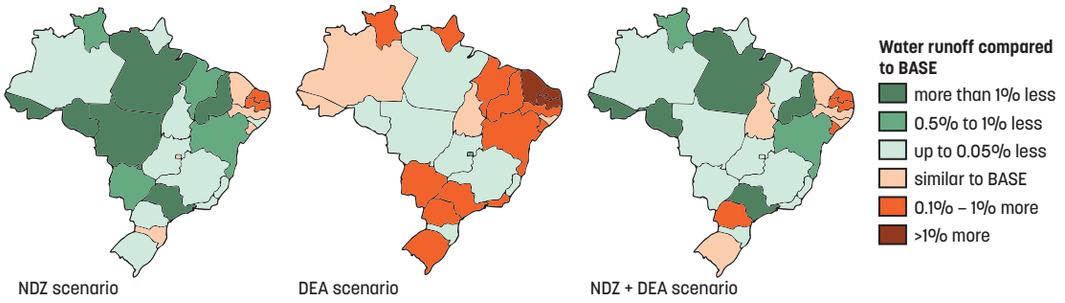
TABLE 2. Economic impact of curbing deforestation, with and without complementary measures to mitigate tradeoffs (internalizing impact of ecosystem services on the economy)

	NZD	DEA	Combine NZD + DEA
Cumulative Economic Impacts (until 2050), R$ Billion (difference from BAU)			
GDP	−92.24	498.18	472.78
Genuine Savings	1860.39	574.37	1990.29
Private Consumption	−105.25	455.88	415.66
Private Investment	−15.38	33.49	27.84
Exports	−62.66	200.33	164.43
Imports	−36.72	232.74	220.54
Land Use Impacts (million hectares)			
Natural Forest	16.58	4.11	16.00
Crops	−3.68	1.36	−1.43
Livestock	−12.90	−2.21	−11.31

Source: Analysis done for CCDR by Banerjee et al., 2022.[153]
Note: Genuine savings are estimated as the gross national savings, reduced by the depreciation of capital stock, depletion of forest and mineral stocks, and cost of damages from GHG emissions.

Several key measures to reduce GHG emissions would also boost resilience to climate change. Curbing deforestation in the two main ecosystems of Brazil—the Amazon and Cerrado biomes—would lower climate risks for agriculture, electricity (hydropower), domestic water supply, and the financial sector. For the agriculture sector, native vegetation loss in the Amazon and Cerrado has implications for erosion, temperature, and precipitation. A recent study estimated that in 2012, extreme heat due to native vegetation loss cost the soy industry US$99 per hectare in lost revenue (in 2005 dollars).[154] The study also projected that by 2050, the extreme-heat regulation value provided to the soy industry by native vegetation could grow by 25–95 percent. Modeling for this report also suggests similarly large effects for water runoff, as illustrated by the maps in Figure 12.

FIGURE 12. Implications for water runoff of curbing deforestation, relative to business as usual (BASE)



Source: Analysis done for CCDR by Banerjee et al., 2022[155]

[153] Banerjee, O. et al., 2022. "Synergies and Trade-offs Between Policies for Reducing Deforestation in Brazil." A Contribution to the World Bank's Country Climate and Development Report for Brazil. Mimeo

[154] Flach, R. et al. 2021. "Conserving the Cerrado and Amazon Biomes of Brazil Protects the Soy Economy from Damaging Warming." *World Development* 146 (October): 105582. doi:10.1016/j.worlddev.2021.105582.

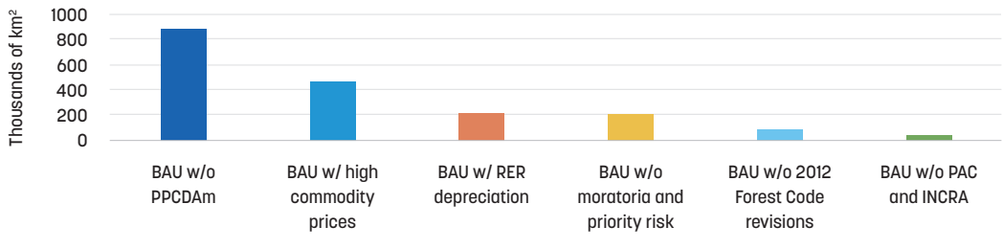
[155] Banerjee, O. et al., 2022. "Synergies and Trade-offs Between Policies for Reducing Deforestation in Brazil." A Contribution to the World Bank's Country Climate and Development Report for Brazil. Mimeo

A mix of policies will be necessary

Analyses have shown that a mix of sectoral policies that reinforce forest law enforcement and promote conservation play a key role in curbing deforestation. A policy mix is necessary because the effectiveness of any one measure can depend on the presence of others: for example, improving forest law enforcement by adequately resourcing satellite monitoring of forests (e.g., the satellite monitoring of clear-cut deforestation and alerts of change in forest cover with PRODES[156] and DETER[157] respectively) and forest law enforcement agencies, removing interference by interest groups, and eliminating uncertainties regarding possible changes to laws. It can be even more effective when complemented with the municipality priority list, which is the list of municipalities with the highest deforestation in the Amazon biome, and designation of sustainable use areas and Indigenous territories. Analysis done for the CCDR found that, between 2000 and 2020, the municipality priority list was more effective when combined with protected areas and with private sector initiatives (e.g., the soy moratorium).

The strength of a mix of sectoral policies in curbing deforestation can be reinforced with certain macroeconomic conditions. An econometric analysis done for the CCDR identifies the impacts of sector policies—such as moratoria on agricultural commodities and the PPCDAm—and the effect of macroeconomic variables (commodity prices, exchange rates) on total deforestation in the Legal Amazon (Figure 13). It used proxies for policies that control for time-varying influences on deforestation (such as prices, exchange rates, etc.) and estimated what deforestation would have been in the absence of different policies and macroeconomic conditions. For instance, deforestation would have been higher by more than 800,000 square kilometers without the PPCDAm, and by more than 400,000 square kilometers with higher commodity prices. The analysis shows the important role of macroeconomic factors, but also the large role of the sectoral policies and their implementation and enforcement.

FIGURE 13. Difference in total deforestation in the legal Amazon, under different policy and macroeconomic counterfactuals for the 2000–2020 period



Source: Analysis done for CCDR by Cavaglia-Harris et al., 2022.[158]
Note: The analysis simulates deforestation under a BAU scenario and a series of counterfactual scenarios in which certain policies were not implemented or macroeconomic variables take different values.

Tackling land-grabbing will be key

Mapping untitled public lands, modernizing the land registration system, and updating the land tax could all help reduce land-grabbing. Mapping untitled public lands would provide the Government with spatial data that can facilitate the designation of public lands as protected areas (including sustainable use lands and Indigenous territories). The regularization of private land claims could then be adjudicated based on this information. The mapping would also help determine which public lands could be

[156] The PRODES project carries out satellite monitoring of clear-cut deforestation in the Legal Amazon and produces, since 1988, annual deforestation rates in the region, which are used by the Brazilian government to establish public policies.

[157] DETER is a quick survey of evidence alerts of changes in forest cover in the Amazon, carried out by INPE. DETER was developed as an alert system to support surveillance and deforestation control, carried out by the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) and other agencies linked to this theme.

[158] Caviglia-Harris, Jill, Katrina Mullan, Thales A. P. West. 2022. "Policy Mixes to Address Deforestation in the Brazilian Amazon." Background Paper for Brazil CCDR.

designated for private use. The public lands that are designated for private use could then be sold to interested private entities on the market, in a manner that complies with regulations regarding selling public property. Modernization of the land registration, analysis, and validation practices would be an important complementary action.[159] Support to accelerate validation of the Rural Environmental Registry (CAR) would help reinforce this effort. The latter would enable the use of incentives and instruments in the current Forest Code, including the mechanism involving trading forest certificates (CRAs). CRAs allow landowners to offset their restoration obligations by paying to protect native vegetation elsewhere, including on other private property where the landowner has maintained more native forest area within the Legal Forest Reserves than obliged by the 2012 Forest Code.[160] Another key complementary measure is changing the parameters of the land tax (ITR). The latter could reward adoption of good practices and efficient use of areas that can be farmed or ranched, helping reduce illegal deforestation.

Increasing agricultural productivity will boost resilience and lower GHG emissions

Bolstering the resilience of agriculture will also be important for lowering the sector's exposure to climate risks and augmenting productivity. Brazil's agricultural sector loses, on average, the equivalent of 1 percent of its annual gross production value due to extreme weather events.[161] Scaling up irrigated agriculture beyond the current irrigated area of 8.2 million hectares,[162] in a manner that recognizes regional differences, could also boost productivity. Irrigated farming is, on average, 2.51 percent more efficient than rainfed farms. Expanding irrigation does entail high investment costs, but it also offers resilience to variable precipitation. Precision irrigation systems would increase efficiency and reduce competition over water resources. Increasing the use of climate-sensitive insurance instruments in agriculture can catalyze the adoption of these practices. Forestry and livestock insurance, which are growing in Brazil, are also helpful to stimulate climate-informed practices.

Scaling up the ABC+ Plan for low-carbon agriculture presents a substantial potential to lower GHG emission in the AFOLU sectors, but improved incentives to farmers are required.[163] Projections indicate that full implementation of the ABC+ Plan to achieve the sector's NDC goals (NDC scenario) provides the opportunity to reduce GHG emissions by 48 percent by 2030, when compared to business-as usual scenario (Table 3). Enabling farmers to further adopt ABC+ practices, however, will require reforming and retargeting the main subsidized rural credit programs under Plano Safra to promote practices associated with NDC goals, as well as providing support for farmers with registration in the CAR and compliance with the Forest Code to facilitate their access to rural credit. Technical assistance and effective extension services are also important. World Bank analysis has found that US$1 of public investment in training and technical assistance can leverage $8 in private investment by farmers in improved agricultural and restoration practices.[164]

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[159] See Stassart, J. et al. 2021. "Weak Land Governance, Fraud and Corruption: Fertile Ground for Land Grabbing." Transparency International. https://comunidade.transparenciainternacional.org.br/land-grabbing.

[160] Soares-Filho, B. et al. 2016. "Brazil's Market for Trading Forest Certificates." *PLOS ONE* 11 (4): e0152311. doi:10.1371/journal.pone.0152311.

[161] Arias, D. et al. 2017. "Agricultural Market Insurance Development: Policy Note – Brazil." Policy Note. Washington, DC: World Bank. http://hdl.handle.net/10986/32203.

[162] ANA. 2021. "Atlas Irrigação 2021: Uso da Água na Agricultura Irrigada (2a Edição)." Brasilia: Agência Nacional de Águas e Saneamento Básico (National Water and Basic Sanitation Agency). https://metadados.snirh.gov.br/geonetwork/srv/api/records/1b19cbb4-10fa-4be4-96db-b3dcd8975db0.

[163] The ABC+ plan is the next generation of the ABC Plan. The ABC plan currently focuses on a limited menu of technological solutions addressing the climate vulnerability of a selected range of farmers and value chains.

[164] Pereira, O.J.R. et al. 2018. "Assessing Pasture Degradation in the Brazilian Cerrado Based on the Analysis of MODIS NDVI Time-Series." *Remote Sensing* 10 (11): 1761. doi:10.3390/rs10111761.

TABLE 3. GHG Emission (in $MtCO_2e$) with and without the ABC+ Plan

			2020	2030 (BAU)	2030 (ABC+)	Change	
Agriculture, Forestry, and Other Land Use (AFOLU)	Agriculture	Livestock	345	358	327	–32	–10%
		Cultivation Systems	145	159	154	–5	–3%
		Total	**490**	**517**	**481**	**–36**	
	Land Use, Land Use Change and Forestry (LULUCF)	Gross emissions	926	928	680	–248	–36%
		Removals	–497	–551	–700	–150	21%
		Total	**429**	**377**	**–21**	**–398**	
	Net emissions		**918**	**894**	**460**	**–434**	**–94%**

Boosting the productivity of agriculture can support skilled job creation along value chains.[165] These jobs have been created on modernized farms and through linkages with industries that supply inputs to the agricultural sector and with the logistics associated with distributing agricultural commodities. The agribusiness sectors have become important employers, especially in secondary cities. As with other sectors, active labor market programs that provide the necessary training will be important if Brazil is to seize the opportunities from skilled job demand.

Policy measures should be tailored to regional variations and support a just transition

Implementation of a range of policy measures for curbing deforestation and scaling up climate-informed landscape management and agriculture resilience will need to be tailored across and within biomes. The Amazon biome (which is larger than the European Union) presents a wide range of realities and challenges on the ground (e.g., accessibility, ecological, demographic, local institutional capacity). In general, however, successful implementation will require linking high-resolution satellite monitoring of forests with measures that penalize illegal activities and reward climate-smart and resilient management of natural assets. Implementation will also require strong and continuous political will at the national and subnational levels to stamp out illegal activities and see through the necessary sectoral, credit, and fiscal reforms. Enhancing involvement of the private sector in delivering market solutions for sustainable food systems will be central to effective implementation. Weak government efforts to address environmental issues have motivated the private sector to find its own solutions and avoid reputational risks in global markets. Moving forward, it will be important to incentivize a climate- and sustainability-conscious private sector.

Land and natural resource management approaches that recognize the interaction across land uses and coordinate across sectors (i.e., landscape management approaches) would help ensure policies and investments to maintain environmental benefits. Brazil has experience in deploying climate-smart landscape management in the Cerrado through multi-ministry coordinated investments, although at a relatively modest scale. These investments support climate-smart agricultural and forest management practices (including forest restoration), expanding use of real-time monitoring systems, and strengthening enforcement. Scaling up such investments will require strengthening local governance, planning, and management capacity, and improving stakeholder ownership and involvement in the governance and operationalization of landscape management. Landscape management approaches involve low capital costs and could be adapted and scaled up in both the Amazon and Cerrado.

[165] Arias, D. et al. 2017. "Agriculture Productivity Growth in Brazil: Recent Trends and Future Prospects." Brazil Productivity Growth Flagship Report. Washington, DC: World Bank. http://hdl.handle.net/10986/29437.

A just transition will be imperative while increasing climate-smart agricultural productivity and curbing illegal deforestation, to avoid creating adverse impacts on formal and informal labor. This could entail developing complementarities between social protection programs and the formalization of rural jobs. It could also entail supporting the diversification of rural economies with forest-based economic activities. Many of the aforementioned actions for eliminating illegal deforestation, tackling land grabbing and improving agricultural productivity also support forest-based economic activities, especially when complemented with enabling conditions for investments in productive concessions for forest goods and services. These joint measures would enable agroforestry in the understory of legal reserves, the harvesting of non-timber forest products, trading forest certificates (CRAs), employment in nature-based tourism, and other economic activities that sustainably manage standing forests while generating economic benefits and social equity. These economic activities would be in line with the objectives of zero illegal deforestation by 2028 and net-zero deforestation by 2050,[166] and ensure the economic opportunities and benefits are accessible to local communities, fostering inclusive development.[167]

The new investments and the costs associated with stopping illegal deforestation, achieving net-zero deforestation, and boosting productivity of agriculture are relatively modest. They are associated with implementing effective forest law enforcement and forest and land governance, scaling up climate-smart agriculture, and initiating carbon removal activities (see details in Section 5). Analysis for this report uses the capital investment needed until 2030, mainly for enhanced land use (e.g., restoration of natural forest areas, plantation forestry, and pasture recovery), and support for biomass and second-generation biofuels. The cumulative revenues, however, well exceed the costs as per the findings from a partial equilibrium analysis that concludes that the production difference between the NDC and BAU scenarios remains positive for soy, corn, sugarcane, and meat (the latter with livestock intensification).

4.2. Low-carbon, more resilient energy and transport systems are within reach

The fundamentals of Brazil's energy sector offer the country a unique opportunity to decarbonize. Brazil's energy and climate change policies and laws have historically been strong in promoting renewable energy scale-up. Measures such as VRE auctions, tax breaks and incentives including reduced interconnection costs have led Brazil to develop a relatively low-carbon power sector (Figure 14).[168] However, recent policies and legislation, including the law requiring 8 GW of new thermal capacity to be installed by 2030, undermine Brazil's climate ambitions and set the country on track to increase energy sector emissions. According to the most recent 10-year national energy expansion plan (Plano Decenal de Expansão de Energia, PDE, 2031),[169] renewable energy is expected to represent 48 percent of the Brazilian energy matrix in 2031, which exceeds the country's original NDC goal of 42 percent by 2030. Fossil fuels play a minor role with only 16.2 GW in gas capacity and 3.2 GW of coal capacity (EPE Statistical Yearbook, 2022). However, while some recent policies and legislation are expected to further facilitate the scaling up of renewable sources and modernization of the power sector, others threaten to undermine Brazil's climate ambitions and set the country on track to increase energy sector emissions. Furthermore, subsidies for fossil fuels are significant and tax waivers and subsidies for coal were recently extended by Congress to 2040.[170]

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[166] Beraldo Souza, T. do V.S. et al. 2019. "Economic Impacts of Tourism in Protected Areas of Brazil." *Journal of Sustainable Tourism* 27 (6): 735–49. doi:10.1080/09669582.2017.1408633; Torres, C.M.M.E. et al. 2017. "Greenhouse Gas Emissions and Carbon Sequestration by Agroforestry Systems in Southeastern Brazil." *Scientific Reports* 7 (1): 16738. doi:10.1038/s41598-017-16821-4.

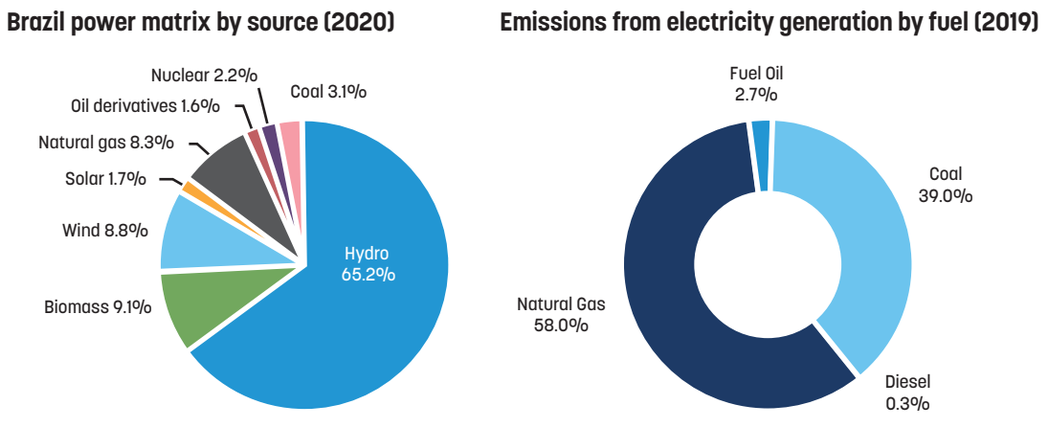
[167] Forest-based economic activities suggested here would be aligned with the notion that some experts and scholars are promoting an Amazon bioeconomy that sustainably manages standing forests while promoting economic prosperity and social equity. See, for example, Bergamo, D. et al. 2022. "The Amazon Bioeconomy: Beyond the Use of Forest Products." *Ecological Economics* 199 (September): 107448. doi:10.1016/j.ecolecon.2022.107448.

[168] https://www.epe.gov.br/pt/abcdenergia/matriz-energetica-e-eletrica.

[169] https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/plano-decenal-de-expansao-de-energia-2031.

[170] Extension of coal subsidies falls under Law 14.299/2022 (https://www2.camara.leg.br/legin/fed/lei/2022/lei-14299-5-janeiro-2022-792216-publicacaooriginal-164327-pl.html); expansion and extension of tax benefits falls under the REPETRO program (MP 795/2017 - https://www.congressonacional.leg.br/materias/medidas-provisorias/-/mpv/130444).

FIGURE 14. An overview of Brazil's power generation mix and GHG emissions



A zero-emission power system can be achieved at negligible incremental cost

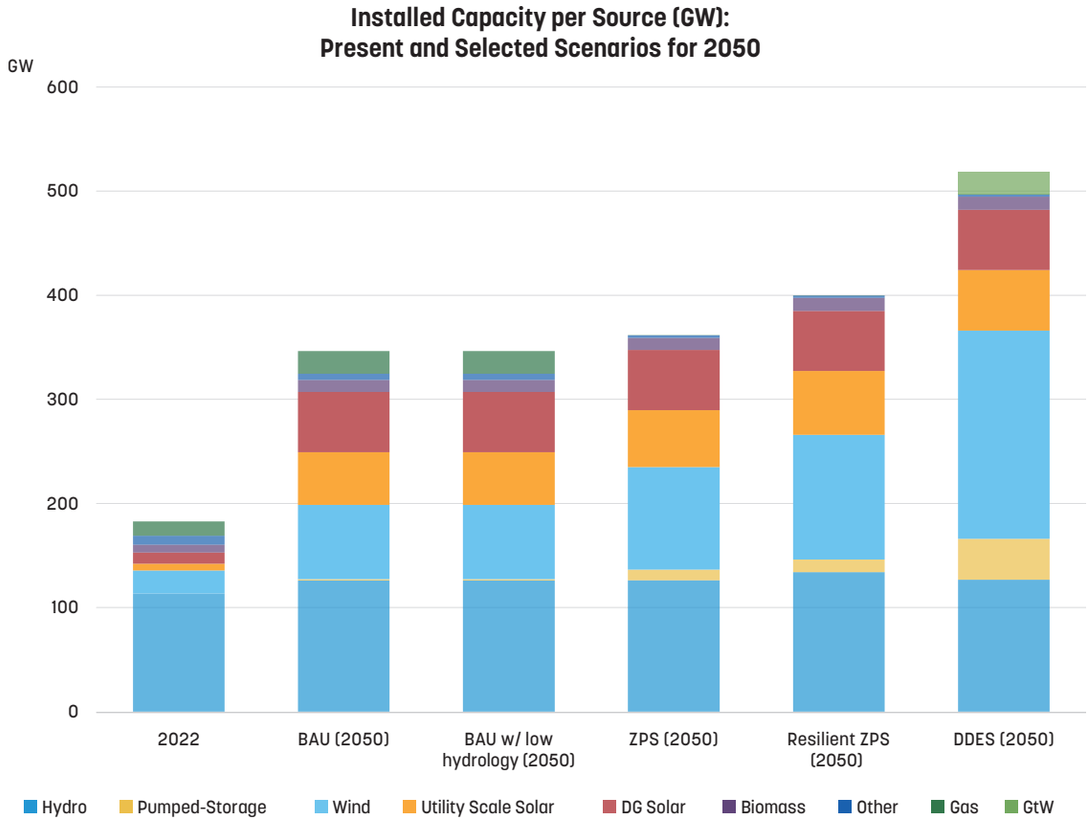
A scenario analysis for this report shows that Brazil could have a power sector with zero (gross) emissions by 2050 at a negligible incremental cost to the power system compared with business as usual.[171] The modeled zero-emission power system (referred to as ZPS) would use 99 percent renewables and 1 percent nuclear power (see Figure 15) and it would cost R$375 billion, compared with R$374 billion for the BAU scenario (Figure 16).[172] Compared with BAU, the ZPS entails 4 percent more installed capacity (361 GW instead of 346 GW in 2050), the addition of 10 GW of pumped hydro storage by 2050, and an additional 9.9 GW of new transmission capacity. Designing the ZPS to be more resilient to climate change and low water availability requires a 15 percent increase in system capacity (to 400 GW by 2050), but the analysis shows it would have lower net costs than the BAU power system under the same low hydrology conditions, due to lower operating expenditures (R$421 billion versus R$431 billion).[173]

[171] Work was done by PSR. The models used were TimeSeries Lab to forecast resource availability, OptGen to forecast least-cost system planning, and SDDP to simulate system operations and estimate sector costs and emissions.

[172] The BAU assumes continuation of the existing policies to support variable renewable energy scale-up, a conservative level of electrification of the economy excluding the penetration of green hydrogen, a moderate level of demand response, hydrological inflows equivalent to 100 percent of the long-term average (LTA), as well as implementation of the 8 GW of gas power expansion under Law 14.182 and extension of subsidies for coal-fired power generation under Law 14.299, and is based on the Plano Decenal de Expansão de Energia (PDE) 2031 (see https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/plano-decenal-de-expansao-de-energia-2031).

[173] For the purpose of this analysis, the low hydrology scenario assumes hydrological inflows at 80 percent of the LTA.

FIGURE 15. Installed capacity (upper panel, GW) and generation (bottom panel, TWh) in 2020 and 2050 in selected scenarios



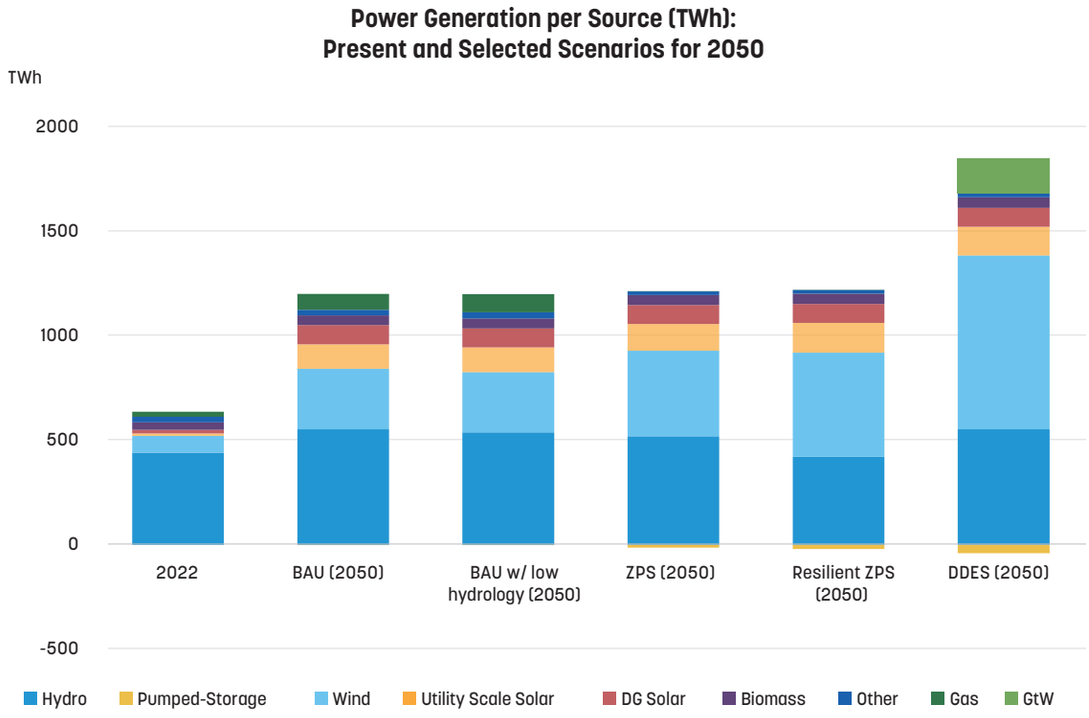
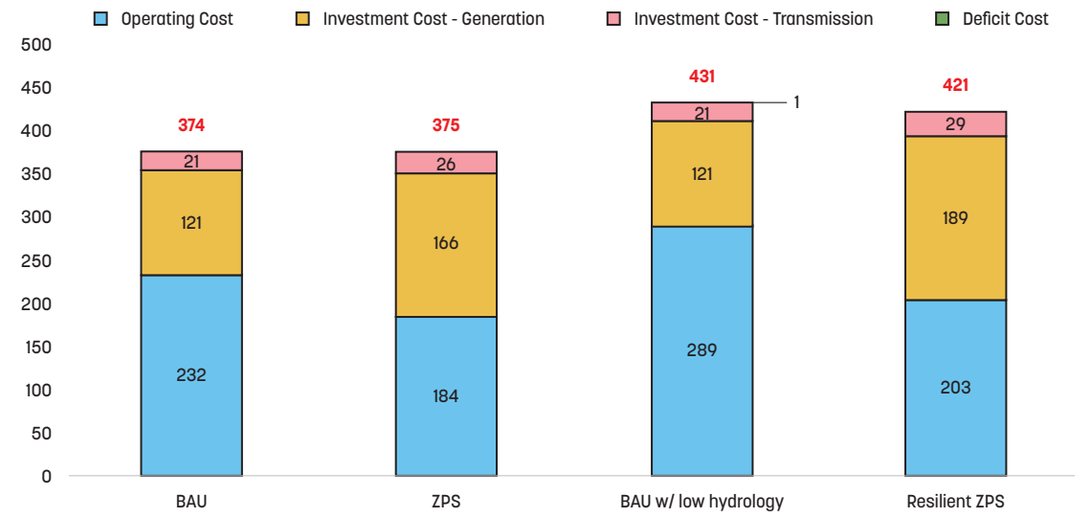


FIGURE 16. Net present cost of Brazil's power system in 2050 in different scenarios (R$ billion)

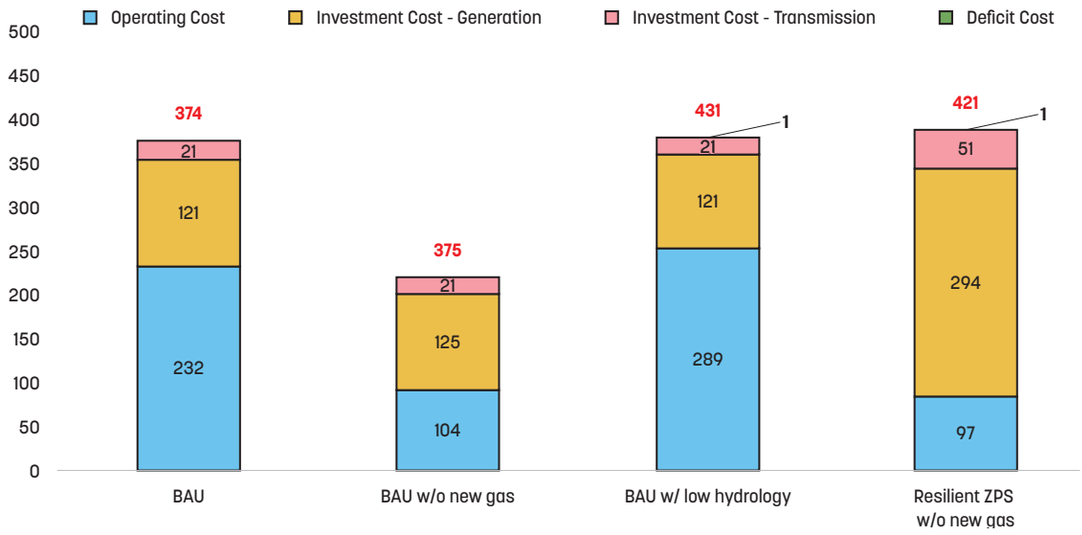


Source: PSR analysis for the World Bank

Additional 8 GW of gas capacity is not necessary, even with increased water scarcity

Brazil's current thermal expansion plans would add significant costs to the power system and economy overall. Forgoing the additional 8 GW of gas capacity would save Brazil 20 percent on its power system costs in the BAU scenario (R$250 billion versus R$374 billion). The analysis also shows that in a scenario with reduced water availability, the net cost of making the ZPS as resilient without the 8 GW of new gas, by adding more renewable energy capacity and storage, would be just 2.5 percent higher (R$442 billion versus R$431 billion; see Figure 17). This shows Brazil can cost-effectively build resilience to climate change without introducing 8 GW of additional inflexible gas capacity. Added gas capacity would also significantly increase the cost of achieving Brazil's net-zero objective in 2050 through asset stranding (see below).

FIGURE 17. Net present cost of Brazil's power system with and without 8 GW of new gas capacity (R$ billion)

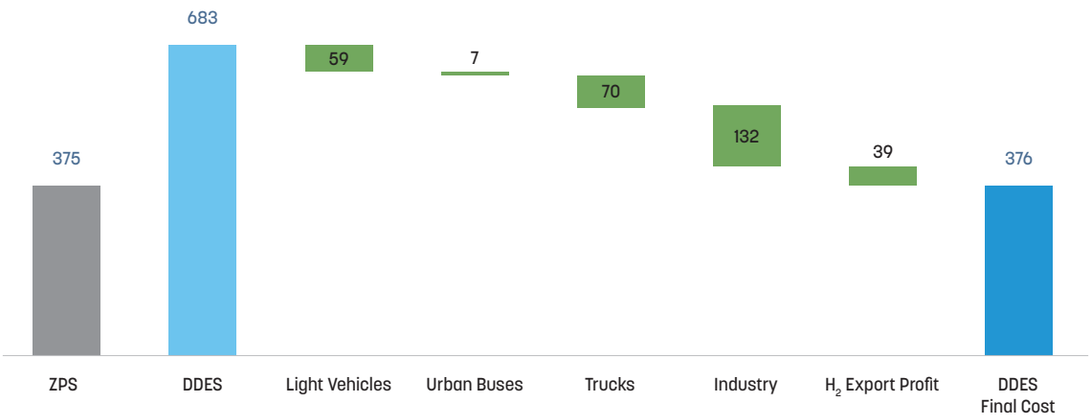


Source: PSR analysis for the World Bank

A decarbonized power system can help decarbonize other sectors and boost Brazil's competitiveness

Brazil's power system can be used to efficiently decarbonize the harder-to-abate sectors of transport and industry. The deep decarbonization of the energy system (DDES) scenario assumes greater electrification of end-use sectors (such as transport and industries) than in the BAU or ZPS scenarios, as well as the use of green hydrogen for domestic fuel switch and export.[174] The DDES scenario therefore sees high electricity demand compared to other scenarios that assume constant demand. This accelerated shift toward electricity does not increase economy-wide energy costs, as fuel savings in the transport and industrial sectors, plus profits from green hydrogen exports, compensate for the increased costs of power system expansion (see Figure 18). However, this scenario would require significant investments for system expansion and deployment of innovative technologies, particularly if designed to be resilient to low hydrology. The power system would be expected to grow to 726 GW of installed capacity, including, among others, a massive scale-up of onshore and offshore wind, pumped storage, and transmission capacity.

FIGURE 18. Net present cost of the deep decarbonization of the energy system (DDES) scenario (R$ billion)



Source: PSR analysis for the World Bank

Brazil can capitalize on its unique conditions to decarbonize its energy system at a low economic cost to increase energy security, economic competitiveness, and innovation. Brazil has an enormous advantage to grow and open new export markets, particularly to Europe, which will increasingly demand and pay a premium for low- and zero-carbon commodities, because of policies like CBAM. Brazil can also capitalize on its comparative advantage in clean technologies to create new jobs, such as offshore wind, where assets and skills of the existing offshore oil and gas industry can be redeployed, supporting a just transition and accelerating the technological learning curve for decarbonization.

[174] The model makes the following assumptions: (1) In the transport sector: the share of EVs in total light vehicle sales would increase to 80 percent by 2050 (versus 70 percent in the BAU), and the share of electric buses would rise to 91 percent (versus 83 percent in the BAU). The assumptions follow BloombergNEF's *Electric Vehicle Outlook 2021* for 2050, with a 10 percent reduction for light vehicles, due to the estimate that ethanol will still have an important role as a fuel in Brazil. (2) In industry, the share of electricity in the sector's total energy demand rises to 35 percent (versus about 20 percent in the BAU), in line with assumptions in the IEA's report *Net Zero by 2050*. (3) In addition, 2.5 Mt green hydrogen consumption is assumed for the transport sector (predominantly by heavy vehicles); 1.8 Mt for fuel switch (steel, ammonia, refineries, high- and medium-heat industries, and combined cycle turbines); and 1.38 Mt is assumed for export. These assumptions are derived from a conservative 40 percent reduction and 10-year delay compared with McKinsey's recent assessment of green hydrogen potential in Brazil.
BloombergNEF. 2021. "Electric Vehicle Outlook 2021." Bloomberg New Energy Finance. https://about.bnef.com/blog/electric-vehicle-sales-set-to-rise-faster-than-ever-but-more-policy-action-needed-to-get-on-track-for-net-zero/; IEA, 2021, "Net Zero by 2050: A Roadmap for the Global Energy Sector"; Gurlit, W. et al. 2021. "Hidrogênio Verde: Uma Oportunidade de Geração de Riqueza com Sustentabilidade, para o Brasil e o Mundo." *McKinsey & Company – Our Insights* (blog). November 25, 2021. https://www.mckinsey.com/br/our-insights/hidrogenio-verde-uma-oportunidade-de-geracao-de-riqueza-com-sustentabilidade-para-o-brasil-e-o-mundo.

Policy interventions are crucial to ensuring Brazil can decarbonize its energy system

Brazil has recently enacted a suite of laws and regulations that are expected to facilitate further scaling up of renewable energy generation, including for distributed solar generation, offshore wind,[175] and a National Hydrogen Program (Programa Nacional de Hidrogênio, PNH_2) was recently launched. The country is also in the process of modernizing its power sector through a series of updated legislation and regulation designed to ensure a sustainable and competitive expansion of the power system.

Reducing government support for inefficient and costly fossil-fuel power generation is critical to improving economic competitiveness while lowering emissions. The oil and gas industry contributes about 13 percent of the country's GDP and 50 percent of the domestic energy supply.[176] Brazil plans to increase its oil production from its large reserves of offshore oil and associated gas (pre-salt) by about 80 percent from 2021 levels, from 2.9 million barrels per day to about 5.2 million barrels by 2030.[177] Fuel production represented 5 percent of total national emissions in 2019, the third largest share in the energy sector.[178] Importantly, Brazil should ensure that its plans to increase extraction of its offshore oil and gas resources does not result in uneconomic domestic use of these resources, which would increase emissions and generate large opportunity costs. Brazil's strategy to extract its oil and gas resources should also be informed by a robust assessment of the policies and institutional reinforcements needed to ensure the associated rents are utilized to maximize their impact on poverty reduction and economic development.[179] This is a challenge that few countries have successfully navigated.[180]

Legal and regulatory actions are needed to create an enabling environment for near-term investments that can displace the system-balancing role that fossil fuels currently play in the power system. With the removal of government support for fossil fuels, new renewable energy generation and storage capacity will be needed to ensure security of supply. The power sector modernization currently under way will be critical to enable this transformation. Repowering and rehabilitation of existing hydropower assets is fundamental for keeping up with growth in terms of both energy demand and capacity to meet the demand. However, many concession contracts will be ending within the next five years, creating a disincentive for investment. It is critical that Brazil implement regulations to incentivize capacity auctions and new instruments for ancillary system services. This will enable more optimal deployment of the existing hydropower assets and new investments in storage. In addition, new regulatory instruments, such as demand response contracts, will be needed to support increased system flexibility.

New policies, regulations, and technological advances are needed to decarbonize industry and transport, while at the same time encouraging energy efficiency. Brazil must continue to improve the enabling environment for green hydrogen development, including building the capacity of the regulatory agency (ANP) and adopting and implementing new federal regulations. Changes in the regulatory framework of the electricity distribution sector are also needed, such as moving away from price-cap schemes and towards revenue-cap schemes with incentives for overall energy efficiency, as well as better design of time-of-use tariffs. Massive scale-up of advanced metering infrastructure (AMI), including smart meter deployment, will be required to enable electrification of the economy. Wind is expected to become the dominant source of electricity generation in the resilient DDES scenario, with a growing and important role of offshore wind; secondary legislation is required to enable large-scale offshore investments by the private sector.

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[175] In January 2022, the Congress approved Law 14.300 for the development of Distributed Generation, and MME recently approved Decree No 10.496, that provides for the assignment of the use of physical spaces and the exploitation of natural resources from offshore enterprises.

[176] https://www.perfilnews.com.br/participacao-do-setor-de-petroleo-e-gas-chega-a-13-do-pib-brasileiro/.

[177] EPE and MME, 2022, "Plano Decenal de Expansão de Energia 2031 [Ten-Year Energy Expansion Plan 2031]."

[178] https://plataforma.seeg.eco.br/sankey. 2018 data was selected to be more representative (pre-COVID).

[179] Fajnzylber, P., D. Lederman, and J. Oliver. 2013. "Pre-Salt Oil Discoveries and the Long-Term Development of Brazil." Economic Premise No. 113. Washington, DC: World Bank. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/662121468020927537/Pre-salt-oil-discoveries-and-the-long-term-development-of-Brazil; see also Jorgensen, O.H. 2013. "Efficiency and Equity Implications of Oil Windfalls in Brazil." Policy Research Working Paper No. 6597. Washington, DC: World Bank. http://hdl.handle.net/10986/15835.

[180] The best international practice is possibly in Norway, which created a national fund using oil revenues, using only the real income from the fund to reduce government debt and finance productive investments for the economy. See Basu, R. 2020. "Intergenerational Equity, the Public Trust Doctrine, Norway and North Sea Oil." MPRA Paper No. 102856. https://mpra.ub.uni-muenchen.de/102856/.

While hydropower remains the backbone of the Brazilian power sector, new strategies are needed to ensure it can support resilience and decarbonization. Brazil must focus on improving water resource management and sector models to ensure they adequately capture the expected impacts of climate change. Ensuring water security should be a top priority, including regulations to establish clear water rights and updated methodologies to ensure that water uses across all sectors are adequate. Incentives to scale up storage investments will play a key role in mitigating drought risks for the power system. Finally, the potential role that demand-side management (DSM) can play to respond to periods of energy scarcity should be further studied, and stronger incentives should be put in place to encourage participation in DSM schemes (including adjustments to the existing time-of-use "white" tariff to provide stronger financial incentives to electricity end-users).

In contrast with many other countries, given Brazil's low reliance on coal for electricity, the cost of decommissioning coal power plants is expected to be modest. Most Brazil's coal power plants have already exceeded their economic life, with an average age of 33 years, and Brazil is planning to close all its other coal power plants even in the BAU (even though existing coal plant contracts are expected to be extended to 2040 under Law 14.299). To manage these closures, Brazil needs to put in place support for the communities affected by those closures. The present cost is estimated at R$59 million (US$12 million) for dismantling, plus economic transfers of R$1.4 billion (US$280 million) to cover associated social costs of a just transition. The benefits of transitioning away from coal include reduced air pollution and the ability to redirect existing subsidies for coal plant operations, which totaled almost R$1 billion (US$200 million) in 2020,[181] to more productive uses for the economy.

Decommissioning and social costs are significantly larger in the gas sector, particularly if the planned new 8 GW of gas capacity is built. Brazil's gas power generation assets are much newer, and under Law 14.182, new gas power plants with 8 GW of capacity would be added in the next eight years. The cost of dismantling of all gas plants to reach net zero emissions is estimated at R$2.2 billion (US$440 million). The required economic transfers are estimated at R$550 million (US$109 million) to support communities in a just transition and R$217 billion (US$43 billion) to compensate plant owners for retiring plants after their contracts close, but before the end of their economic life. Without the 8 GW of additional gas plants, the cost of compensation would drop to R$23.6 billion (US$4.7 billion).

Decarbonizing logistics and transportation will require very large investments

Brazil's heavy reliance on road transport and fossil fuel-powered vehicles comes at a high environmental cost, especially in terms of air pollution and GHG emissions. Private cars dominate interurban passenger travel, making up about 57 percent of the total in 2017, followed by air (24 percent) and buses (16 percent).[182] Two-thirds of freight in Brazil traveled by road in 2017,[183] similar to the share in countries with much smaller territories, such as Belgium and France.[184] A more balanced freight modal split for Brazil, similar to other large countries, such as China and the United States, might be 42 percent road transport, 43 percent railways, and 14 percent waterways.

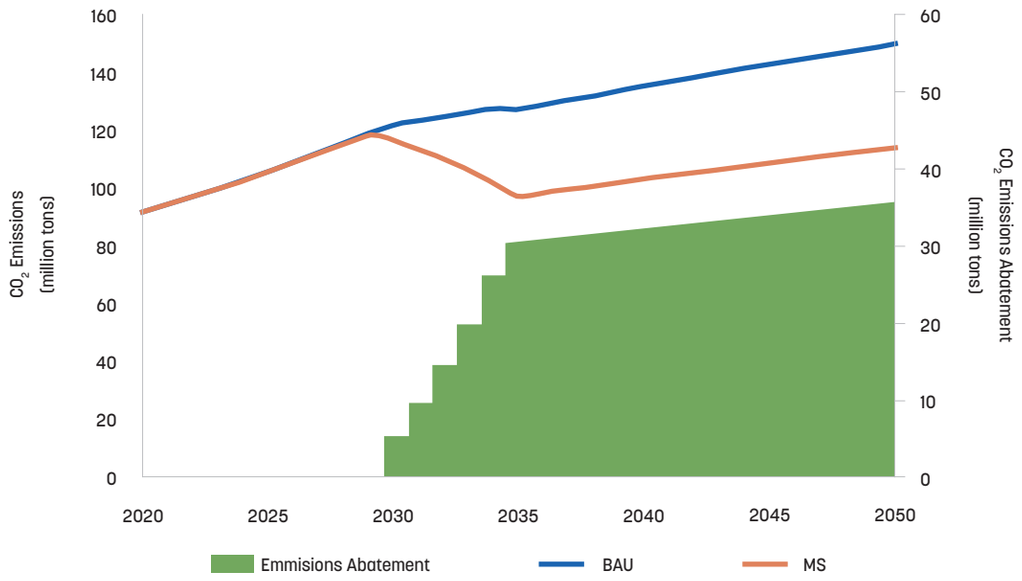
[181] INESC. 2021. "Subsídios aos Combustíveis Fósseis no Brasil (2020): Conhecer, Avaliar, Reformar." Instituto de Estudos Socioeconômicos. https://www.inesc.org.br/subsidios-aos-combustiveis-fosseis-no-brasil-2020-conhecer-avaliar-reformar/.

[182] EPL, 2021, "National Logistics Plan 2035: Executive Report (English Version)."

[183] In 2017, the shares were 66.2 percent for road, 17.7 percent for rail, 9.2 percent for coastal cabotage (coastal shipping), and 5.6 percent for waterways, with air freight and other means making up the rest. See Table 6 in EPL, 2021.

[184] See OECD freight transport data: https://data.oecd.org/transport/freight-transport.htm.

FIGURE 19. CO_2 emissions in BAU and modal shift (MS) scenarios for freight



Source: World Bank staff estimates using EPL (2021) data and the ESALQ-LOG model

Note: Considering emissions only in road, rail, and waterway modes

In the freight sector, a modal shift strategy, with investments made in the period 2020–2035, could reduce emissions from 2030 onwards by shifting from trucks to barges or trains (Figure 19). The strategy would make emissions peak by 2030 and decline until 2035, when the entire new rail and waterway infrastructure would be in full operation. However, with the growth of the Brazilian economy, emissions would then resume growing until 2050, but at levels below the peak in 2030.[185] Even with a modal shift, road transport will be needed for short-distance trips from production regions to multimodal terminals, requiring additional action through a fuel shift toward electricity or hydrogen.[186]

The path for Brazil to achieve net zero emissions for freight thus also requires switching to electric and hydrogen-fueled trucks and trains. Renewable fuels in general (including biofuels) have been identified as an option to reduce emissions during the transition (see Box 2). However, this has to be done in a manner that does not compromise the development of electric and hydrogen vehicles—the options envisioned by many other countries committed to emission targets.[187]

Box 2. Biofuel expansion: opportunities and risks

Brazil has long supported the production of biofuels (ethanol and biodiesel). It currently mandates blending 27 percent anhydrous ethanol in gasoline and 11 percent biodiesel in diesel. Nearly 34 billion liters of biofuels were consumed in Brazil in 2018, primarily derived from food crops.[188] Bioethanol use grew out of Brazil's sugarcane industry, while the biodiesel mandate was introduced in 2003, with the National Program of Biodiesel Production and Use (NPBP).

[185] Espinet Alegre, Xavier and Tais Fonseca de Medeiros. 2022. Transport Deep Dive. Background Paper produced for Brazil CCDR.
[186] Ibid.
[187] Ibid.
[188] Lei Ordinária 13.576, of 26.12.2017; available at: www.planalto.gov.br/ccivil_03/_ato2015-2018/2017/lei/L13576.htm.

The biodiesel blending mandate has ramped up quickly, from 2 percent in 2008 to 10 percent in 2018. Brazil's National Council for Energy Policies (CNPE) has proposed increasing the blending rate by 1 percentage point per year, to reach 15 percent by 2025, if certain technical requirements are met. The rapid expansion of Brazil's biodiesel industry parallels the expansion of its soy industry, which provides more than two-thirds of its biodiesel. Mandatory blends are important for biodiesel, for which consumption is driven by the mandate and by increases in diesel consumption.

Brazil's 2016 nationally determined contribution (NDC) under the Paris Agreement set a goal of increasing the share of sustainable biofuels in the energy mix to about 18 percent by 2030. Extensive analysis, including from the Intergovernmental Panel on Climate Change (IPCC), has shown that the impact of biofuel production on direct and indirect land conversion depends on the feedstock and policy framework. This is important in Brazil, given the impact of crop production on deforestation. Brazil's RenovaBio Program aims to contribute to the NDC by reducing GHG emissions in biofuel production, commercialization, and use. The program is a carbon pricing instrument for liquid fuels. It uses a tradeable asset (CBIO) representing 1 tCO_2e of avoided biofuel emissions relative to a fossil fuel baseline.

As Brazil takes steps toward electrifying transport, biofuels can be a transitional fuel, as long as the right policy framework and feedstocks are in place. Electric vehicles (EVs) are the most energy-efficient option among the clean technologies in terms of GHG emissions and air quality. They also have lower GHG emissions abatement costs relative to Diesel VI and biodiesel. However, RenovaBio can help reduce emissions during the transition phase, more so than the mandatory blend, if its strict environmental criteria are met—that is, no deforestation, compliance with legal reserve requirements of the current forest code (e.g., 80 percent in the Amazon biome), and compliance with agricultural zoning. If met, these can limit direct adverse impacts on deforestation.

The biofuel industry has become more productive through agricultural intensification, double cropping, and the use of second-generation technologies (including reuse of agriculture waste such as straw, bagasse, and vinasse). The industry has helped to create co-product industries, such as biomethane and low-carbon intensity electricity from agriculture residues. Models comparing a business-as-usual (BAU) scenario with an NDC scenario that includes RenovaBio and other land use commitments have found that meeting the RenovaBio targets for biofuels would increase sugarcane production by 19 percent, and use maize produced as a second crop. This would entail an increase of 794,000 hectares of sugarcane and 610,000 hectares of maize as a second crop.[189] For biodiesel, there would be no increase in soy production (including for the 15 percent blend), as the requirements are met under the BAU scenario. An effective crediting system could further help the sector develop sustainably if targeted at second-generation biofuels.

The policy needs to remain vigilant of potential unintended consequences. In addition to ensuring compliance with RenovaBio criteria, effective forest protection (see Section 4.1) will be necessary to minimize indirect deforestation. While increasing evidence points to limited competition between crops for fuel production and crops for food production,[190] it is necessary to monitor for indirect land use effects and impacts on food prices. In terms of air pollution, high-biodiesel blends may lead to compatibility issues in fleets that are not adapted for its use, leading to higher nitrogen oxide (NOx) emissions, as well as higher maintenance costs for vehicles.

[189] Corn ethanol in Brazil is 95 percent second crop. Second maize is a "sequential crop" (two harvests in the same year) with soybeans. No additional area is needed for second crop maize. The additional 239,000 ha of first-crop maize is an induced effect. (Background paper produced for Brazil CCDR: Moreira, M et al., 2022. "Options for Greener and Climate-Smart Growth deep understanding of Brazilian agriculture and land use sectors." Agroicone)

[190] Moreira, M et al., 2022. "Options for Greener and Climate-Smart Growth deep understanding of Brazilian agriculture and land use sectors." Agroicone. Background paper produced for Brazil CCDR.

Brazil's transport system faces significant climate change risks

Climate change is expected to magnify the exposure of Brazil's transportation infrastructure network to floods, landslides, fires, and extreme heat. By 2040, the increase in extreme heat exposure will range from 55 percent (large airports) to 94 percent (waterways) of assets.[191] More than 30–50 percent of transport infrastructure assets are in areas that are projected to see an increase in extreme precipitation events. By 2040, the average annual occurrence of intense precipitation events is projected to be at least 20 percent greater than Brazil experienced in 1970–1999.[192]

Brazil needs to make major investments in transport infrastructure to improve access and to maintain its existing infrastructure. Brazil would need to invest at least R$2,170 billion (or US$434 billion) in road infrastructure alone to meet the transport-related Sustainable Development Goals (SDGs) by 2030. For adequate rural access, Brazil must invest R$775 billion (US$155 billion) in new infrastructure, R$350 billion (US$70 billion) to maintain the existing network, and R$540 billion (US$108 billion) to replace assets that reach the end of their service life before 2030. In addition, to achieve the level of transport coverage of the best-performing cities in Latin America and the Caribbean in every city with more than 500,000 inhabitants by 2030, Brazil needs to invest R$400 billion (US$80 billion) in new mass transit infrastructure.[193]

Making all new infrastructure investments more resilient to natural hazards, including climate change impacts, would increase upfront costs, but would pay for itself over time. Investment needs will be increased both by decarbonization needs, and by the need to ensure all infrastructure is resilient to current and future risks. The exposure analysis suggests that the exposure of the road system to floods and landslides will increase to 38 percent in 2030 and 65 percent in 2040. Assuming future roads have the same exposure, and based on a simple assessment of the cost of resilience per kilometer[194] at 20 percent of the construction cost for assets exposed to floods and 2 percent for assets in areas with increasing rainfall, the additional investment need for making roads climate-resilient is estimated to be R$110 billion, or $22 billion (about R$15 billion per year, discounted at 6 percent), with avoided losses estimated at R$235 billion (US$47 billion) and a benefit-cost ratio around 2.1.[195] In contrast, economic analysis suggests that road retrofit outside of normal replacement schedule has a benefit-cost ratio below 1, except for the most critical assets. For instance, the upgrade of the main corridors for soy exports would cost around R$2 billion (US$400 million) for benefits at R$2.6 billion (US$520 million) and a benefit-cost ratio of 1.3.

[191] Data for the 2040-decade annual average increase, according to the CMIP5 RCP8.5 higher-end (95th percentile) model.

[192] The intense precipitation metric measures the maximum annual five-day sum of precipitation ("wettest five-day period"). The results presented for exposure are the increase in intense precipitation on annual average basis for each decade (2030, 2040), relative to the annual average value for 1970–1999.

[193] Under a cost-effective scenario that assumes that increases in mass transit infrastructure are reached using a combination of bus rapid transit (75 percent), surface rail (10 percent), and subways (15 percent). These estimates increase significantly if OECD cities are used as the benchmark, or if rail solutions are used to solve existing deficits.

[194] Miyamoto International. 2019. "Overview of Engineering Options for Increasing Infrastructure Resilience: Final Report." Background Paper for the Lifelines Report. Washington, DC: World Bank Group. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/474111560527161937/Final-Report.

[195] Based on asset exposure to RCP8.5 projection of increase in intense precipitation in 2030 and 2040.

4.3. As economic and population hubs, cities are critical for climate action

Building urban resilience will be important to tackle growing disaster risks

Promoting resilience and adapting Brazilian cities to climate change impacts requires building capacity at the municipal level and securing financing to invest in multiple areas. Brazil counts on a robust national planning, policy, and regulatory framework guiding various aspects of urban development. Historically, although several environmental laws have restricted the use of river plains, for instance, many of these areas have been and continue to be occupied by those who do not have the means to access affordable land, housing, infrastructure, and urban services. Local government capacities vary across Brazil's 5,570 municipalities; therefore, action should be tailored and responsive to the wide range of challenges they face. Nevertheless, even the most capable municipalities face constraints in terms of their capacities to plan, and most importantly, to enforce land use and occupation regulations.

Brazil should use urban planning, management, and finance to support green and resilient cities. This will vary depending on the scale and capacities of the cities. In the near term, Brazilian metropolises and regional capitals may focus on strengthening their planning and regulatory frameworks to create new incentives and opportunities for climate action, as was done by Sao Paulo, Belo Horizonte, and Porto Alegre. All three cities are harmonizing sector plans (e.g., urban development plans, urban transport and mobility plans, urban water management plans, water, sanitation, drainage and SWM plans etc.), with a comprehensive regulatory setup, including zoning, land use regulations, building standards, and other urban management and financial instruments. There is also coordination with other levels of government. All these elements provide the conditions and incentives for public and private investments to materialize in line with the guidelines, actions, and targets defined within the City Climate Action Plans.

Cities also need to strengthen their capacities in urban planning, urban management, and mobilization of financing to better address their mitigation and adaptation needs. Of particular importance are efforts to build capacities to understand the economic impacts of floods and droughts; conduct evidence-based climate-sensitive planning and decision-making; improve the collection and use of data, including to monitor progress towards the achievement of climate commitments and results; share knowledge; and incentivize private sector investments in climate resilience. For smaller subregional urban centers, the short- and medium-term priorities would be capacity building to enable them to prepare and review their urban development, land use plans and regulations, and climate action plans. The last of these identifies adaptation and mitigation actions at the municipal level to reduce emissions and boost resilience to climate change.

Investments in urban resilience need to address the combined challenges of social exclusion, lagging access to infrastructure and services, and exposure and vulnerability to extreme climatic events, through a combination of structural and non-structural interventions. Large-scale solutions can range from upgrading of informal settlements, to new gray and green infrastructure to improve drainage and flood mitigation, to nature-based solutions (NBS)[196] such as urban linear parks, to regenerating areas of environmental value along water courses. These types of interventions are suitable for Brazilian metropolises and larger regional capitals and should be implemented systematically. Non-structural (or "soft") measures are also needed, and suitable for a broader scale of cities, including where local governments face deeper fiscal and investment constraints. The measures include better knowledge of risks and impacts of hazards, and the strengthening of early warning and disaster preparedness and response systems. Improving disaster preparedness capacity will also require effective coordination with civil protection and defense systems, as well as community engagement.[197]

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[196] Nature-based solutions are actions to protect, sustainably manage, or restore natural ecosystems, that address societal challenges such as climate change, human health, food and water security, and disaster risk reduction effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.

[197] For example, at the state level, the Santa Catarina Flood Modelling Technical Assistance (http://www.hudd.com.br/websigsc/) has empowered both government and civil society to better address disaster risks in the state. The products allow the private and public sector as well as civil society to both adapt and mitigate disaster risks (floods and landslide susceptibility) with the novel geographic information systems (GIS) platform implemented with the results from World Bank technical assistance (TA). As an example, the Government of Santa Catarina has launched the SC Resiliente Program (see https://www.scresiliente.sc.gov.br/) using the TA to support some of the policy recommendations.

Brazil needs to broaden opportunities for financing resilient infrastructure. Despite existing policies and plans for disaster risk management, insufficient investment has led to limited action towards mitigating disaster risks. In terms of financing, multi-year reserves are not used at the national level, and only a few states have established their own disaster funds. Efforts have been made, such as the establishment of the National Calamity Fund (FUNCAP), but they remain non-operational.[198] The country still lacks an ex-ante strategy for the financial management of disasters and support to the most exposed cities.

Box 3. Best practice case studies from São Paulo, Belo Horizonte, and Porto Alegre[199]

São Paulo, Belo Horizonte, and Porto Alegre, all state capitals,[200] have created enabling environments for climate action. All three are harmonizing sector plans (development, transport and mobility, water management, sanitation, drainage, etc.), with a comprehensive regulatory setup, including zoning, land use regulations, building standards, and other urban management and financial instruments. They are also coordinating with other levels of government. Ultimately, and in cohesion, these efforts can provide the conditions and incentives for public and private investments to materialize.

Each city's timing and approach has been different, highlighting the need to tailor efforts for greener, more resilient, and inclusive development. In Belo Horizonte and Porto Alegre, the climate action plans and the most recent urban development plans and regulations have been developed in parallel, making it easier to align policies and objectives. In both cases, however, the planning and regulatory instruments are quite new, making it difficult to measure results. Belo Horizonte's most recent urban development plan was approved in 2019, followed by complementary regulations in 2020. In Porto Alegre, a number of climate-informed sector provisions, incentives, and regulations to promote compact city development and green and resilient infrastructure and building solutions were issued in 2021. The city's urban development and climate action plans are still under preparation, however. In São Paulo, on the other hand, the comprehensive review and approval of the urban development planning and regulatory setup dates back to 2013. Despite having just recently prepared a climate action plan in 2019, the city has a good record of implementation and evidence of successful climate action towards mitigation and adaptation.

In terms of financing, land value capture (LVC) and similar instruments represent a significant portion of Brazilian municipalities' investment capacity and are particularly important in the current context of limited fiscal space. Charging for additional building rights (Outorga Onerosa do Direito de Construir, OODC) is one of the key instruments in São Paulo and Belo Horizonte. It generates most of the resources being channeled to funds for affordable housing and densification of the urban core (e.g., Fundo Municipal de Urbanização, FUNDURB, in São Paulo; and Fundo Municipal de Habitação Popular, FMHP, and Fundo de Desenvolvimento Urbano das Centralidades, FC, in Belo Horizonte). It thereby

[198] World Bank. 2014. "Coping with Losses: Options for Disaster Risk Financing in Brazil." Washington, DC: World Bank. http://hdl.handle.net/10986/29397.

[199] Monteiro, Emanuela et al., 2022. "Urbanization and Climate: Enabling Resilient, Low-Carbon and Productive Cities." Background paper for the Brazil CCDR

[200] Belo Horizonte is the capital of the Minas Gerais state, in the Southeast region of Brazil, holding a population estimated at 2.53 million people (IBGE estimates, 2021). São Paulo is the capital of the São Paulo state, in the Southeast region of Brazil, and it is also the largest city in Brazil in terms of population, estimated at 12.3 million (IBGE estimates, 2021). Porto Alegre is the capital of the Rio Grande do Sul state, in the South region of Brazil, holding a population estimated at 1.49 million people (IBGE estimates, 2021). Belo Horizonte, Porto Alegre and São Paulo have the 813th, the 317th, and the 231st largest municipal GDPs per capita among the 5,570 Brazilian municipalities, respectively. They also are part of the third, seventh, and top most populous metropolitan regions in the country, respectively (IBGE, 2019). All of these municipalities have nearly reached 100 percent urbanization rates.

contributes to a virtuous cycle of inclusive, compact, and transit-oriented development. The resource mobilization by FUNDURB alone increased from about R$300 million in 2013 (prior to the city master plan's approval in 2014) to more than R$880 million in 2021. Of this, 30 percent is earmarked for investments in urban mobility, and another 30 percent for affordable housing (São Paulo Municipal Office for Urban Development, or SMDU, 2022).

Another powerful instrument to finance the climate agenda is the Certificate of Potential Additional Construction (Certificado de Potencial Adicional de Construção, CEPAC). In São Paulo, CEPAC has been used to leverage resources to finance public-private urban development operations (Operações Urbanas Consorciadas, OUCs) in strategic areas mostly located along and around transport corridors and nodes, where there is inherent interest from private developers and where higher densities are permitted; it is also how Belo Horizonte intends to implement its transit-oriented development policies. Between 1997 and 2016, OUC alone leveraged more than R$10 billion, the equivalent to 30 percent of all municipal investments over the period in São Paulo (SMDU, 2016).

City planning and regulatory instruments in these Brazilian cities also include practical incentives for private developers to adopt climate-focused solutions. Instruments such as Gentilezas Urbanas e Benefícios Urbanísticos in Belo Horizonte, and Quota Ambiental in São Paulo help to promote rainwater infiltration and reservation; to increase vegetation, provide shade and effective ventilation systems (tree planting, green rooftops, green façades, etc.); to incentivize active mobility; and to increase the use of renewable sources of energy.

Low-carbon cities can be more productive and livable

Brazilian municipalities are already starting to take action to address climate change. The first-ever municipal-level mapping of GHG emissions in Brazil was published in March 2021, covering all 5,570 municipalities from 2000 to 2018.[201] It shows that many cities have been implementing low-carbon and resilient urban development policies, including compact development, urban land use mechanisms to address underutilization of land, densification of city centers, transit-oriented development and incentives for clean public transport, renewable energy, green infrastructure, and energy efficiency for new construction or retrofitting. Recent analysis found that a bundle of low-carbon measures could enable Brazil to cut urban GHG emissions by 75 $MtCO_2e$ (35 percent) by 2030 and 238 $MtCO_2e$ (88 percent) by 2050, relative to a baseline scenario that reflects the first round of NDCs submitted under the Paris Agreement.[202] Full implementation of the required measures for reducing urban emissions by 75 $MtCO_2e$ would entail incremental investments of US$1.7 trillion by 2050.[203] These investments could pay for themselves through energy and materials savings alone, however, yielding cumulative returns with a net present value of US$369.7 billion by 2050. They could also generate employment, supporting over 4.5 million new jobs by 2030, most of which are concentrated in the energy and construction sectors.

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[201] See SEEG Municípios at https://plataforma.seeg.eco.br. For an English-language summary of key findings, see the March 4, 2021, press release at https://seeg.eco.br/en/press-release. This is an extension of Brazil's Greenhouse Gas Emission and Removal Estimating System (SEEG), an initiative of the Climate Observatory.

[202] Stockholm Environment Institute. 2020. Technically feasible urban mitigation potential of buildings, transport, waste, and energy sectors. Analytics done for CUT, 2021 "Seizing Brazil's Urban Opportunity: Prioritising Urban Transport and Housing Investments for Inclusion and Resilience."
The analysis covers: i) CO_2 emissions from energy use (buildings and transport); ii) emissions from the production of key materials used in urban infrastructure; and iii) methane emissions from waste. It does not cover other urban sources of emissions, such as industry, or carbon sinks (such as urban parks or forests). The analysis distinguishes between emission reductions achievable within the cities, and additional abatement that is possible if the electricity supply is fully decarbonized. The numbers given here include both categories.

[203] Vivid Economics. 2020. "Economic impacts of urban mitigation investments." Analytics done for CUT, 2021 "Seizing Brazil's Urban Opportunity: Prioritising Urban Transport and Housing Investments for Inclusion and Resilience."

Land use and urban planning to promote compact urban form and transit-oriented development can greatly reduce GHG emissions while boosting productivity and making cities more inclusive. Compact urban form reduces the need to travel and, with it, dependence on private vehicles; it also reduces the length of trips and makes it easier to walk or bike, which reduces travel costs and yields health benefits. Moreover, reduced traffic congestion means less air pollution and less time wasted commuting. Compact urban form also reduces the cost of municipal infrastructure and service delivery, and it helps preserve natural ecosystems, biodiversity, and food security. Small and medium-sized urban areas can reconsider their current growth patterns and adopt measures to reduce sprawl and the costs of service provision. Large cities are focusing on medium and high-capacity transit corridors to enable transit-oriented approaches that promote density, bring jobs and homes closer together, and promote walkability. Urban transport also requires effective metropolitan coordination and harmonization of urban transport plans, as currently Brazilian municipalities administer their transit and transport systems independently.

GHG emissions from cities could also be reduced by incentivizing energy efficiency through green building certifications. The adoption of green building certification programs such as the International Finance Corporation (IFC)'s EDGE[204] is one of the most relevant ways to promote this agenda. Between 2017–2020, Brazil certified about 8.2 million square meters of floorspace as green,[205] positioning itself as a leader in this realm in South America. However, this is less than 10 percent roughly of total building construction and it is mainly concentrated in the São Paulo area (about 60 percent of all existing green buildings in the country). Advancing with green buildings will require raising awareness regarding the business case for certifications such as EDGE among key stakeholders: developers, financial institutions, public policy makers, and associated advisors. Certification is a key element to reduce risks of greenwashing; therefore, Brazil will need to provide a definition for green building and promote measurable reporting.

Social service delivery can also be adapted to use more environmentally friendly technologies. Energy efficiency improvements could be integrated across all social sectors, including improving overall school and healthcare infrastructure to be more resilient to extreme weather events. For example, in Mato Grosso, it was calculated that nearly 71 percent of public schools do not manage their waste adequately and, due to weather conditions, there is an intensive use of air conditioning in 73 percent of schools.[206] Across Brazil, many health and education facilities need significant electricity upgrades to promote energy efficiency, including alternative energy sources and update of power transformers.

Solid waste management represents an important component in reducing GHG emissions (mainly methane) in Brazil's cities. For example, GHG emissions inventories show the solid waste sector produced 22 percent of emissions in Rio de Janeiro (0.5 tCO_2e per capita), 16 percent in Salvador (0.13 tCO_2e per capita), 8.6 percent in Curitiba (0.2 tCO_2e per capita), and 8.2 percent in São Paulo (0.11 tCO_2e per capita).[207] Brazil has less open dumping of solid waste than the average for upper middle-income countries, at 23.2 percent (versus 30 percent), while 53.3 percent of Brazil's solid waste is placed in sanitary landfills with gas capture.[208] Waste generation in Brazil is expected to increase from 81.9 Mt in 2020 to 122.3 Mt in 2050. Total emissions from solid waste in 2020 in Brazil were estimated at 92.3 $MtCO_2e$ and based on MCTI mitigation options could be reduced to 77.5 $MtCO_2e$ by 2050 by increasing methane capture and destruction.[209]

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[204] The EDGE certification system and application is a design tool and an affordable certification method developed and owned by the IFC that recognizes different levels of ambition for green buildings up to zero carbon emissions. Third-party EDGE certification providers licensed by IFC have been certifying buildings since 2015. See https://edgebuildings.com.

[205] Including different international certification systems as LEED, AQUA, EDGE and others. This is original analysis from IFC.

[206] Findings discussed with Secretary of Education of Mato Grosso during preparation of a project, 2022.

[207] C40 Cities Knowledge Hub, accessed through https://www.c40knowledgehub.org/s/article/C40-cities-greenhouse-gas-emissions-interactive-dashboard?language=en_US.

[208] Kaza, S. et al. 2018. *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Washington*, DC: World Bank. http://hdl.handle.net/10986/30317.

[209] Methane capture would be 36 percent reduction in waste emissions (possible usage as biomethane); methane burning would be 14 percent reduction in waste emissions. https://openknowledge.worldbank.org/handle/10986/30317.

Investment in water, sanitation, and waste management, and in other urban infrastructure is necessary for Brazil's development agenda. The additional investment costs to ensure that the infrastructure is resilient to climate change, uses potential biomethane from waste management, and promotes energy efficiency, have not been estimated. It is anticipated that, with appropriate economy-wide and sectoral policy measures, most of these investments would be either partly or fully financed by the private sector, given their potential for risk-adjusted revenue generation.

Sustainable mobility is key to reduce emissions and boost growth

In the urban transportation sector, travel demand management (TDM) is a key complement to infrastructure investment. While reliance on individual cars can be reduced by targeted measures like charging for parking or the establishment of low emission zones or congestion charges, complementary action on spatial planning and alternative transportation modes is essential to continue improving access to jobs and services. Introducing congestion charges for private vehicles in Belo Horizonte and São Paulo could generate R$140.3 million and R$720.9 million per month, respectively, which is revenue that could finance improved mass transit.[210] Simulations of low emission zones (LEZs) resulted in wide-ranging levels of emissions reductions, depending on the year selected for banning vehicles made before the specified year. When complemented with a fee-for-car usage (applied to all vehicles), cities obtained a meaningful source of revenue. Using LEZs in São Paulo, Belo Horizonte, and Porto Alegre could avoid up to 11.5 $MtCO_2$ per year. The regulatory framework needs to be approved to ensure that the measures to discourage car use are valid in any city in the national territory and confirm that it is consistent with Brazilian laws and its constitution.

Cities are also exploring and introducing clean fuel alternatives, especially in the public transport fleet. While still nascent, electrification of the public transport bus fleets plays an important role in the transition to electromobility. Electric buses, with zero GHG emissions at the tailpipe, are the most energy-efficient options among the clean bus technologies. In the case of Belo Horizonte, these buses have a lower cost of abatement of GHG emissions than biodiesel buses.[211] Cities such as São Paulo have introduced changes in their climate change laws requiring a 50 percent reduction of CO_2 emissions from public transportation system within 10 years and 100 percent reduction within 20 years.

While there is no coordinated national strategy, there are efforts to promote electromobility on a large scale. Implementation in Brazil is slowly ramping up, both on the policy side and on infrastructure supply. There are federal tax exemptions for electric vehicles in seven Brazilian states.[212] There are also incentives sponsored by the Brazilian Development Bank (BNDES)[213] and a few other consumer initiatives,[214] such as exemption or reduction of import tax rates for electric and hybrid vehicles and a reduction of import tax rates of parts and equipment intended for the production of electric and hybrid buses. The Ministry of Regional Development (MDR) and the Ministry of Mines and Energy (MME), with the mandate at the national level for strategic planning and target setting of electric bus penetration and infrastructure planning, have proposed a financing facility together with guidelines in implementation to prepare pilots in Brazilian cities.[215]

Light-duty EVs currently have a low level of deployment even in major cities, such as São Paulo, and the rest of Brazil. Brazil's Rota 2030, the country's automotive industry policy, places a major emphasis on developing a more sustainable inward-looking domestic automotive industry. The policy requires manufacturers to improve vehicle energy efficiency by 11 percent within the planning horizon. While the

[210] Transport Demand Management study commissioned by the World Bank for the CCDR (2022).

[211] Study on Transitioning to Low Or Zero-Emissions Public Transport commissioned by the World Bank for the Brazil CCDR.

[212] Maranhão, Piauí, Ceará, Rio Grande do Norte, Pernambuco, Sergipe and Rio Grande do Sul. These states do not have many EVs yet, but they are relevant at the national level.

[213] López, G., and S. Galarza. 2016. "Movilidad eléctrica: Oportunidades para Latinoamérica." Report for the United Nations Environment Programme, with support from EUROCLIMA. Centro Mario Molina Chile. https://wedocs.unep.org/xmlui/handle/20.500.11822/26304.

[214] Slowik, P. et al. 2019. "International Evaluation of Public Policies for Electromobility in Urban Fleets." International Council on Clean Transportation. https://theicct.org/publication/international-evaluation-of-public-policies-for-electromobility-in-urban-fleets/.

[215] World Bank. 2021. "Analysis of impact of electromobility scale-up in the Brazilian power sector."

deployment of EVs is unlikely to change significantly until the 2030s, much later than developments in electric buses, the current supply of specialized public EV charging infrastructure in Brazil will need to be scaled up significantly to meet the estimated demand.

Decarbonized power supply would magnify the economic and environmental benefits of EV adoption. Assuming a decarbonized electricity grid, modeling for this report shows the increased electricity demand for EVs could be met at a lower cost (R$24 million[216] or US$4.80 million) per year than with the current power matrix. In addition, slightly lower electricity prices from greening the grid would reduce the negative impact of EV adoption on non-transport spending by R$62.1 million (US$12.42 million) per year compared with a scenario with the current power matrix. In terms of environmental impacts, the decarbonized grid is estimated, in 2021, to generate additional health benefits valued at R$2.8 million/year (US$0.56 million/year) from nitrogen oxide (NO_x) reduction, R$9.95 million/year (US$1.99 million/year) from sulfur dioxide (SO_2) reduction, and R$67.4 million/year (~US$13.48 million/year) from PM_{10} reduction.

[216] This is incremental cost with reference to the current power matrix.

5. Economic Costs, Investment Needs and Financing Options

Main Messages

- Infrastructure investment needed for climate action is estimated at about 1.2 percent of GDP per year over 2022–2050, and just 0.8 percent in 2022–2030.
- These incremental investments for climate action represent about 22 percent of the baseline investment needs to close Brazil's infrastructure gap and achieve the country's development goals.
- The private sector will play a central role in the transition of the Brazilian economy toward a more resilient and decarbonized development path. In particular, private sector finance is expected to cover the majority of capital investments required to expand the power system—but for that to happen, the right enabling environment needs to be put in place.
- Public finance is also expected to play a key role, which would require repurposing existing spending and subsidies. This is particularly important to finance a just transition in agriculture and energy and to incubate early investments in areas such as electrification of the economy and green hydrogen.
- Brazil has been accessing a mix of available climate finance and has the potential to benefit from recent developments in carbon markets. Dedicated climate finance is a source of financing that should continue to support Brazil's efforts to address climate change. There are also new opportunities for the commercialization of forest carbon credits and REDD+ in Brazil.

5.1. Investment needs are significant, but manageable

Meeting Brazil's development objectives will require increased infrastructure investments. Infrastructure spending has dropped dramatically from approximately 4.8 percent of GDP in the 1980s to just over 2 percent in the 2010s and just 1.7 percent in 2021, a volume insufficient to replace depreciated capital, let alone expand the infrastructure stock (Figure 20). The World Bank (2022) estimates that the level of investment needed for Brazil to achieve its infrastructure-related SDGs by 2030 is 3.7 percent of GDP per year.[217]

Maintenance and the replacement of assets represent almost half of total infrastructure investment needs.[218] There are also important sectoral differences in investment, with transportation having the largest financing gap, requiring 2 percent of GDP for transport annually until 2030 (up from the 0.34 percent invested in 2019). While the financing gap is smaller in the remaining sectors. Brazil needs to increase the level of investment in water and sanitation from 0.2 to 0.44 percent of GDP, and in telecommunications from 0.43 to 0.46 percent of GDP. Electricity investments would need to increase from 0.73 to 0.9 percent of total investment needs.

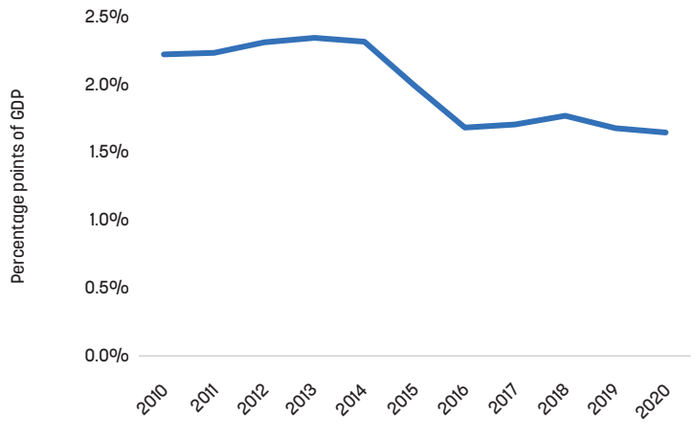
A resilient and low-carbon development path requires larger upfront investments, but in Brazil, the significant role of land use makes the transition less capital-intensive than in many other countries. The CCDR estimates the additional investments required to ensure the country achieves its development objectives in a resilient and low-carbon manner and meets its 2050 net zero commitment (Table 4). These

[217] World Bank. 2022. Brazil Infrastructure Policy Assessment. Forthcoming.

[218] In some sectors, such as electricity distribution and water connections, maintenance and the replacement of existing assets represents up to 75 percent of total investment needs.

investments are additional to a business-as-usual development path based on the forthcoming Brazil Infrastructure Policy Assessment (World Bank 2022), and they are based on the recommendations made in Section 4. They include, for instance, the incremental cost of building all new infrastructure assets so that they are more resilient to current and future climate risks, the increase in investments needed to build a decarbonized but resilient power system (compared with a business-as-usual power system), additional investments to trigger the electrification of the transport system, and investment in pasture recovery, plantation forestry, and natural forest restoration.

FIGURE 20. Total infrastructure investments as a percentage of GDP



Data sources: IADB, 2019 and World Bank WDI, 2021.

TABLE 4. Additional investment needs and economic costs for resilient and low-carbon development

R$ billion	2022–2030	2022–2050
POWER		
Decarbonization (CAPEX)	-0.2	299.1
Transmission and distribution (CAPEX)	0.7	36.2
Resilience to reduced hydrology (CAPEX)	1.0	102.4
Higher resilience and adaptation to lower hydrology (OPEX)	0.8	-61.6
Operational and fuel costs (OPEX)	0.5	-26.9
Air pollution externality	0.1	-2.3
Decommissioning costs (gas and coal)	0.0	2.4
TRANSPORT		
Resilience for roads (CAPEX)	111.7	111.7
Change in road disruptions	-73.3	-235.4
Decarbonization (CAPEX)	248.0	1,091.1
Fuel used (OPEX)	-1.6	-136.0
Air pollution externality	-0.1	-10.4
Congestion, accidents and road damage	-0.3	-23.0
FOREST LANDSCAPES		
Pasture recovery, plantation forestry, natural forest restoration (CAPEX)	124.8	124.8
Pasture recovery, plantation forestry, natural forest restoration (OPEX)	89.2	244.2
Revenue from recovery of pastures, forest plantations and restoration of natural forests	-218.2	-597.0

Enforcement cost	1.5	1.5
Biodiesel and ethanol (CAPEX)	16.0	16.0
Biodiesel and ethanol (OPEX)	24.8	94.3
Revenue from biodiesel and ethanol	-36.2	-130.7
INDUSTRY		
Air pollution externality	-0.2	-13.9
Fuel used	-2.3	-132.0
H_2 export profit	-0.2	-39.0
TOTAL INVESTMENTS AND ECONOMIC COSTS IN THESE SECTORS		
Additional investment needs (CAPEX)	502.0 (0.8% of GDP)	1,781.4 (1.2% of GDP)
Additional economic cost	-215.6 (-0.4% of GDP)	-1,065.6 (-0.7% of GDP)
Total	286.4 (0.5% of GDP)	715.8 (0.5% of GDP)

Investment needs for climate action represent about 1.2 percent of GDP over the 2022–2050 period, including about 0.8 percent of GDP in 2022–2030. They also represent around 22 percent of the investment needs estimated over the same period to close the infrastructure gap and achieve the country's development goals. These investment needs are largely driven by investment in the transport system, to finance the infrastructure needed for modal shift toward non-road transportation. These large investment needs are partly compensated by economic savings, in the form of avoided energy spending in transport or industry, or reduced congestion or air pollution). These economic benefits amount to around 0.3 and 0.7 percent of GDP over 2022–2030 and 2022–2050, respectively. Overall, total economic costs of the resilience and net-zero pathway proposed in this CCDR are about 0.5 percent of GDP, without accounting for avoided climate change impacts (which would depend on action in the rest of the world).

Public spending needs will be increased by transition-related spending, for compensation or social expenditure. While these expenditures are transfers, not aggregate economic costs, they will nevertheless increase pressures on public finance. Over 2022–2050, social expenditures to facilitate the transition of workers and communities affected by the transition are R$700 million (US$140 million) for coal and R$550 million (US$109 million) for gas, which remains small due to the small number of workers in these sectors. Over the same period, compensation to asset owners is small for the sole coal power plant that would have to close before the end of its lifetime (R$1.9 billion or US$370 million), but very large for gas power plants (R$217 billion or US$43 billion). This high cost for closing gas power plants from 2022–2050 is largely due to the plan to construct new gas power plants in the next few years. Other needs to support the transition, such as retraining or reskilling for affected workers in agriculture or industry, were not estimated in this CCDR.

These increased needs for infrastructure investment and social spending will take place in a context of limited fiscal space and increased pressure due to an aging population. As a result, a supporting enabling environment will be required to mobilize private investment toward more resilience and low-carbon development, and the country climate strategy will need to rely on multiple sources of finance, including repurposing of public expenditures and strategic use of climate finance opportunities.

5.2. Multiple sources to finance climate resilience and reach net-zero emissions

The law that instituted the National Climate Change Policy or PNMC (Law 12.187 of December 29, 2009) called for the use of a range of financing instruments to reach the NDC. It established the National Fund for Climate Change, the use of fiscal and tax measures that lead to the reduction and removal of GHGs, the use of credit lines and specific financing from public and private financial agents,

specific allocations for climate change actions in the Union budget, and the use of other financial and economic sources aimed at mitigation and adaptation, including those of international origin. Decree 7.390/2010, which regulated some of the articles of Law 12.187, specifies that the preparation of pluriannual plans (PPA) and annual budget laws by the Federal Government must include programs and actions that meet the objectives of the PNMC.

However, public financing for climate action remains very low. Between 2003 and 2021, an average of only 0.13 percent of total government spending went to environmental management (EM), or 0.08 percent if the spending within environmental management on water resources is excluded.[219] At its peak (in 2013) environmental spending was 0.2 percent of the total budget. In 2021, as fiscal space tightened due to the COVID-19 crisis, EM spending fell to one of the lowest levels in the past two decades. There has been an increased search for financing outside the public budget. Brazil has instruments such as the Amazon Fund which, as of 2020, had raised R$3.4 billion in donations, with R$1.8 billion in projects and 20 percent of the funds for monitoring.[220] The instrument is currently inactive, however, due to decisions taken by the Ministry of Environment. Other forms of climate finance from global and bilateral climate funds have also been mobilized in Brazil, including for Reducing Emissions from Deforestation and Forest Degradation (REDD+). It is anticipated that new financial sources may also become available through emissions trading, given the approval, at COP26, of the Paris Agreement rule book, which includes Article 6. The latter allows countries to voluntarily cooperate with each other to achieve emission reduction targets set out in their NDCs. There are also investments and specialized companies in the voluntary market for the commercialization of forest carbon credits and REDD+ in Brazil.

There are also subnational efforts to mobilize financing for climate action. Sixteen FUs have created "state funds" aimed at financing environmental actions, including mitigation and adaptation measures. The amounts available for financing also greatly vary among states, ranging from a few thousand reais to R$492 million in the case of the Rio de Janeiro State Fund for Environmental Conservation and Urban Development (2018 data).

Brazil could tap into a wide range of sources for mobilizing financing for the additional investment needs. These include repurposing carbon-intensive subsidies to support the low-carbon transition and direct financing of climate-smart actions/investments by using climate criteria for approval of public investment and in public procurement procedures. There is also significant potential for increased engagement with the Brazilian financial sector to exploit opportunities for green investments that involve more extended payback periods, and need long-term, patient financing. Existing private sector engagement can also be scaled up, and there will be new opportunities associated with climate finance (e.g., performance-based payments, green bonds, etc.).

Repurpose agriculture and energy subsidies and tax breaks

In both sectors, there are substantial subsidies that incentivize environmentally harmful and economically inefficient activities. In the power sector, subsidies for coal alone totaled almost R$1 billion (US$200 million) in 2020. Tax waivers and subsidies for coal have been extended until 2040.[221] As discussed in Section 4.1, the share of Brazil's tax expenditures (tax breaks) that went to agriculture grew from 8.93 percent in 2006 to 12.01 percent in 2021, with a majority of these expenditures being allocated for agribusiness and forest industry rather than the ABC program and rural insurance.[222] In parallel, the current parameters of the ITR make extensive cattle ranching consistent with a lower ITR tax bracket. The overall impact of the ITR is thus to incentivize land conversion.[223]

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[219] Young et al., 2022. "Fiscal Aspects of Environmental Policy in Brazil." Background Paper prepared for the CCDR.

[220] http://www.amazonfund.gov.br/export/sites/default/en/.galleries/documentos/rafa/RAFA_2020_en.pdf.

[221] INESC, 2021, "Subsídios aos Combustíveis Fósseis no Brasil (2020): Conhecer, Avaliar, Reformar."

[222] Leitão et al., 2020, "Do Pasto ao Prato: Subsídios e Pegada Ambiental da Carne Bovina." Available at https://www.escolhas.org/wp-content/uploads/2020/07/Do-pasto-ao-prato-subsidios-e-pegada-ambiental-da-cadeia-da-carne-SUMÁRIO-EXECUTIVO2.pdf.

[223] Ibid.

Repurposing existing tax breaks and subsidies could finance a just transition in agriculture and the energy sector. In the agriculture sector, the Government could link eligibility for subsidized credit to the use of climate-smart practices, as described in Section 4.1, and support farmers' enrollment in the CAR. The subsidies for coal-fired power generation could be redirected to support the energy transition, in order to reduce the fiscal burden on the public sector. Subsidies for coal power generation are paid for by end-users through a sectoral fund called the Energy Development Account (Conta de Desenvolvimento Energético, CDE), which also funds a social tariff for low-income consumers and benefits for rural consumers, as well as the Fuel Consumption Account (Conta de Consumo de Combustíveis, CCC). These funds could be redirected to support the clean energy transition.

Brazil's financial sector has a large role to play

Green loans are now mainly provided through earmarked credit to large and mid-sized firms in the energy sector—in particular, hydro and solar power companies—and are geographically concentrated. Half are concentrated in electricity, gas, and other utilities, and most of the growth in green loans can be attributed to the energy sector. If the energy sector is excluded, the share of loans that are green has been stagnant.[224] The lion's share of green lending originated in São Paulo, Rio de Janeiro, and Minas Gerais, where most hydropower plants operate.[225] In addition, northeastern states have experienced a strong increase in solar and wind energy plants, backed by Banco do Nordeste financing lines.

Going forward, bank financing will be key for enabling the transition, especially if it can provide patient capital. Green investments usually involve more extended payback periods, hence the need for long-term financing. The Brazilian financial sector is best placed to exploit these opportunities. It will be important for the patient financing to reach small and medium-sized enterprises (SMEs) in a wide range of sectors. The participation of smaller firms in reaching net-zero commitments is crucial given their density in key value chains for Brazil. However, the use of earmarking should not generate distortions that can undermine productivity.

In 2021, the Central Bank of Brazil instituted new rules for strengthening of risk management structures, based on the recommendations of the Task Force on Climate-Related Financial Disclosures (TCFD).[226] Rural credit has received particular attention, given its importance to Brazil's economy and the objectives of the PNMC. The new regulations call for credit restrictions on projects with activities that overlap with Conservation Units, areas embargoed by federal environmental agencies, or Indigenous and Quilombola lands, among others. There is the need to ensure that policies to curtail lending to carbon-intensive sectors do not inadvertently slow decarbonization in the sectors that are hardest to decarbonize, by starving them of the financing needed for their low-carbon transformation. Earmarking creates a challenge in that it can result in the inefficient allocation of credit, undermining productivity in Brazil's economy. Reforming the credit system to better link subsidies to public goods benefits is important.

A green taxonomy identifies the activities or investments that deliver on environmental objectives, helping drive capital more efficiently toward priority environmentally sustainable projects. A well-defined and structured taxonomy can support better-informed and more efficient decision-making and responses to investment opportunities that contribute to achieving national environmental objectives. In the absence of formally agreed-upon definitions, market actors tend to introduce their own; the result is a lack of comparability, reliability, and accountability, as well as higher transaction costs. A national green taxonomy is useful to provide guidance to the overall financial market, and efforts of the Brazilian Federation of Banks (FEBRABAN) on a green taxonomy guide are positive developments in the context of scaling up green financing opportunities across the Brazilian financial sector.[227]

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[224] Faruk Miguel, Federico Diaz, Fausto Patiño, Alvaro Pedraza and Gabriel Sensenbrenner. 2022. "Banks' exposure to climate risks in Brazil and green lending trends." CCDR background note.

[225] Ibid.

[226] See https://www.bcb.gov.br/detalhenoticia/579/noticia and https://www.fsb-tcfd.org.

[227] FEBRABAN. 2021. "Guia Explicativo da Taxonomia Verde da FEBRABAN." Federação Brasileira de Bancos.

National development banks (NDBs), such as the Brazilian National Development Bank (BNDES) can play a critical role in delivering global climate and sustainable development goals. With a large volume of financing for development originating domestically, Brazilian NDBs are key in financing the development priorities of the government, especially for areas where private finance is not available.

There are multiple opportunities for private sector engagement

A preliminary and indicative estimate, for this CCDR, of the total investment rate by the private sector in Brazil as a percentage of GDP is approximately 15–17 percent. A few industries in Brazil in which private sector companies have led innovation include agribusiness, forestry,[228] renewable energy,[229] public transportation arrangements with electric vehicles, green buildings, green retrofitting, and waste-to-energy plants. Sanitation services are expected to also go through an important disruption by developing performance-based contracts and the local treatment of sewage. The consolidation of a solid concession and PPP framework and a clear indication by the government of the priority projects provide an enabling environment for private investment. Recent examples include energy transmission and sanitation, where the government has successfully delivered multiple concessions.

The private sector is expected to become a key source of financing for most of the investment in the coming years in sectors such as energy and transportation, helping close the infrastructure gap that harms productivity growth. In the power sector, given the high level of private sector participation that already exists, it is reasonable to expect private financing to cover much of the capital investment needed to expand the power system. However, an enabling environment has to be put in place, and some public support will likely be needed to accelerate innovation and incubate early investments in areas such as electrification of the economy and green hydrogen.

In agriculture, the private sector is well positioned to invest in activities that result in removals of emissions (e.g., agroforestry, restoration of pastureland), implement climate-smart agriculture, boost agricultural productivity, and support biomass and second-generation biofuels. The World Bank Group is conducting studies to assess the financial viability of supporting restoration of degraded pastures with agroforestry systems.

Climate finance will continue to play a key role in Brazil

Brazil could continue to access a mix of available climate financing. This includes dedicated climate finance, financing from the domestic and international private sector, climate markets and offsets, multilateral development bank (MDB) lending, and government spending. Brazil is currently tapping into more than R$500 million (US$100 million) in targeted finance from the Climate Investment Funds.[230] Brazil also received more than R$480 million (US$96 million) from the Green Climate Fund for Reducing Emissions from Deforestation and Forest Degradation (REDD+) in the Amazon for the time period of 2014–2015. Dedicated climate finance (grants, concessional loans, performance-based payments such as REDD+, and PES for clearly defined ecosystem services) is a source of financing that should continue to support Brazil's efforts to address climate change, considering the global and regional public-good nature of some of the key actions. There are also opportunities to mobilize external financing via REDD+ for Indigenous peoples and local communities for areas where they have the right to the forest resources (i.e., Indigenous lands and extractive reserves) and a jurisdictional REDD+ approach focused on rewarding state governments for avoiding illegal deforestation.

https://portal.febraban.org.br:443/pagina/3292/1103/pt-br/consulta-publica; see also Hussain, F.I., L. Tlaiye, and M. Jordan. 2020. "Developing a National Green Taxonomy: A World Bank Guide." Washington, DC: World Bank Group. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/953011593410423487/Developing-a-National-Green-Taxonomy-A-World-Bank-Guide.

[228] This has been in large investments in pulp and paper plants, improvement of planted forests, and increased use of technology and climate-smart practices in grain production and other perennial crops.

[229] There are efforts to aggregate solar projects by using credit funds and there is an active R&D agenda associated with biofuel.

[230] See https://www.climateinvestmentfunds.org/country/brazil.

Green bonds and sustainability-linked bonds also offer significant sources of financing for Brazil's transition to a productive, low-carbon, and resilient growth path. In 2017, several important institutional investors signed the Brazil Green Bonds Statement.[231] It expressed their interest in seeing a strong Brazilian green bonds market grow, and presented actions to help achieve this goal. Some of the main barriers to expansion of the green bond market include perceptions of higher risks. In addition, there is the need to address some of the institutional constraints mentioned earlier, including examining the impact of subsidized credit, addressing deficiencies in the legal and judicial systems for handling issues that could emerge, and lastly the risk-averse investment culture.

The development of green financing instruments should also take into consideration the different risk/return profile of potential investors, as well as the capacity of local firms to tap into financial markets. While large institutional investors such as pension funds and financial institutions are better positioned to tap into green financing instruments offered by capital markets (such as green bonds), a large share of the local private sector is composed of less sophisticated firms that may require a different set of instruments and incentive structures. In this context, it would be important for public authorities to adequately segment the market for green finance and develop a strategy to offer green financing instruments, including de-risking structures, corporate loans, project finance loans, revolving credit facilities, derivatives, and others which can support the achievement of Brazil's climate goals.

[231] See https://www.climatebonds.net/files/files/Brazil_Green_Bond_Statement.pdf.

6. Big opportunities, but also real challenges for Brazil

The main message of this CCDR is that Brazil has a prime opportunity to achieve stronger and more inclusive economic growth, build resilience to climate change, and achieve net zero emissions by 2050. Compared with its peers, and because of the importance of land-use emissions and its large renewable energy potential, Brazil is even well-positioned to benefit from global decarbonization trends. And because its current economic model does not deliver the productivity growth it needs to achieve high-income status, there are clear synergies to be captured. Structural policies that promote better use of resources will boost growth, reduce the pressures that lead to deforestation and inefficient energy use, and promote the growth of low-cost green solutions in renewable energy, industry, and transport.

Still, the transition entails real challenges and will require efforts on multiple fronts. Structural growth-enhancing interventions to boost productivity are not enough. They will need to be complemented with economy-wide and sectoral interventions. While the cost of these interventions is manageable—and often even negative when lifecycle costs are considered—they nevertheless face difficult implementation, institutional, and political economy challenges. For example, stronger forest law enforcement, a shift away from fossil-fuel power generation, the electrification of transport, or stricter hazard-informed urban planning create significant distributional effects that will need to overcome political economy challenges, be effectively managed, and sometimes be accompanied by compensation to ensure a just transition.

This CCDR focuses on a subset of issues and a few sectoral deep dives to explore the opportunities and challenges created by climate change, but it does not provide definitive answers. The net-zero pathway proposed in the report is illustrative. Other paths are possible and need to be explored before the country agrees on a long-term decarbonization strategy. Particularly important for the country at this stage is to translate its 2050 commitments into a long-term decarbonization strategy that can guide policy making and defining of shorter-term plans and milestones, to inform future NDC and infrastructure decisions.

While the deep dives proposed in this CCDR target the main vulnerabilities in the country, the report does not cover fully all the challenges that climate change poses to the Brazilian people, and it does not provide an exhaustive quantification of these risks. Possible follow-up studies are already proposed in this report—for instance, on the best options to boost the resilience of the power system to lower water availability, the possible implications of large-scale ecosystem changes on agriculture and water scarcity, or the appropriate carbon pricing solutions in the context of large volatility in energy prices.

This CCDR highlights the urgency for some interventions, because of the irreversibility of some decisions (such as lock-in to gas-fired power generation). It also emphasizes many synergies and low-hanging fruit that would accelerate development and increase resilience or reduction emissions and do not need to be delayed for more studies. Informed of its unique vulnerabilities and building on its unique resources, Brazil can build on these synergies to implement strong climate action and accelerate its journey toward high-income status while achieving its commitment to achieve net-zero emissions by 2050 and protecting its people from the impacts of climate change.

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