Assessment of the policy framework's impact on the renewable energy generation expansion in the Brazilian power grid

Initiative for Climate Action Transparency

Initiative for Climate Action Transparency – ICAT

ICAT Brazil Project phase 3

Assessment of the policy framework impact on the renewable energy generation expansion in the Brazilian power grid

Output 5 – Recommendations for policymakers on how to improve the existing legal and regulatory framework

July 2024

Initiative for Climate Action Transparency – ICAT

Recommendations for policymakers on how to improve the existing legal and regulatory framework

Deliverable #5

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List of abbreviations

ACR	Regulated Trading Environment
ACT	Assessing Low Carbon Transition
ACT-DDP	Assessing Low Carbon Transition – Deep Decarbonization Pathways
AFOLU	Agriculture, Forestry, and Other Land Use
AGE	Adjustment Auction
ANEEL	National Electric Energy Agency
BEN	National Energy Balance
BNDES	National Bank for Economic and Social Development
CAPEX	Capital Expenditures
CBC	Brazil Climate Centre
CBios	Biofuel Emission Certificates
CCC	Copenhagen Climate Centre
CCEAR	Energy Trading Contracts in a Regulated Environment
CCEE	Electric Energy Trading Chamber
CEOs	Chief Executive Officer
CEPEL	Electric Energy Research Center
CGE	Computable General Equilibrium Model
CIMV	Interministerial Committee on Climate Change and Green Growth
CNPE	National Council of Energy Policy
CONACEN	The National Council of Electricity Consumers
COP	Convention on Climate Change
COPPE	Alberto Luiz Coimbra Institute of Graduate Studies and Engineering Research
CPS	Current Policies Scenario
CTJL	Jorge Lacerda Thermoelectric Complex
DDP BIICS	Deep Decarbonization Brazil, China, India, Indonesia, and South Africa
DDS	Deep Decarbonization Scenario
DEMO	Demographic Parameter Estimation Model
DG	Distributed Generation
DIPS	Declarations of Prior Interference
EECS	Electric Energy Compensation System
ELETROBRAS	Brazilian Electric Power Company
EPE	Energy Research Company
ESEP	Electric System Expansion Planning Model
FNMC	National Fund for Climate Change
FONTE	National Energy Transition Forum
GIZ	Gesellschaft für Internationale Zusammenarbeit
GHG	Greenhouse Gas
GW	Gigawatts
HEV	Hybrid Eletric Vehicle

HGV	Heavy Goods Vehicles
HPP	Hydroelectric Power Plant
IBGE	Brazilian Institute of Geography and Statistics
IASA	International Institute for Applied System Analysis (IASA)
ICAT	Initiative for Climate Action Transparency
ICE	Internal Combustion Engines
iCS	The Institute for Climate and Society
IDDRI	Institute for Sustainable Development and International Relations
IEPM	Integrated Energy Planning Model
IKI/BMU	International Climate Initiative / Nuclear Safety
IMACLIM	General equilibrium model of the economy
IMAGINE	Insights from Modelling and Analysis for Global Interactions and National Engagement
iNDC	Intended Nationally Determined Contribution
IRENA	International Renewable Energy Agency
LCV	Light Commercial Vehicles
LEE	Existing Energy Auction
LEN	New Energy Auction
LER	Reserve Energy Auction
LFA	Alternative Sources Auction
LSI	Isolated System Auction
LT-MCM	Long-Term Macroeconomic Consistency Model
LULUCF	Land use change and forestry sector
LpT	Luz para Todos (Light for All)
MATRIZ	Brazilian Energy Mix Model
MMDG	Distributed microgeneration and mini-generation of electricity
MME	Ministry of Mines and Energy
MRV	Measurement, Reporting, and Verification
NAMAs	Nationally Appropriate Mitigation Actions
NDC	Nationally Determined Contribution
NGPS	New Government Policy Scenario
NIB	New Industry Brazil
OPEX	Operational Expenditure
PCL	Local Content Policy
PDE	Ten-Year Energy Expansion Plan
PERS	Social Renewable Energy Program PERS
PLANDEP	Petroleum Refining Study Model
PLANTE	National Energy Transition Plan
PNE	National Energy Plan
PNEf	National Plan for Energy Efficiency
PNMC	National Policy on Climate Change
PNTE	Brazil's National Energy Transition Policy

PPE	Energy Planning Program
ProGD	Power Generation Development Program
Proinfa	Incentive Program for Alternative Sources of Electric Energy
PTE	The Ecological Transformation Plan
REN	Aneel Normative Resolution
RenovaBio	National Biofuels Policy
SAM	Social Accounting Matrix
SCEE	Electric Energy Compensation System
SDG	Sustainable Development Goal
SHPP	Small Hydroelectric Power Plant
SIN	National Interconnected System
TEJ	Just Energy Transition Program
TFP	Total Factor Productivity
UFRJ	Federal University of Rio de Janeiro
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNICA	Union of the Sugarcane and Bioenergy Industry
VRE	Variable Renewable Energy

Contents

Tables

Figures

Forewords

This report is part of the ICAT Brazil Project phase 3, hereafter referred to as ICAT project, which is implemented by Centro Brasil no Clima (Brazil Climate Centre – CBC) in partnership with Centro Clima (PPE/COPPE/UFRJ) with support from the Initiative for Climate Action Transparency (ICAT) and technical support from the UNEP Copenhagen Climate Centre (UNEP CCC).

The previous phases of the ICAT project aimed at the enhancement of the transparency framework in Brazil by developing MRV indicators to assess climate policies and actions at the national (1st phase) and subnational (2nd phase) level. These phases developed mitigation scenarios that provide critical insight for policy development at the national and sub-national levels and proposed MRV indicators to track the implementation of the Brazilian NDC.

The third phase of the ICAT Brazil project, which started in March 2023, builds off insight gained from the first two phases, by providing a detailed analysis of the electricity sector in Brazil. The project assesses the potential expansion of the power sector in the country through variable renewable energies (wind and solar photovoltaic) and biomass, the sustainable development impacts of sectoral policies by applying the ICAT's Sustainable Development Methodology and contributes for the Just Energy Transition planning in Brazil.

This report is the Output 5 of the ICAT project, prepared by Centro Clima/COPPE/UFRJ, and has the primary objective of providing key recommendations for stakeholders, aiming to facilitate the implementation of the DDS for the Brazilian power sector, and for policymakers on how to improve the existing legal and regulatory framework.

1 Introduction

Scenarios are not predictions about the future, but rather ‘stories’ illustrating visions and elements of possible futures. They serve as a powerful approach to reveal the dynamics of change within a system and create parameters. The scenarios presented in outputs 2 (current policies scenarios) and 3 (deep decarbonization scenarios) for 2060 are not intended to forecast the future of the electricity supply; instead, they aim to outline possible pathways to guide responses, determine which paths to take, and what policies and programs to develop. By exploring these diverse trajectories, scenarios help stakeholders understand potential developments and make informed decisions in an uncertain environment.

A well-structured political and regulatory framework is important for the continuous development of renewable electricity in Brazil which, including hydro, wind, solar, and biomass, reached 87.9% of the total supply in 2022 (EPE, 2023a). Brazil has achieved considerable success in developing a renewable power matrix, primarily driven by its abundant natural resources and policy measures. Programs such as the Incentive Program for Alternative Energy Sources (PROINFA), created in 2002 and the financial support from the Brazilian Development Bank (BNDES) have played an important role in fostering this growth. These initiatives have laid a robust foundation for the expansion of renewable electricity sources such as wind and solar.

Despite these achievements, there are still significant challenges that need to be addressed to ensure the sustainable and continuous development of renewable power in Brazil. Regulatory barriers, infrastructure limitations, and financing issues remain obstacles that hinder the full potential of the renewable energy sector. To overcome these challenges, it is essential to refine and improve the existing legal and regulatory framework, modernise and expand grid infrastructure, enhance financial mechanisms, and promote innovation and technology. This report aims to provide policymakers with strategic recommendations to enhance Brazil's renewable electricity policies, ensuring a more resilient and sustainable energy future.

In the context of Brazil’s climate mitigation ambitions, the renewable power sector plays a crucial role. The expansion and integration of renewable power will be essential for meeting the country’s enhanced climate targets and driving sustainable development. This sector is pivotal in reducing greenhouse gas emissions, supporting the transition to a low-carbon economy, and achieving Brazil’s environmental goals.

Thus far, the success of Brazil's renewable energy sector demonstrates the critical role of supportive policies and effective regulatory measures. However, to maintain and accelerate this growth, it is necessary to address the existing gaps and challenges within the policy framework and follow strategic recommendations.

To help achieve these goals, we are presenting suggestions that aim to optimize Brazil's renewable power potential, reduce greenhouse gas emissions, and enhance energy security. This report provides an assessment of the current policy framework's impact on renewable energy generation in Brazil and offers actionable recommendations for policymakers. The recommendations are designed to improve the existing legal and regulatory framework, addressing key challenges, and promote the continued growth of renewable electricity in Brazil. Through the proposed efforts, Brazil can solidify its leadership in renewable power and achieve its long-term sustainability and climate goals.

2 Policies implemented and their long-term impact

Assessing the current policy framework for the electricity sector and its impacts is crucial for ensuring the sustainable and continuous development of renewable power in Brazil, while supporting Brazil's climate change mitigation ambition under its Nationally Determined Contribution (NDC) submitted to the United Nations Convention on Climate Change (UNFCCC). Although Brazil's NDC is economy-wide, renewable energy policies implemented in the country offer significant GHG emissions reductions and thus have an overall positive impact on further global warming. Against this backdrop, this section analyzes Brazil's legal and regulatory framework for policies affecting electricity consumption and generation, with a focus on the expansion of VREs and biomass.

Over the recent decades, Brazil has implemented several key energy policies that have significantly shaped its energy landscape. These policies, projects, and programs include RenovaBio, Light for All, PROCEL, generation and transmission auctions, the Capacity Reserve Mechanism, and more recently, initiatives such as PLANTE and FONTE, Fuels of the Future, the new PAC (Growth Acceleration Program), as well as efforts aimed at promoting a new bioeconomy in Brazil.

This section will summarize the main policies mentioned in Output 2, highlighting the most recent updates, and policies underdevelopment with a primary focus on renewable electricity sources and improvements in energy security and efficiency.

2.1 Current electricity sector policy framework

This section presents a summary of Brazil's legal and regulatory framework for the expansion of VREs and biomass, focusing on the sectoral policies affecting electricity consumption and generation. The details were presented in ICAT 3 Project, Output 2.

2.1.1 Brazilian emission objectives and Nationally Determined Contribution (NDC) pledge

Brazil has played a relevant role in international climate change negotiations since its beginning in 1992, as a host country of UNCED. In, the 2023 update of Brazil's NDC to the Paris Agreement, announced at the Climate Ambition Summit (New York), returns the country's climate ambition to the level of the First NDC of 2015: Emission levels of 1.32 $GtCO_2e$ (reduction of 48%) in GGE by 2025 and 1.20 $GtCO_2e$ (reduction of 53%) in GGE by 2030. Brazil's commitments also include a long-term objective to achieve climate neutrality by 2050. Achieving GHG neutrality by 2050 requires negative CO_2 and emissions in other sectors, such as AFOLU.

Besides the economy-wide mitigation targets, the initial version of Brazil's first NDC had some sectoral goals, such as achieving 28-33% of non-hydro renewables in the power generation mix by 2030. It is worth mentioning that in both CPS and DDS (all four scenarios), the share of renewables in supply – other than hydropower – increased to 42-43% by 2030 (wind, biomass and solar – including utility-scale and distributed power generation).

The current version does not include any sectoral goals. The Brazilian 2023 NDC pledge consists of an economy-wide, absolute mitigation target. This allows the country to allocate efforts towards the most cost-effective measures through flexible pathways, which is a positive aspect. However, the lack of specific targets for each sector means there is no precise control over what can or cannot be done within each sector.

2.1.2 Energy Efficiency Initiatives in Brazil

The connection between energy efficiency and sustainable profitability has become clear in recent years. In an era where technology boosts wealth creation and economic growth, energy-efficient practices are crucial for success. Brazil has implemented energy efficiency policies, including minimum efficiency indices, labelling, and endorsement seals, since the creation of the Brazilian Labelling Program (PBE) in 1984. The most relevant initiatives include:

i) Brazilian Labelling Program (PBE)

Created in 1984 and coordinated by Inmetro, the Brazilian Labeling Program (PBE) classifies products based on their performance in energy efficiency, noise, and other criteria, helping consumers make informed purchasing decisions and encouraging industry competitiveness. Key features include:

- Product Evaluation: PBE evaluates products like refrigerators, washing machines, air conditioners, and lighting products;
- Energy Efficiency Classification: Products are labelled from A (most efficient) to E (least efficient) based on energy performance;
- Consumer Information: Provides standardized energy labels for easy comparison and informed choices;
- Consumer Empowerment: Helps consumers reduce energy consumption and lower electricity bills;
- Market Influence: Encourages manufacturers to produce more energy-efficient products;

- Energy Conservation: Contributes to energy conservation and reduces greenhouse gas emissions.

Overall, PBE promotes energy efficiency and sustainability in Brazil by providing valuable product information and encouraging efficient technology adoption.

ii) National Program for the Conservation of Electric Energy (Procel)

Created in 1985, Procel is a government initiative aimed at promoting electric energy conservation and efficiency in Brazil. It helps reduce electricity consumption, promote sustainable energy practices, and shape the market towards energy-efficient products and technologies. Some key features include:

- Energy Efficiency Standards: Establishes criteria for equipment and appliances, including refrigerators, air conditioners, and lighting products;
- Procel Seal: Awards this seal to products that meet or exceed energy efficiency standards, helping consumers identify efficient products;
- Public Awareness Campaigns: Educates consumers, businesses, and industries on energy conservation and the benefits of energy-efficient products;
- Technical Assistance: Guides industries, businesses, and consumers on implementing energy-saving measures;
- Research and Development: Supports initiatives to improve energy efficiency technologies and practices;
- Monitoring and Reporting: Tracks energy consumption trends and the impact of energy efficiency measures (Published in annual reports);
- Regulatory Support: Collaborates with regulatory agencies to integrate energy efficiency into policies.

Procel has significantly contributed to energy conservation, cost savings, and reduced greenhouse gas emissions in Brazil.

iii) The PotencializEE

The PotencializEE – Transformative Investments in Energy Efficiency is a collaboration between Brazil and Germany for Sustainable Development. This initiative is implemented by the MME and coordinated by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Its goal is to raise awareness about energy efficiency among more than 5,000 small and medium-sized industries in São Paulo, conduct 1,000 energy diagnostics, and implement 425 energy efficiency projects, with funding from financial institutions and a Guarantee Fund. The program aims to enhance the competitiveness of the participating companies and reduce energy consumption by 7,267 GWh and carbon emissions by 1.1 million tons of CO2 equivalent (MME, 2024f).

In addition to the MME, the program involves the Ministry of Development, Industry, Commerce and Services (MDIC) and the Energy Research Company (EPE) to evaluate new public policies, SENAI to provide technical support to the industrial sector, Desenvolve SP and BNDES for financing, the Brazilian Association of Energy Conservation Service Companies (ABESCO), and the National Program for Electric Energy Conservation (Procel).

iv) Other Initiatives

- National Plan for Energy Efficiency (PNEf): Created in 2011, it outlines strategies to improve energy efficiency in industry, transportation, and residential sectors;
- National Energy Efficiency Fund: Established in 2021, it funds energy efficiency projects and aligns PBE Edifica with the Brazilian building performance standard NBR 15575/2021, providing consumers with information on potential energy savings;
- Regulatory Agencies: Agencies like ANEEL and ANP implement regulations to promote energy efficiency in the electric and oil sectors;
- Regional Programs: Various regions and states have their own energy efficiency programs targeting specific sectors or regions;
- Partnerships: Brazil collaborates with international organizations like UNDP and the World Bank to enhance energy efficiency efforts;
- Legislation: Numerous laws and regulations in Brazil address energy efficiency, especially within environmental and sustainability contexts.

2.1.3 Incentive Program for Alternative Sources of Electric Energy (Proinfa)

Established by Law No. 10,438/2002, Proinfa is one of the largest programs promoting alternative electricity sources. Its goal is to increase the use of renewables like small hydroelectric, wind, and biomass plants. Project costs are divided into monthly quotas collected by distributors, transmitters, and cooperatives, based on the Proinfa Annual Plan (PAP) prepared by Eletrobras and sent to ANEEL. All free and regulated consumers of the National Interconnected System (SIN), except low-income consumers, contribute to these quotas (CCEE, 2024).

2.1.4 National Biofuels Policy (RenovaBio)

Launched in December 2016 by the Ministry of Mines and Energy, RenovaBio aims to expand biofuel production sustainably. It sets decarbonization goals to increase biofuel use in Brazil's energy mix. Distributors can purchase Biofuel Emission Certificates (CBios) from producers based on avoided emissions throughout the biofuel lifecycle.

RenovaBio also promotes bioelectricity from agricultural wastes like sugarcane bagasse. In 2022, sugarcane bioelectricity produced 18,400 GWh, 72% of Brazil's biomass electricity. Though only 15% of potential was used, full utilization could reach 151,000 GWh, covering over 30% of the National Integrated System's energy needs.

Expansion depends on incentives, biomass availability, and infrastructure investment. With RenovaBio's support, bioelectricity could grow by more than 55% by 2030, contributing to a more diversified and sustainable energy mix (EPE, 2020b)

2.1.5 Energy auctions – generation and transmission

Brazil has an energy auction system to buy electricity generated by new power plants and expand transmission lines.

Brazil is renowned for its extensive experience with renewable energy auctions, including wind, solar, biomass, and small hydropower plants. Introduced in the 2004 market reform, these auctions serve various political goals. Two main types have promoted renewable energy: regular new energy auctions and reserve auctions (IRENA, 2017).

Energy auctions are now the primary method for energy procurement in Brazil, conducted by the Chamber of Electric Energy Commercialization (CCEE) under ANEEL's delegation. The auctions aim to ensure energy supply at the lowest cost by using market mechanisms to increase contracting efficiency. SIN distributors contract their resources through these auctions in the Regulated Trading Environment (ACR), with the lowest tariff criterion defining winners.

Eight types of auctions help maintain a diverse and modern energy mix. The auction of Alternative Sources (LFA) targets renewables, and Brazil's first LFA was held online in 2007. Projects must be registered with the Energy Research Company (EPE) to participate. Once approved, companies join the Electric Energy Trading Chamber (CCEE) platform. Distribution companies act as buyers, entering Energy Trading Contracts in a Regulated Environment (CCEAR) with successful entrepreneurs. In addition, wind sources have also begun participating in New Energy Auctions (LEN) and Reserve Energy Auctions (LER) (CCEE, 2023).

Projects must be registered with the Energy Research Company (EPE) and participate virtually via the Electric Energy Trading Chamber (CCEE). Companies can also independently install renewable energy plants, complying with sector regulations and obtaining necessary authorizations.

Transmission auctions in Brazil play a critical role in the development and expansion of the country's electricity infrastructure. These auctions serve as mechanisms for selecting companies or consortia to build, operate, and maintain transmission lines, substations, and related infrastructure. The federal government signed contracts for new transmission lines in 2023 and plans new ones in 2024. The transmission auction was planned to transport the increased supply of renewable energy (wind and solar) generated in the Northeast region and targeted for other regions. In addition, the tenders also aimed at boosting existing networks, ensuring greater capacity and reliability for the system's operation.

2.1.6 Distributed Electric Power Generation Development Program (ProGD)

Launched in 2015 by the Ministry of Mines and Energy, ProGD encourages the development of distributed generation from renewable sources. Key benefits include low investment costs and financing options with quicker returns. While primarily targeting solar energy, ProGD also supports wind microgeneration through favourable credit lines and incentives for industries manufacturing renewable energy components, along with the creation of energy credits between consumer-generators and distributors (BRASIL, 2015).

2.1.7 Just Energy Transition Program (Law n. 14,299/2022)

Law No. 14,299/2022 establishes the Just Energy Transition Program (TEJ), aiming for carbon neutrality while considering socioeconomic impacts and resource valorisation. The program prepares Santa Catarina for the closure of coal-fired power generation by 2040, promoting a responsible and sustainable end to coal exploitation (BRASIL, 2022b).

Key components include:

- Council Planning: A council (Decree n. 11,124/2022) will plan actions, set guidelines, and identify responsibilities and funding sources for the program;
- Socioeconomic and Environmental Goals: Aligns with federal carbon neutrality targets, ensuring sustainable use of energy and mineral resources;
- Jorge Lacerda Thermoelectric Complex (CTJL): Includes contracting electricity generated by this thermoelectric plant during the transition.

The program ensures a timely, responsible, and sustainable transition away from coal in Santa Catarina.

2.1.8 Offshore Wind Energy Regulation (Decree n. 10,946/2022 and Bill n. 11,247/2018)

Decree n. 10,946/2022 governs the use of physical spaces and natural resources in the inland waters under federal jurisdiction, territorial sea, exclusive economic zone, and continental shelf for offshore electricity generation, including wind energy (BRASIL, 2022a).

Key points include:

- Focus on Offshore Wind: Offshore wind energy is prominent, with 97 projects under licensing by IBAMA, totalling 234 GW (IBAMA, 2024);
- Need for Refinement: The decree requires refinement to address regulatory and environmental issues.

Recommendations for improvement (DECARBOOST, 2023):

- Include environmental analysis during prism use assignments;
- Create a marine spatial plan defining prohibited areas;
- Develop a methodology for selecting winning projects in case of overlap;
- Define steps for presenting Declarations of Prior Interference (DIPS);
- Establish a one-stop shop for DIPS submissions;
- Create incentive policies, such as exclusive auctions, for offshore wind energy.

Bill n. 11,247/2018 (CAMARA, 2018) originally addressed the expansion of institutional responsibilities related to the National Energy Policy, aiming to promote the development of electricity generation from wind sources located in inland waters, territorial sea, and exclusive economic zone.

However, heavily criticized amendments have been added. Below are some of the attached amendments (EPBR, 2023).

- Mandates that coal-fired power plants with contracts expiring by 2028 will have their contracts renewed until 2050, with a 70% inflexibility rate;

- Mandates the installation of 4.25 GW of natural gas thermal plants: 1,250 MW in the Northeast and 1,000 MW in the Midwest in regions without natural gas supply, as well as 1,000 MW in the North and 1,000 MW in the Southeast. The contracts must be made by 2031;
- Mandates the installation of 4.9 GW in small hydroelectric power plants (PCHs). Contracts must be made by 2025 for 3,000 MW in the Midwest, 1,500 MW in the South and Southeast, and 400 MW in the North and Northeast regions;
- Extends the deadline for the connection of distributed generation plants by 12 months and changes the starting point to the signing of the contract, instead of the distributor's report;
- Amends the Proinfa rules. It maintains the 20-year extension already in effect under the Eletrobras privatization law but changes the amount paid for the energy;
- Establishes that ANEEL will calculate the tariff benefit of keeping each plant operational, and if it is lower than that of the A-6 auction in 2019, it will indicate a lower value for contract renewal.

According to the National Association of Energy Consumers, a bill like the 11,247/18 should not be used or become a tool for compulsory contracting, market reserves, and maintaining subsidies for generation sources that are already competitive (CANAL ENERGIA, 2023).

2.1.9 Distributed microgeneration and mini-generation of electricity (MMDG) and the Electric Energy Compensation System (EECS)

ANEEL Normative Resolution n. 482/2012(ANEEL, 2012) enabled consumers to generate their own electricity from renewable sources or qualified cogeneration and supply surplus to the local distribution network for compensation. Key points include:

- Net Metering: Allows consumers to feed surplus renewable energy back into the grid and offset their electricity bills;
- Connection Standards: Establishes technical standards for safely connecting small-scale renewable energy systems to the grid;
- Timeframe: Consumers can accumulate credits for excess energy produced over five years, which are credited to their next electricity bill;

- Renewable Energy Expansion: Encourages the growth of distributed solar and other renewable energy installations, making them financially viable for individuals and businesses.

These rules initially defined by Resolution n. 482/2012, were improved by Resolution No. 687/2015(ANEEL, 2015), and further updated by Law No. 14,300/2022 (ANEEL, 2022).

2.1.10 Legal Framework for Distributed Generation (Law n. 14,300/2022)

Law n. 14,300/2022(ANEEL, 2022), the "Legal Framework of Distributed Generation," established regulations for distributed microgeneration and mini-generation, the Electric Energy Compensation System (SCEE), and the Social Renewable Energy Program (PERS). This law enables the generation of renewable energy on-site or near the consumption point, allowing consumers to receive energy credits on their bills. The main goal of the new framework is to provide legal security and predictability, as rules for the small-scale distributed generation were already provided, but only in the form of a regulation – Normative Resolution No. 482/2012 from ANEEL.

Key points:

- Defines maximum power limits of 75 kW for microgeneration and 3-to-5 MW for mini-generation, depending on the energy source;
- Allows reallocation of surplus credits to other consumer units of the same owner within the same concession area (Electrical Energy Compensation System);
- Permits the transfer of electricity bills to the consumer-generator for shared generation setups, facilitating credit transfers (ownership unification);
- MMGD to be subject to distribution tariff rules (e.g., tariffs that cover operational costs and physical assets of distributors), according to specific provisions. Specific transition periods for the application of such rules were enacted.

Since the law's enactment, over 2.640 micro and mini-generation connections have been made, totalling more than 29 GW of installed power, representing significant growth in distributed generation in Brazil (ANEEL, 2024).

According to the Law, starting in 2029, users of distributed generation will only be compensated for the portion of energy benefiting from solar distributed power. The legislation established a schedule for charging distribution fees to consumers who install photovoltaic panels after January 2023. To offset the removal of incentives, the National Energy Policy

Council (CNPE) published the guidelines for valuing the costs and benefits of MMGD for the electric system through Resolution No. 2/2024(BRASIL, 2024b).

ANEEL must follow these guidelines to dictate the tariff model and consider the effects of distributed generation on the Brazilian energy matrix, including impacts on transmission and distribution networks (energy losses during and locational impacts of network connections), operational costs, supply quality, and sectoral charges. This includes considerations for investment and expansion in distribution and transmission infrastructure (improvements, reinforcements, and equipment replacements), operational costs impacting distribution companies, centralized generation, and ancillary services to ensure system stability while avoiding double-counting benefits.

ANEEL must assign a monetary value to each guideline's impact, summing these to result in a net value, indicating either a general benefit or cost. ANEEL will also calculate the financial impact of MMGD on the electrical system and reflect this in the bills of consumers participating in the SCEE. This resolution instructs ANEEL to periodically review the rules and procedures related to MMGD costs and benefits, ensuring they stay updated with technological, economic, and regulatory changes in the electrical sector. Resolution No. 2/2024 dictates the guidelines, but investors still do not know what the official energy compensation rules will be starting in 2029.

2.1.11 Environmental Credit Line

Financial institutions recognize the importance of investing in renewables for GHG emission reduction and aligning with environmental and social responsibility. They offer various incentives and credit lines to support sustainable development projects in the electricity sector. Notable offerings include:

- BNDES Finem – BNDES Power Generation: Supports the expansion and modernization of renewable and natural gas thermoelectric energy generation (BNDES, 2023);
- Bank of Brazil Renewable Energy Credit: Finances residential photovoltaic systems (BB, 2023).

Additionally, BNDES manages the National Fund for Climate Change (FNMC) with the Ministry of the Environment, funding renewable energy projects and initiatives to combat climate change.

It is worth mentioning the existence of a Local Content Policy (PCL) for the development of wind energy in Brazil, whose main objective is to promote the national production chain in the wind sector, boosting job creation, technology transfer, and local technological development.

The main instruments of the Local Content Policy are:

- Local content requirements in wind energy auctions: These determine the minimum percentage of national components that must be used in the production of wind turbines and other equipment for wind projects participating in energy auctions;
- BNDES Financing: The National Bank for Economic and Social Development (BNDES) offers credit lines with lower interest rates for wind projects that meet local content requirements.

2.2 Emerging policies and programs impacting the electricity sector

2.2.1 Provisional Measure n. 1,212/2024 (Renewables MP 1.212)

Provisional Measure[1] n. 1,212/2024 aims to promote and develop clean and renewable electric energy projects, with an emphasis on wind and solar sources, in addition to implementing measures to reduce electricity tariffs for consumers in the short term (BRASIL, 2024a).

This Provisional Measure amends laws No. 9,427/1996, No. 9,991/2000, and No. 14,182/2021 to include new provisions that benefit the renewable energy sector and reduce electricity costs. Currently, the Provisional Measure is awaiting review by a joint committee composed by members from both the Chamber of Deputies and the Federal Senate. The committee has a deliberation deadline of June 8, 2024. After this date, the Provisional Measure will gain urgent status.

The provisional measure allows for the early receipt of funds from Eletrobras, a former state-owned company privatized at the end of the previous administration. These funds, initially intended for research, development, and energy efficiency programs by ANEEL, will now be redirected to reduce electricity bills in the short term. MME estimates that this action could decrease annual energy adjustments by 3.5% to 5% (SENADO, 2024).

There are some criticisms of Measure No. 1.212/2024, due to the relationship between subsidies and tariff moderation in the Brazilian electricity sector – particularly regarding

[1] A legal instrument used in Brazil that allows the executive branch to enact laws temporarily. These measures have the force of law immediately upon issuance but must be approved by the legislature within a certain period to become permanent.

renewable energies - and to a short-term mechanism for tariff reduction, to prevent tariff increases in the state of Amapá (GESEL, 2024).

Regarding renewable energy plants, the Provisional Measure also adjusts the benefit deadlines for installation projects, aligning them with the construction schedule of the new transmission lines auctioned by the federal government. Additionally, it reduces energy adjustments in Amapá to the average observed in the North Region, expected to be 9%. Before this regulation, it was projected that electricity bills in Amapá would increase by 44% this year (SENADO, 2024a).

The Provisional Measure could potentially raise electricity tariffs instead of lowering them. Extending subsidies can increase costs for consumers, particularly in the regulated market. These subsidies are seen as adding to the financial burden on residential consumers without providing sufficient benefits. Critics advocate for comprehensive structural reforms rather than temporary solutions, warning that the continued reliance on isolated measures and the lack of a thorough regulatory overhaul could lead to a significant crisis in Brazil's electric sector by 2030.

The National Council of Electricity Consumers (CONACEN) emphasized that the expansion of solar and wind power plants, taking advantage of subsidies considered unnecessary, is inconsistent. These plants have been pressuring captive consumers with costs of involuntary over-contracting by distribution companies. It urged the federal government to make efforts to reverse subsidies that are no longer necessary for incentivized sources and for mini and micro-distributed generation, as well as to request a comprehensive legal reform in the electricity sector (CONACEN, 2024).

2.2.2 New Industry Brazil (NIB)

Brazil launched an action plan for Neo-industrialization in January 2024. The plan aims to promote the country's growth with an emphasis on sustainability, innovation, and reducing greenhouse gas emissions, in addition to encouraging the bioeconomy and energy transition. Named New Industry Brazil (NIB), this industrial policy seeks to stimulate technological development, increase the competitiveness and direct investments, create better jobs, and expand Brazil's presence in the global market (SENADO, 2024b).

The goals have a focus on t bioeconomy, decarbonization, and energy transition and security (mission 5). The objective is to increase the share of biofuels in the transportation energy matrix by 50% currently, green fuels represent 21.4% of this matrix. Additionally, there is an expectation to increase the use of biodiversity by the industry and reduce the carbon emissions of the industrial sector by 30%, which is currently 107 million tons of CO2 per trillion dollars produced. To promote the ecological transformation of the industry, the production of bioenergy and equipment for renewable energy generation are priority areas (MDIC, 2024).

Recommendations for the decarbonization of the electric sector in the industry:

- Adoption of renewable energies;
- Improvement of energy efficiency;
- Electrification of industrial processes;
- Incorporation of energy storage technologies;
- Utilization of smart grids;
- Government incentives and policies.

Although the NIB does not have a specific focus on renewable energy or biomass, the measures outlined in the plan can create a more favourable environment for the development of these sectors. For example, incentive for research, development, and innovation (RD&I), and the plan also includes the creation of financing lines and support programs for RD&I in areas such as renewable energy, energy storage, and biomaterials.

2.2.3 Climate Plan

The Climate Plan, to be presented in 2025, is an update to the National Climate Change Policy (2016) with Brazil's targets for reducing greenhouse gas emissions. It serves as the main guide on the transition to a low-carbon economy, providing a roadmap for Brazil to continue reducing deforestation and advancing towards a low-carbon economy with the aim of achieving climate neutrality. To this end, the Climate Plan, which is the responsibility of the Federal Government, proposes two working groups (Adaptation and Mitigation) divided into 15 sectoral adaptation plans for the climate crisis (MME, 2024b) and 8 sectoral plans with emission mitigation targets (MME, 2024c) both have energy sector subgroups, coordinated by the MME. These plans will be based on technical and scientific data and societal participation.

Currently, the development is in the phase of listing the necessary actions in each area by the respective ministries. The goal is to reduce to 1.32 $GtCO_2e$ in 2025, 1.2 $GtCO_2e$ in 2030, guide and boost mitigation and adaptation in the country until 2035 and reach net-zero greenhouse gas emissions by 2050. The plan will also account for costs associated with mitigation, adaptation (infrastructure, energy, agriculture), and losses and damages (as seen in the current situation in Rio Grande do Sul).

2.2.4 Ecological Transformation Plan

The Ecological Transformation Plan (Plano de Transformação Ecológica - PTE) (MF, 2023) was presented as a proposal from the Global South (developing or emerging countries) to promote sustainable development. It will be structured around six pillars: sustainable financing, technological development, bioeconomy, energy transition, circular economy, and infrastructure and adaptation to climate change. Measures include the implementation of a regulated carbon market, the creation of technological innovation hubs in universities, the expansion of forest concession areas, the electrification of bus fleets, the promotion of recycling, the issuance of sustainable sovereign bonds, the creation of a sustainable taxonomy restructuring of the Climate Fund to finance activities involving technological innovation and sustainability and reduce the risks of natural disasters.

The energy transition pillar includes programs influencing the electricity sector, such as the electrification of urban public transport buses with national content rules in public procurement and addressing bottlenecks for the expansion of wind and solar power in the Northeast, and the replacement of oil-based generation in isolated systems (Amazon Energy Program). It is a development plan aimed at increasing employment and productivity, but with environmental sustainability and social justice combined. It brings the social aspect into the energy transition, ensuring a just transition and addressing the social impact of this transition.

2.2.5 National Energy Transition Policy

Brazil's National Energy Transition Policy (PNTE - Política Nacional de Transição Energética), currently under development by the MME, aims to establish a regulatory and strategic framework to promote the country's long-term energy transition. The political drivers are industrialization on new bases (greener and technological), combating poverty and promoting social inclusion, socioeconomic development and jobs, engagement, social participation and diversity, mitigation of carbon emissions, reduction of deforestation and promotion of the green economy and climate adaptation (MME, 2023b). Energy scenarios supports the design of this energy policy indicating a plurality of uncertainties, risks, and trajectories (CEBRI *et al.*, 2023).

PNTE is an instrument for integration and coordination of national policies. This policy is designed to increase social participation and foster coordination and integration of inclusive dialogue on energy transition (MME, 2024e), facilitating communication with investors and the public, as well as aligning with other public policies (economic, social, industrial, environmental, and climate), such as the National Climate Change Policy and the Ecological Transformation Plan. This involves a cross-sectoral approach with a legal-regulatory framework, an investment portfolio, capital allocation and financing, and addressing the social dimension of the transition.

The National Energy Transition Plan (PLANTE- Plano Nacional de Transição Energética) and the National Energy Transition Forum (FONTE- Fórum Nacional de Transição Energética) are key components (instruments) of this policy. PLANTE aims to transparently develop and present energy transition policies, emphasizing economic, social, and environmental development. The plan adopts a sectoral approach, covering energy in industry, transportation, the electricity sector, the oil and gas sector, and the mineral sector (MME, 2024d). FONTE will enable the integration of views from social movements and other societal actors, promoting structured and coordinated dialogue, understanding how society is affected and how to better plan Brazil's energy future (MME, 2024a).

The articulation of Brazil's Energy Policy will be integrated with other public policies, addressing the energy trilemma: energy security, energy equity, and sustainability. The policy aims to transform energy into a driver of sustainable development and a strategic factor for the country, promoting employment and income, social inclusion, reduction of socioeconomic and regional inequalities, economic growth, reindustrialization, climate change mitigation, preservation of biodiversity and environmental quality, improvement of quality of life (MME, 2024d).

2.2.6 Electricity for all Program (Programa Luz para todos)

In 2000, there were 2 million rural households without access to electricity services, according to the census by the Brazilian Institute of Geography and Statistics (IBGE). Aiming to promote the universalization of electric power in Brazil, the Federal Government established the National Program for the Universalization of Access to and Use of Electric Energy – Luz para Todos program through Decree No. 4,873/2003 (UNBPAR, 2024).

The Program aims to democratize access to electricity, helping to combat energy poverty, promote social and productive inclusion of vulnerable communities, and foster citizenship and improve the quality of life for rural populations and those in the Legal Amazon that still do not have access to the public electricity distribution service (MME, 2024f).

To achieve this, it uses clean and renewable energy sources for electricity generation, always considering sustainability, the continuity of public electricity distribution services, and the preservation of the Amazon biome.

2.2.7 Amazon Energy Program (Programa Energias da Amazônia)

Decree No. 11,648/2023 established by the Ministry of Mines and Energy (MME), launched the Amazon Energy program. Its objective is to reduce the use of fossil fuels in the region and, consequently, decrease greenhouse gas emissions through electricity generation from renewable sources (MME, 2023a).

According to 2022 generation data, it is estimated that the current 211 isolated locations, not connected to the SIN, emit around 2.3 million tons of CO_2 annually. The Amazon Energy program aims to transition energy generation, which is mainly diesel-based in the isolated systems of the Amazon, to renewable sources (MME, 2023). Approximately R$ 5 billion in investments are planned to facilitate this transition, replacing fossil fuel-fired power plants with renewable energy plants (CANAL SOLAR, 2023).

The program aims to integrate isolated systems, promote renewables in remote areas, and connect communities without access to the electrical grid if technically, economically, and socio-environmentally viable.

2.2.8 Restructuring the electricity sector

Today, recent proposals are in Public Consultation MME No. 21/2016 and No. 33/2017, Bill No. 1,917/2015, and Bill No. 414/2021 (formerly Bill No. 232/2016), being discussed in a Working Group (WG Modernization - MME Ordinance No. 187/2019). The reports address regulatory issues (the contracting process, separation of capacity and energy, and the already implemented hourly price formation-PDL), technological issues (new technologies), commercial aspects (opening of the free market), and social and environmental advancements. The electric sector is transitioning from a system based on large-reservoir hydroelectric plants with thermal complementation to a diversified matrix with the addition of more variable renewable sources.

Currently, the free electricity market is restricted to large consumers, while others are served by the so-called captive market, which requires electricity consumption to be through a single distributor available in the region. With the approval of Bill No. 414, all consumers will have access to the free energy market, with the possibility of entering bilateral contracts with other suppliers, in addition to regional distributors, for power supply.

Thus, this modernization involves different fronts to adapt the electric sector to new characteristics. For example, the hourly PDL implemented to capture appropriate prices for wind and surplus energy, and the discussion of separating capacity and energy for greater system reliability.

2.2.9 Greenhouse Gas Emissions Trading System (SBCE) – Bill n. 2,148/2015

Bill n. 2,148/2015 establishes the Brazilian Greenhouse Gas Emissions Trading System (SBCE), sets emission caps, and outlines rules for trading compensation credits. The bill was approved by the House of Representatives in December and the Senate is revisiting the Bill.

The Bill creates greenhouse gas emission limits for companies. Those exceeding the limits must purchase credits to compensate, while companies under the limits can sell their excess credits on the market.

Key Points:

- Emission Limits: The bill sets emission limits for companies, requiring those that exceed these limits to purchase credits;
- Compensation Credits: Companies under the emission limits can sell their credits;
- Exemptions: The bill excludes agribusiness sectors from regulation;
- Vehicle Emissions: A new provision requires vehicle owners to buy carbon credits to compensate for emissions, regulated by state and federal transit authorities.

Carbon Credits Generation

The Bill lists several actions that can generate carbon credits, including:

- Restoration and conservation of permanent preservation areas (APPs) and legal reserves;
- Management of sustainable use conservation units;
- Agrarian reform settlement projects.

Regulated Market

The proposal establishes a regulated market for emission compensation credits linked to the SBCE, which will be developed in five phases over six years. The system will trade Brazilian Emission Quotas (CBE) and Verified Emission Reduction Certificates (CRVE).

Regulations

Activities emitting over 10,000 tons of CO_2 equivalent annually must submit monitoring plans and annual emission reports to the SBCE managing body. Those emitting over 25,000 tons must also submit periodic compliance reports.

Governance and Transparency

The SBCE will include a managing body, a deliberative body, and a permanent advisory committee. The bill mandates public consultations on norms and technical standards for emission measurement, reporting, verification, and allocation plans.

Conversion of Credits

Current credits from the voluntary market can only be converted into CRVEs with proof of actual carbon reduction or removal according to accredited methodologies. These credits must be registered in the central SBCE registry.

Senate Project

The report of Bill No. 2,148/2015 in the House addresses 11 other bills appended to it, including Bill No. 412/2022, originally proposed by a senator. Despite recognizing the positive aspects of Bill No. 412/2022, the House rapporteur recommended its rejection, incorporating many of its provisions into Bill No. 2,148/2015 instead. Any amendments made by the Senate will require final approval by the House.

3 Summary table

Table 1 summarizes the existing policies and programs that directly and indirectly influence the electricity sector.

Table 1 – Summary of policies and programs that directly and indirectly influence the electricity sector

Title	Description	Attention points
Brazilian emission objectives and Nationally Determined Contribution (NDC) pledge	International commitments position Brazil as a climate leader. 2050 net zero target	Ambitious economy-wide targets. Sectoral mitigation targets still under definition
Energy Efficiency Initiatives in Brazil	Reduced energy consumption, cost savings, and lower environmental impact	
Incentive Program for Alternative Sources of Electric Energy (Proinfa)	Diversification of the energy matrix and promotion of renewables	
National Biofuels Policy (RenovaBio)	Reduction of greenhouse gas emissions and promotion of biofuels	
Energy auctions - generation and transmission	Competitive process reducing costs and attracting investments	
Distributed Electric Power Generation Development Program (ProGD)	Encourages distributed generation, reducing transmission losses	
Just Energy Transition Program (Law No. 14,299/2022)	Seeks a just energy transition with a focus on social impacts	Complex implementation requiring coordination among various entities. Postponement of subsidies for coal until 2040.
Offshore Wind Energy Regulation	Utilization of offshore wind potential, diversifying the energy matrix	Need for a regulatory framework, adequate infrastructure. Political interference (various amendments): postponement of subsidies for renewables, new conditions facilitating the contracting of natural gas-fired thermal power plants, incentives for SHPP, and even new incentives for coal mining.
Legal Framework for Distributed Generation (Law No. 14,300/2022)	Provides legal certainty for investments in distributed generation	Investors still do not know what the official energy compensation rules will be, starting in 2029.
Environmental Credit Line	Facilitates financing of sustainable projects	Restrictive eligibility criteria Limited access for small and medium-sized enterprises
Provisional Measure n. 1.212/2024	Encourages the use of renewable energy sources	Extending subsidies
New Industry Brazil (NIB)	Promotes modernization and sustainability of Brazilian industry	Lack of detail on how goals will be achieved

Title	Description	Attention points
Climate Plan	Directs efforts to mitigate climate change	Conflict between economic growth and environmental sustainability Ambition of goals may not match execution capacity
Ecological Transformation Plan	Integrates economic development with environmental protection	May be seen as too ambitious without a clear execution plan
National Energy Transition Policy	Guides the transition to a more sustainable energy matrix	Coordination and implementation challenges Need for complementary policies to ensure effectiveness
Luz para todos (Electricity for all)	Expands access to electricity, promoting social inclusion	High implementation cost in remote areas
Amazon Energy Program	Promotes the use of renewable energy in the Amazon	Logistical challenges and high costs
Restructuring the electricity sector	Modernizes and makes the sector more efficient	A complex process that may cause short-term uncertainties. Need to ensure that restructuring benefits all stakeholders fairly
Greenhouse Gas Emissions Trading System (SBCE) – Bill 2148/2015	Creates a carbon market that covers all sectors except the agricultural sector	Scope and coverage, emission permit allocation, monitoring, reporting and verification (MRV), pricing mechanism, offset limits, international alignment with other carbon trading schemes and enforcement mechanisms.

Source: Prepared by the authors.

4 Unlocking DDS for the Brazilian electricity sector

Unlocking the deep decarbonization scenario (DDS) for the Brazilian electricity sector is a critical aspect in Brazil. As highlighted by IRENA (COP 28 IRENA AND GRA, 2023) the key enablers to fast-track the energy transition, by increasing renewable power, revolve around critical aspects such as infrastructure and system operation, policy and regulation, supply chains, skills and capacities, finance, and international collaboration. To maintain high levels of renewables in the electricity matrix and decarbonize even further to be able to follow the DDS trajectory, some bottlenecks need to be eliminated. Within the Brazilian electricity landscape, specific initiatives must be undertaken, including robust electricity transmission planning, technology transfer and financing, recognizing the unique attributes of different electricity sources, particularly the role of hydroelectric plants for the system and energy storage technologies, implementing carbon pricing mechanisms, and ensuring coordinated climate policy efforts between the federal government and regional entities. In this context, Brazil's journey towards deep decarbonization requires a holistic approach and a multifaceted strategy to embrace sustainability and renewable energy sources.

4.1 Electricity Transmission Planning – Infrastructure

The Brazilian transmission lines expansion plan is an area of emphasis and opportunities rather than a barrier. In this direction, planning for the expansion of transmission infrastructure (grid integration and infrastructure development) is crucial to address aspects of grid stability, transmission capacity, and infrastructure upgrades. This encompasses the construction of new transmission lines, the reconductoring of existing lines, and the optimization of current infrastructure to enhance efficiency.

Transmission networks play a significant role in the secure and effective operation of power systems. This role calls for well-organized and comprehensive procedures that are designed to be used in the operational and expansion of these complex networks (MAZAHERI *et al.*, 2021). Therefore, the expansion of the national transmission network is vital to enable the integration of variable renewable sources and to enable national hydroelectric power plants to serve as pillars of flexibility, stability, and security in the operation of the system.

The transmission system interconnects power generation across various watersheds, facilitating the linkage of the power system between regions. The transmission network (Figure 1) connecting electrical subsystems, allows for the transfer of energy, integrating generation resources to leverage energy complementarity among power plants in different regions. The operationalization of surplus electrical energy transfer and exchange between subsystems, along with the optimization of water storage in hydroelectric reservoirs, ensures greater security, cost-effectiveness, and energy reliability in serving the market. The Brazilian National Interconnected System (SIN in Portuguese - *Sistema*

Interligado Nacional) integrates diverse energy production sources and enables supply to the consumer market (ONS, 2023).

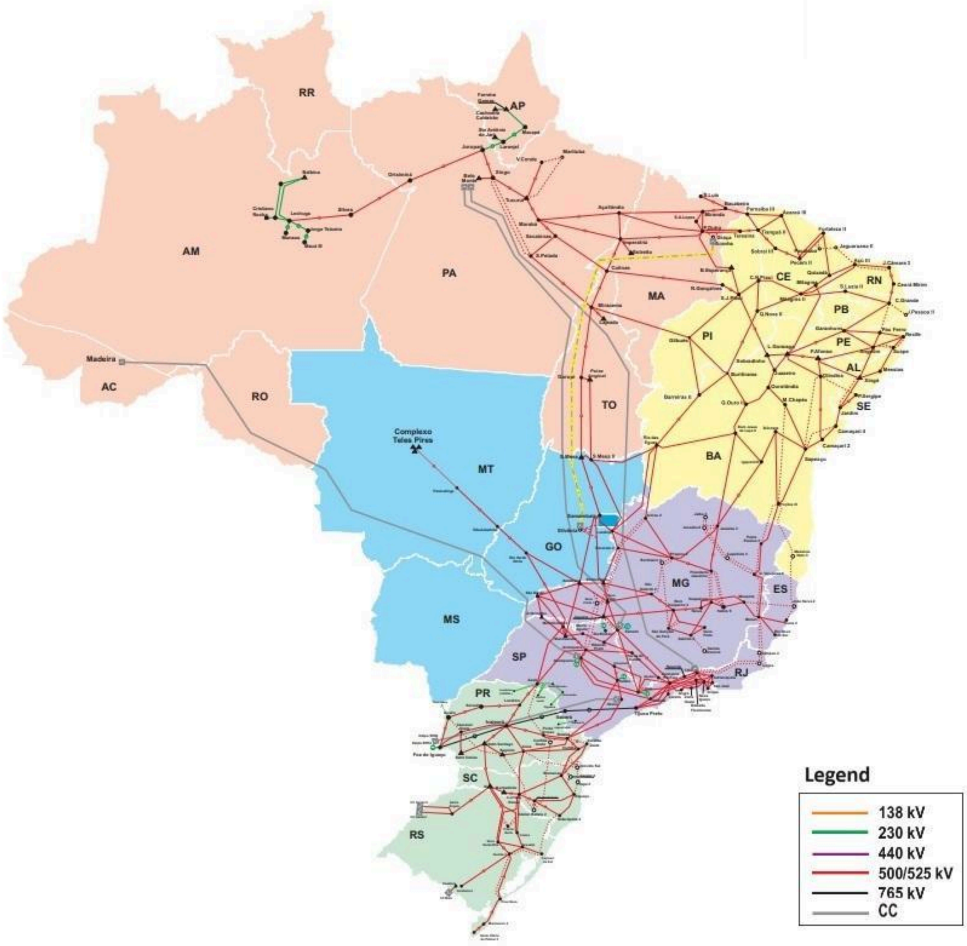

Figure 1 – National Interconnected System (SIN) – Prospective Brazilian Transmission Lines by 2027
Source: ONS (2023).

Brazil has characteristics that favor the integration of large-scale non-dispatchable renewable sources, such as onshore and offshore wind and solar. The Brazilian electricity system is based on hydroelectric powerplants, which can adjust their generation to meet immediate energy needs, eliminating the need for additional expenditures on thermal power plants.

Brazil's continental dimensions and the diversity of electricity sources, mainly from distant hydroelectric plants, necessitate significant investments in the transmission sector. This is crucial to ensure a reliable energy supply and meet the country's growing energy demand.

The operational flexibility provided by the transmission lines in the grid is essential, enabling dynamic control and redirection of energy flows to meet fluctuating demands and address emergencies. With the growing prevalence of renewable energy sources, transmission lines play a vital role in integrating these variable power supplies into the main grid. Additionally, they foster broader market participation, and enhance service quality, contributing significantly to the overall resilience and reliability of the electrical system.

Transmission lines enable the integration of electricity generation from renewable sources at inexpensive prices when the source is situated at various locations within the system, contributing to the reduction of the need for storage and generation expansion. This, in turn, helps maintain tariffs at lower prices. Therefore, effective planning and operation of the transmission system, in addition to providing flexibility to the overall system, can contribute to achieving the objective of tariff moderation, a key pillar of energy policy and an essential element for a just energy transition.

The deployment of cost-saving transmission infrastructure will contribute to the 7th Sustainable Development Goal, which is to ensure reliable, sustainable, modern, and affordable access to energy for all (ONU, 2023).

Given Brazil's vast territory, it is crucial for the national electricity grid that the infrastructure of the electric power transmission sector operates efficiently. Electricity transmission in Brazil encounters challenges primarily because of the considerable distances between hydroelectric plants and major consumption hubs (CARDOSO JÚNIOR *et al.*, 2014).

The transmission system is crucial in ensuring energy security through the exchange and complementation of energy between different subsystems, However, it is also essential to integrate the isolated systems. According to EPE (2021), the vast majority (96%) of the installed capacity in the Isolated Systems' power plants consists of thermal generation from diesel and fuel oil, while 2.2% comes from natural gas plants, 1.1% from biomass, and only 0.7% from hydroelectric generation.

Several of these areas remain disconnected from the SIN due to challenging accessibility (small, dispersed, and remote communities) and environmental, logistical, and economic obstacles. To address this issue, strategies proposed by the Climate Policy Initiative (PUC-RIO, 2023) include creating favourable conditions for renewable energy projects to compete in auctions designated for serving Isolated Systems. This involves adjusting auction regulations to factor in the environmental impact of energy sources in bidding processes, facilitating electricity access for underserved populations by incentivizing decentralized solar generation, and improving the effectiveness of the "Mais Luz para a Amazônia" (More electricity for the Amazon) program through enhanced supervision and community engagement initiatives. In this regard, the “Programa Energias da Amazônia” (Energy Program of the Amazon) has made some advancements with the increased incorporation of renewable energy sources and the interconnection of isolated systems. As of 2023, the integration of the Patrintins area into the SIN marks a significant achievement, as the municipality in Amazonas was connected through the Tucuruí transmission line.

The integration of intermittent resources into the power grid relies on the transmission lines' interconnection, reserve capacity, and complementarity among energy resources, ensuring an augmented capacity for supply. This distribution of generation among resources enhances security by mitigating resource variability (PIMENTA *et al*., 2015).

The National Electric System Operator (ONS in Portuguese) is responsible for coordinating and controlling the operation of electricity generation and transmission facilities in the SIN, to optimize the use of all sources. ONS is also responsible for planning the operation of the country's isolated systems (ONS, 2023). Currently, Brazil hosts 212 remote communities, predominantly situated in the Northern region (including Rondônia, Acre, Amazonas, Roraima – Boa Vista, Amapá, and Pará), as well as the island of Fernando de Noronha and selected areas in Mato Grosso. Despite their low energy consumption, these locations account for less than 1% of the nation's total demand (ONS, 2024).

4.1.1 Leveraging the complementarity of electricity sources and system operation.

According to KOUGIAS et al., (2016) current techniques for managing load demand fluctuations and reserve operations (storage, contingency, reserves) lead to extra costs or partial reduction in energy production. Therefore, alternative solutions should be considered, such as optimizing the complementarity between different intermittent sources to manage the total energy output and its temporal stability.

Energy complementarity refers to the capacity of two or more resources to exhibit complementary patterns of energy availability throughout time (EPE, 2017). These resources may originate from similar or disparate sources. Ideally, perfect complementarity between two resources would occur when one is abundant while the other is scarce, and vice versa, ensuring a balanced energy supply throughout varying conditions.

Because of the Brazilian large territorial dimensions, there are significant hydrological differences between the country regions, with periods of drought and rainfall not coinciding. To take advantage of this diversity and minimize the risks of supply failures, the national interconnected transmission lines allow energy exchanges between several regions throughout the country (CEMIG, 2023).

Typically, a larger separation between the installation sites of the generator park results in reduced correlation among energy resources, such as wind speed, river flow, and solar energy (NOGUEIRA, 2020). For example, the seasonal complementarity between wind and water inflows in the Northeastern region diminishes the requirement for seasonal storage in that area. The complementarity between different energy sources, known as the portfolio effect, is critical to ensuring a stable, reliable, and resilient energy supply. The portfolio effect not only smooths out variations in energy sources but also optimizes the utilization of available resources. At times when one source may be producing below maximum capacity, others may be compensating, resulting in more stable global production. Combining these sources into a portfolio approach, it is possible to mitigate the challenges associated with fluctuation in power generation.

In other words, the absence of wind, solar, or hydroelectric resources in a particular region can be compensated by the resources available in another region. For instance, Figure 2 illustrates the daily offshore wind resource pattern in the Southeast and Northeast regions during August 2013. It is noticeable that in the Southeast, wind speed declines after 10 am, while the opposite trend is observed in the Northeast.

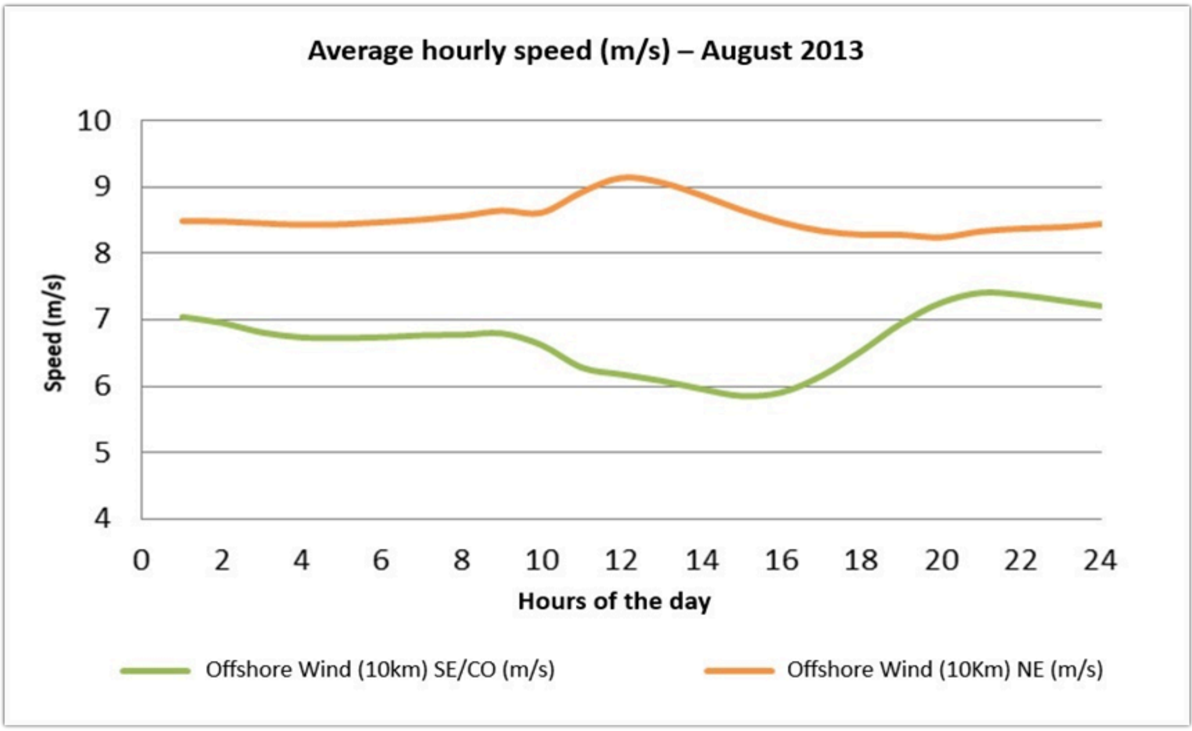

Figure 2 – Daily offshore wind speed profile in the Southeast and Northeast regions in august 2013
Source: Prepared by the authors based on PFENNINGER & STAFFELL (2023).

HAYDT *et al*. (2015) observed that combining all the wind farms in the Northeast region of Brazil leads to a significant improvement in reliability indices for the electrical system compared to individual farms. That is, the complementarity among different regions contributes to the enhancement of reliability. While this study did not assess joint operation with other sources, it highlighted a positive synergy among wind, solar, hydroelectric, and thermal generation sources, which tends to increase the percentage of guaranteed power index in the integrated generation system.

The irregularity of wind and solar energy generation, alongside substantial capacity expansion, can present operational challenges for the system (AMARO PINAZO *et al.*, 2022). However, due to the diverse composition of the Brazilian electrical grid, it is possible to capitalize on certain attributes, such as the complementarity with hydropower, biomass, and solar sources (NOGUEIRA, 2020).

It is important to note that climate change affects the climatic conditions that are crucial to renewable resources. Due to climate change, renewable energies in Brazil are vulnerable (LUCENA *et al.*, 2009, RUFFATO-FERREIRA *et al.*, 2017). In Brazil's poorest regions, climate changes may negatively affect electricity generation (particularly hydropower) and biofuels production (LUCENA *et al.*, 2009). Brazil's energy matrix is sensitive to climate variations due to hydroelectricity and wind power (RUFFATO-FERREIRA *et al.*, 2017). One recommendation for addressing climate change more efficiently and securely involves diversifying the electricity supply through a hydro-solar-wind system. Forecasts indicate an increase in wind intensity and solar radiation on Earth. Consequently, an optimized approach would involve implementing wind and solar power plants, avoiding the use of water from hydroelectric plants. Hydropower plants could store water for extended periods, compensating for dry periods. The integration of a hydro-solar-wind system would mitigate the dispatch and procuring new fossil fuel-based power plants in the Brazilian electrical system (ZENG *et al*., 2024).

Every renewable source exhibits its unique seasonality, modulation, and instantaneous production characteristics, and when combined, they can enhance the stability of collective production. Particularly from an electrical system operation viewpoint, diversifying sources and benefiting from the portfolio effect can help alleviate systemic impacts arising from the instantaneous variability in power availability, particularly from variable renewable projects like wind and solar photovoltaic (EPE, 2019).

In summary, investments in high-capacity transmission infrastructure are crucial for the DDS, facilitating efficient electricity transportation from high-production regions to high-demand areas. They also enable a smooth integration of variable renewable energy sources, enhancing energy security through the portfolio effect by diversifying energy sources. This diversification increases the system's resilience to outages and extreme weather, resulting in a more reliable power grid. Transmission networks allow operators to utilize resources regardless of their physical location (EPE, 2019).

4.2 Technological Transfer, financing and funding

Increasing public and private financing is essential to enhance access to low-cost financing in the developing world. In addition, as already mentioned, substantial support from Annex I countries is vital to facilitate financial flows towards mitigation actions in non-Annex I countries. According to ZENG *et al*. (2024) a strong and enduring cointegration connection exists between the progress of low-carbon energy, financial technology, financial development, biodiversity preservation, and natural resource utilization. It is worth noting that both FinTech advancements and accessible sustainable financing mechanisms have a positive impact on the adoption of low-carbon energy practices.

Collaboration between the private sector, public sector, academia, and through multilateral and bilateral agreements will make a difference in the energy transition. Connecting global opportunities to Brazil and vice versa is crucial.

Banks are crucial for leveraging sustainable financing by mobilizing international resources. Connecting with national and multinational banks is vital. The Inter-American Development Bank (IDB), for example, promotes financial innovation, and currency hedging can attract external savings for investment in Brazilian green assets. Access to climate and multilateral green funds, such as the Climate Investment Fund, Green Climate Fund, Global Environment Facility, and Adaptation Fund, can finance better electricity projects with less bureaucracy. The BNDES Climate Fund offers attractive fixed interest rates.

Innovation space is necessary, as researchers and entrepreneurs explore new routes and efficiencies. This must be done responsibly, aligning credit programs to facilitate access to resources and enable new technologies.

The transfer of intellectual property or technology from scientific and technological institutions is a way for companies to internalize technological innovation into their production processes, ensuring competitiveness, adding value to their products/services, and generating wealth (BRASIL, 2023).Technology transfer involves the conveyance of patents, industrial designs, and technical expertise, among others, through licensing agreements, assignments, strategic partnerships, or other forms of collaboration. This process enables companies to leverage scientific and technological advancements, accelerating their innovation capacity, adapting to market and societal demands, achieving productivity gains, and reducing costs (SEBRAE, 2023).

Collaboration between countries and the exchange of successful experiences, such as offshore wind technology, storage (batteries) and hydrogen, can lead to cost reduction. Access to climate-friendly technologies with affordable costs is desirable, and it helps developed countries to support developing countries. Thus, countries can share knowledge and technologies in renewable energies such as solar, wind, and biomass to promote sustainable development.

No single solution addresses the complexities of energy transition. Emerging technologies plays an important role in energy transition. Disruptive technologies, such as hydrogen, 2nd generation ethanol, biorefinery, ocean energy, small modular reactors, nuclear fusion, floating solar, concentrated solar power, platform ships, and carbon capture and storage, offer transformative potential. Although not considered in our scenarios, these disruptive technologies can contribute significantly to the greater expansion of variable renewables in the Brazilian electricity matrix as costs decrease and a well-structured production chain develops.

Disruptive technologies can significantly alter the energy market, though we still lack sufficient data to predict their integration into the energy matrix and their consequences (MME/EPE, 2020). For example, the production of green hydrogen and CCS (in industries and thermal power generation) involves relatively high implementation and operation costs and requires substantial initial investments. In Brazil, these and other technologies can become viable as costs decrease through a learning curve and the implementation of incentive policies, legal and regulatory advancements, and other stimuli. R&D stimulus policies should aim to increase technological capacity.

4.3 New technologies regulations and supply chain

Implementing regulations for new technologies in Brazil is notably lengthy and bureaucratic. Factors such as political maneuvering complicate the regulatory framework, as seen with offshore wind energy, hydrogen, and the carbon market.

A structured regulatory process is essential, but excessive bureaucracy hinders development. Legislation on offshore wind energy and the carbon market often oscillates between the Senate and the House without progress.

Developing the supply chain for new technologies presents challenges and opportunities. Much of Brazil's solar technology is imported, highlighting the need to boost domestic production. The onshore wind energy sector is well-established, and there is potential to develop a value chain for offshore wind energy and hydrogen.

The DDS does not foresee integrating disruptive technologies until 2050, focusing on energy efficiency in the industrial sector and adopting offshore wind energy post-2030 due to economic reasons. However, other technologies like Small Modular Reactors, offshore thermal power plants with carbon capture, hydrogen, floating solar, smart grids, and hybrid power generation should not be disregarded. These technologies require greater regulation, environmental impact studies, and feasibility assessments.

A consistent regulatory framework ensures the development of new supply chains, contributing to Brazil's energy sector and economy. The energy transition creates opportunities for investment in technological innovations, generating employment and income. Developing human capacity to participate in these new investment plans is crucial.

Appropriate regulatory frameworks and governance are essential to support these developments, ensuring that new production chains can grow, contributing to the development of Brazil's electricity system and economy.

4.4 Valuing the different attributes of energy sources and the role of hydroelectric plants

Section 5.2.3 of the Output 2 ICAT report highlights that the electrical system future will require increased capacity and flexibility making the attributes of generation sources more crucial for the expansion and operation of the interconnected system. It is worth noting that there is no single technological solution. The environmental benefits of sources, economic aspects, and meeting the energy requirements of the system, among others, must be evaluated.

Still according to Output 2, a more comprehensive understanding and optimized utilization of hydroelectric generation and reservoirs are crucial to shape the future trajectory of Brazil's electrical system. With the increasing adoption of variable renewable energy sources, it is necessary to adjust the operation of hydroelectric plants, whose importance for the operation and security of the system becomes even more significant.

According to MME/EPE (2020), hydroelectric plants, even those with continuous flow, have a certain degree of resource management and the ability to meet capacity, flexibility, and various ancillary service requirements. The regularization reservoirs, with greater resource storage capacity, function as the system's batteries and contribute to optimizing the use of resources and operating costs. However, hydroelectric plants receive compensation solely for energy production and not for the other services they provide, such as storage, which is also crucial for various water uses like irrigation and supply.

Natural gas can serve as a complementary source to VRE sources during critical hydro periods. However, the issue of remuneration for these services is crucial. One way to compensate for the role of natural gas in this context is through market mechanisms that value its availability and reliability as a backup energy source during periods of low production from the other mentioned sources. This could involve financial incentives such as differentiated tariffs or capacity payments, recognizing the value of the flexibility and reliability provided by natural gas to ensure supply stability during critical moments. Additionally, government policies promoting the integration and diversification of energy sources can also play a role in adequately compensating for the role of natural gas as a complement to hydroelectric, VRE and biomass energy.

Each energy source has distinct characteristics that can be evaluated based on criteria such as sustainability, cost, reliability, environmental impact, among others. Therefore, in addition to optimizing the operation and planning of the electricity sector, it is important to assess the benefits of the sources, such as the environmental benefits provided by renewable generation (EPE, 2019). Economically, it is noteworthy that other services, in addition to meeting the energy requirement of the system, can compose the remuneration of generators. This condition can provide new business models and leverage the development of new projects. To better understand, quantify and remunerate these attributes, methodological and market design improvements are still needed (EPE, 2021a).

The main guideline is to diversify the sources of electricity generation through a system that incorporates hydroelectric, solar, and wind resources, providing a more efficient and reliable response to climate change. Forecasts indicate an increase in wind strength and solar radiation hitting the Earth. However, Brazil experiences a decrease in precipitation CLIMAINFO, 2023). Furthermore, complementing variable energy sources can be achieved through measures such as increasing the operation of biomass-fired thermal power plants. At the same time, this approach would reduce the need to activate and contract new power plants from fossil fuel sources in the Brazilian electrical system. This would support Brazil's NDC ambitions by lowering greenhouse gas emissions and facilitating the country's transition to a more sustainable and resilient energy system, aligning with broader climate and energy goals. This also involves an increase in energy storage, either centrally in hydroelectric plants or through new technologies such as batteries alongside photovoltaic or wind generation and hydro pumps.

Historically, hydroelectric plants have played a fundamental role in supplying peak demand. However, several limitations have impacted their ability to fully meet the needs of the electrical system. Environmental restrictions for new constructions in sensitive areas and the effects of climate change are critical factors affecting the implementation and operation of these plants.

The advancement of climate change poses a significant challenge for hydroelectric plants, reducing their ability to meet peak demand due to climatic variability and the availability of water resources. Additionally, the location of potential hydroelectric sites in remote or distant areas from demand centers exacerbates this issue.

Given these challenges, several strategies can be proposed to ensure the stability of the Brazilian electrical system. Contracting flexible gas thermal plants, incentivizing demand response are some of the suggested measures, other energy storage technologies (batteries and enhancing the capacity of existing hydroelectric plants, are also considered viable alternatives).

4.5 Energy storage technologies

The implementation of storage solutions plays an important role in balancing the intermittency of VRE sources, thus enhancing energy reliability and resilience. This strategic investment allows for better utilization of renewable energy while mitigating potential grid challenges associated with variability in generation. Furthermore, the gradual scaling of storage capacity aligns with the evolving energy landscape, ensuring a smoother transition towards a sustainable and decarbonized energy system.

Energy storage technologies assist in bridging the temporal and geographical gaps between electricity supply and demand and are promising tools for achieving a low-carbon future, as they allow for the decoupling of energy supply and demand (LANDRY *et al.*, 2015). Examples of these technologies include reversible hydroelectric plants (pumped storage hydropower), hydrogen, batteries, compressed air energy storage systems, supercapacitors, magnetic superconductors, heat pumps, and molten salts. These storage solutions do not provide firm energy but can offer power during peak demand periods (they consume energy to be available when required) (EPE, 2020b).

Reversible hydroelectric power plants are characterized by their ability to store surplus energy for later use during periods of high demand. Typically, these plants operate with a pumped-storage system and can function in daily, weekly, and seasonal operation cycles. In these facilities, water is pumped from a lower reservoir to an upper reservoir through a pump-turbine during periods of low energy demand. When the stored energy needs to be consumed, the process is reversed, with water flowing from the upper reservoir to the lower one, driving hydraulic turbines along the way and generating electrical energy (GESEL, 2021).

As the electricity sector continues to evolve, the strategic deployment of storage technologies remains pivotal in supporting renewable energy growth and optimizing grid operations. The projected expansion of storage capacity in the specified scenarios reflects a proactive approach to address energy storage needs and enhance the overall efficiency and effectiveness of the energy transition process.

According to the report Batteries and Secure Energy Transitions IEA, 2024), to triple global renewable energy capacity by 2030, while maintaining electricity security, as agreed upon at COP28, 1,500 GW of storage will be required worldwide. To deliver this, storage deployment (battery storage, pumped storage, compressed air, and flywheels) must continue to increase by an average of 25% per year by 2030, which will require action from policymakers and industry, taking advantage of the fact that battery storage can be built in a matter of months and most locations. Further cost reductions are necessary to achieve this goal, along with diversification across supply chains – from critical mineral extraction and processing to battery manufacturing.

In Brazil, the use of energy storage systems is still in its infancy, mainly in the research project phase. The viability of storage solutions depends on the proposed applications, existing regulations, and their local and temporal remuneration mechanisms. The current regulatory framework of the Brazilian electricity sector hinders the participation of storage solutions by commercializing energy production as the sole product. Hourly pricing was a first step in integrating these resources, but adequate compensation for services rendered is important for the development of different storage technologies (LANDRY *et al*., 2015).

4.6 Carbon pricing mechanisms implementation

The price paid for goods, in general, does not reflect the environmental impacts caused throughout their life cycle. Carbon pricing is a way of attributing a cost to the impacts generated by the increase in GHG emissions into the atmosphere (EPE, 2020c). The pricing of carbon emissions can be considered an effort to try to correct market failures arising from the non-inclusion, in economic systems, of the global socio-environmental externalities associated with GHG emissions (EPE-BNDES, 2021).

The Senate is revisiting the regulation of the carbon market in 2024 as detailed above. Bill No. 2,148/2015, which creates the Brazilian System of Greenhouse Gas Emissions Trading, establishes emission ceilings, and provides rules for the sale of offset credits. Those exceeding these limits for greenhouse gas emissions will be required to offset their emissions by acquiring titles. On the other hand, companies that manage to keep their emissions below the limit will receive quotas that can be traded in the market. The system is expected to include governing, deliberative, and advisory bodies, with clear rules for carbon credit trading (SENADO, 2024).

4.7 Coordination of Federal Government Climate Change Policies, goals, and incentives

Considering the autonomy of states as a constitutional principle to be upheld, the Federal Government needs to coordinate with the states in defining policies on the subject, ensuring that mandatory policies and goals for the productive sector and society are coherent with the National Policy. Similar care in defining restrictive measures should be taken when establishing incentives, which must be predetermined and in harmony with the goals.

There should be no legislative interference in the planning process of the electrical sector. There is a need for the government to regain prominence in Brazil's energy policies. In recent years, the direct interests of the private sector have influenced the national congress to pass laws and decrees benefiting specific sectors in the electrical industry. For example, Law 14.182/2021 (BRASIL, 2021), on the privatization of the Centrais Elétricas Brasileiras S.A (Eletrobras) and Bill 11.247/2018 on the exploration of offshore wind energy, which originally had one purpose but received various amendments,

Beyond capitalization, the privatization law for Eletrobras, which also addresses the granting of new concessions for power generation, directly affects the planning of the electricity sector. Inflexible gas-powered thermal plants with compulsory generation contribute to an increase in annual emissions.

The law mandates the contracting of 8.000 MW natural gas-fired thermal generation in the North, Northeast, Midwest, and Southeast regions, with distinct milestones between 2026 and 2030. It foresees a minimum inflexibility of 70% for a supply period of at least fifteen years. Additionally, it dictates that at least 50% of the declared demand of distributors must come from Small Hydroelectric Plants, up to 2.000 MW in the 2021 A-5 and A-6 auctions, and 40% in other A-5 and A-6 auctions until 2026.

To complement variable renewable sources, thermal power generation needs to be flexible, with low-capacity factors, operating in an optimal combination with variable renewable sources to meet system requirements. However, the law mandates the compulsory (inflexible) contracting of at least 70% of the maximum generation capacity, meaning the plants operate almost continuously.

According to MME/EPE (2022), this change in the matrix composition resulting from the incorporation of Law No. 14.182/2021 leads to higher operating costs for the electrical system. For the lowest total cost to meet system requirements, The alternative would be through the expansion of variable renewable sources along with fully flexible thermal power plants (without compulsory generation)(EPE, 2021b).

The requirement for the predetermined contracting of natural gas-fired thermal power plants in specific volumes and locations constitutes a market reserve and introduces significant regulatory uncertainty, impacting investments and consumer tariffs (INSTITUTO E+ TRANSIÇÃO ENERGÉTICA, 2021). The continuous operation of these thermal power plants for a minimum of 15 years will result in the emission of over 300 Mt CO_2e or 20 Mt CO_2e per year, in comparative terms, the entire Brazilian electricity generation sector emitted 53.4 Mt CO_2e in 2019, Thus, these new thermal power plants alone have the potential to contribute nearly 40% of the annual greenhouse gas emissions of the entire Brazilian electric sector (IEMA, 2023).

This requirement for the contracting of natural gas-fired thermal power plants contradicts the proposal for the modernization of the electrical sector that the MME seeks to implement, aiming for greater competitiveness and a more appropriate allocation of risks (IEMA, 2023). Moreover, it directly interferes with the planning of the electrical sector, a responsibility of the MME based on studies by the EPE. The law also conditions investments in new gas pipelines and reinforcements in the transmission network, imposing additional costs on the electrical sector and its consumers (from the regulated market) by predefining the location of thermal power plants.

Barroso *et al.* (2020) emphasize that the construction of pipelines for interiorization is a long-term investment that, in the context of energy transition and climate change, runs the risk of becoming a stranded asset (obsolete before the end of its useful life). This is because natural gas may be replaced or subject to higher taxes soon.

There is a recommendation for optimal efficiency and fewer regrets that the expansion of the transmission network occurs after auctions for the contracting of thermal power plants (Law

14.182/2021)(BRASIL, 2021). This is because more specific information, such as the connection point and the individual installed capacity of each generation project, will only be known upon their effective contracting.

The other mentioned example of political interference in energy planning is the Bill 11.247/2018 (CAMARA, 2023) which was approved by the Chamber of Deputies in 2023 and forwarded to the Senate. This Bill originally established a legal framework for the exploration of offshore wind energy but underwent various amendments, including the postponement of subsidies for renewables, new conditions facilitating the contracting of natural gas-fired thermal power plants, incentives for SHPP, and even new incentives for coal mining.

Another example of how policy can interfere in energy planning is the Law No, 14.299/2022 (BRASIL, 2022) that establishes the Just Energy Transition Program and extended until 2040 the contracts for coal-fired thermal plants in Santa Catarina. The program was intended to prepare the region for a “probable” decommissioning of coal energy projects by 2040. However, in effect, it instituted economic subsidies that allow the complex to sell energy above market prices and indirectly pay for additional energy from coal and fossil fuels.

Brazil boasts highly competitive renewable energy sources. However, add-ons in laws could lead to increased energy costs, jeopardizing its systemic competitiveness. In addition, this competing agendas can undermine consistent climate action and risk locking in further greenhouse gas emissions through continued investment in energy-intensive infrastructure.

Furthermore, it is essential to highlight that Brazil is internationally recognized for having one of the most renewable energy mixes globally and playing a leading role in climate negotiations. However, the country is also one of the world's largest oil producers, Brazil has a long-standing policy of subsidies, which are government resources allocated through the public budget to support or expand energy production and consumption through tax exemptions and direct budgetary expenditures. The ongoing discussions of further oil exploration in the Amazon basin exacerbates this contradiction[2], posing significant environmental risks and undermining Brazil's commitments to climate action and sustainability.

In 2022, the value of benefits granted to the oil and gas industry was five times higher than the incentives directed towards renewable energies. According to EPE, 2023b) R$ 80.9 billion (15.70 billion U.S. dollars[3]) did not enter or left the public coffers in the form of subsidies to fossil fuels granted by the federal government in 2022. This amount is 20% higher compared to 2021 (R$ 67.7

[2] The new president of Petrobras, Magda Chambriard, advocates for the advancement of exploratory activities along the Brazilian coast, including the Equatorial Margin.
[3] 1 U.S. Dollar from 2020 = R$ 5.15

billion – 4.37 billion U.S. dollars). However, the funding for renewable energy was R$ 15.5 billion (3 billion U.S. dollars) in 2022.

Over the last five years, for every R$ 1.00 invested in renewables, R$ 5.60 was spent on fossil fuels. Fiscal support for renewables remains significantly lower when compared to fossil fuels: between 2018 and 2022, R$ 334.6 billion was allocated to fossil fuels, while only R$ 60.1 billion (11.67 billion U.S. dollars) went to renewables. During this period, subsidies for fossil fuels increased by 123.9%, while those for renewables grew by 51.7% (INESC, 2022).

Projections and energy plans (PDEs and PNE 2050) indicate that Brazil can maintain the high renewable characteristic of its electrical and energy matrices in the medium and long term, despite challenges that need to be addressed to uphold this objective. One such challenge is aligning mitigation strategies related to energy consumption in the transportation and industrial sectors, given the separation of responsibilities among involved ministries, their priorities, and budgets (EPE, 2020a). Achieving this alignment requires significant coordination in defining common agendas and objectives related to greenhouse gas emissions mitigation, necessitating political collaboration. The expansion planning for electricity sector must be conducted based on technical foundations and not under the influence of sectoral lobbies and political interference.

There is an initiative in this direction, represented by the explicit decision in Resolution CIM No. 3/2023, which addresses the update of the Climate Plan and establishes technical groups to address mitigation and adaptation aspects (EPE, 2023b).

5 Recommendations for policymakers and stakeholders

As highlighted in the session 4, the key challenges for unlocking the DDS for the Brazilian electricity sector revolve around critical aspects such as infrastructure and system operation, policy and regulation, supply chains, skills and capacities, finance, and international collaborate.

Strengthening Political, Legal, and Regulatory Frameworks:

- Policy Integration: Ensure coherent integration of renewable energy policies across various sectors. Effective communication and collaboration mechanisms between government ministries and agencies (e.g., energy, environment, finance, and agriculture) are crucial. Aligning renewable electricity policies with agricultural policies can promote bioelectricity use and reduce land use conflicts;
- Holistic Electricity Strategy: Incorporate renewable electricity goals within broader economic and social development plans. Establish clear, long-term objectives for renewable power adoption, supported by policies in other sectors like transport and industry;

- Streamlined Legislation: Ensure existing laws and regulations are free from contradictions and redundancies to maintain a stable environment for electricity planning. All relevant legislation should support renewable power deployment, minimizing regulatory uncertainty for investors and avoiding vested interests.

Enhancing Financial Mechanisms

- Financial Incentives: Provide financial incentives, such as tax breaks and subsidies, and ensure a stable financial environment for renewable electricity projects. Attracting more private and foreign investment is essential;
- Specific Tax Incentives: Create specific tax incentives, such as tax exemptions during the investment phase for new technologies like offshore wind;
- Credit Lines and Green Bonds: Establish specific credit lines or maintain existing financing rules from institutions like BNDES. Encourage the issuance of green bonds for renewable electricity projects to attract institutional investors.

Promoting New Renewable Energy Projects

- Upfront Investments: Recognize that new renewable energy projects, including offshore wind, hydrogen, and storage, require significant upfront investments. Despite long-term benefits and decreasing technology costs, the initial capital required can be prohibitive;
- Scenarios and Market Risks: Develop scenarios to reduce uncertainties for market actors, decrease market risk premiums, and lower financial costs;
- Securing Financing: Institutions like BNDES, IDB, and other development banks play a pivotal role in promoting the energy transition. Pooling resources and recognizing the financial sector's role in determining the cost of capital is essential.

By addressing these key challenges, Brazil can enhance its regulatory frameworks, attract necessary investments, and promote sustainable development in the electricity sector.

Investing in Grid Infrastructure

- Upgrade and Reinforce Networks: Modernize transmission networks to handle increased loads from renewable energy sources, improving capacity and reliability;
- Connect Remote Sites: Expand grid infrastructure to connect remote renewable energy sites to major consumption centers;
- Smart Grid Technologies: Implement smart grid technologies to manage the variability of renewable energy sources, ensuring stable and reliable power supply;
- Energy Storage Solutions: Promote energy storage solutions, like batteries and pumped hydro, to balance supply and demand and store excess renewable electricity.

Funding for Research and Development

- Increase R&D Funding: Boost funding for renewable technologies research;
- Foster Collaboration: Encourage collaboration between universities, research institutions, and the private sector to drive innovation;
- Advance Emerging Technologies: Focus on improving efficiency and reducing costs of emerging technologies;
- Public-Private Partnerships: Establish partnerships to leverage expertise and resources for innovative research;
- Local Expertise Development: Support technical training programs for the installation, maintenance, and operation of renewable energy systems.

Balancing Development with Environmental and Social Impact.

- Just Transition: Balance renewable electricity development with environmental protection and social impacts;
- Job Creation and Social Inclusion: Promote renewable energy projects to stimulate local economies, create jobs, and ensure equitable distribution of clean electricity benefits.

Global Leadership

- Leverage G20 Leadership and COP30 Hosting: Use Brazil’s leadership roles to position itself as a key player in the global energy transition;
- Enhance and Expand Renewable Mix: Advance Brazil’s energy transition by enhancing and expanding its renewable power mix;
- Global Energy Hub: Aim to become a global energy hub, providing services, innovation, and equipment to other nations;
- Set an Example: Invest in energy transition to set an example and potentially lead global efforts towards sustainable energy;
- From Comparative Advantage to Competitive Edge: Highlight Brazil's unique strengths to move from a comparative advantage to a competitive edge in the global market.

6 Conclusion

Brazil has successfully developed electricity policy framework to incentivize renewable technology development, starting with hydro and biomass, and expanding to wind and solar power over the last decade. However, maintaining a renewable power matrix requires focus on various aspects. There are still challenges to overcome, such as streamlining regulatory frameworks for new technologies, enhancing financial mechanisms, and investing in grid infrastructure. Addressing these challenges will be crucial in ensuring the continued growth of renewable power mix and achieving Brazil's long-term energy transition.

These critical steps are essential to continue developing Brazil's renewable electricity potential. To help achieve these goals, suggestions that aim to optimize Brazil's renewable power potential, reduce greenhouse gas emissions, and enhance energy security have been presented.

Brazil's electric sector can play a leading role in decarbonizing the country's economy and the world through transport and industry electrification and contributing to net-zero emissions plans. However, this depends on evolving the power mix toward renewables. Policies conflicting with this, such as laws favoring fossil fuel-based power generation, hinder decarbonization efforts. Government action is crucial in guiding market responses towards emission reduction while promoting economic growth.

The future of Brazil with the transition towards a secure and an even more decarbonized electrical matrix lies in diversification. Embracing a diverse range of energy sources and technologies will not only enhance energy security but also contribute significantly to the country's efforts in mitigating climate change.

The report emphasizes the need for a comprehensive, coordinated approach involving transmission infrastructure development, diversified renewable energy integration, storage technology deployment, international collaboration and financial support, a carbon pricing mechanism, policy coordination and a robust regulatory framework and developing the supply chain for new technologies to achieve a sustainable and resilient energy sector in Brazil. Addressing these challenges requires a coordinated effort from policymakers, industry stakeholders, and financial institutions.

Brazil must seize the opportunity to position itself as a key player in the global energy transition agenda. Given its size and systemic importance, the country has the capacity to not only advance its own energy transition, enhancing and expanding its renewable power mix, but also to lead and benefit the worldwide shift towards sustainable energy. By leveraging its resources, expertise, and proactive policies, Brazil can set an example and potentially become a global energy hub, providing services, innovation, and equipment to help other nations leverage the country’s capabilities.

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