Firjan SENAI SESI

Firjan Journey for
Energy Transition in Industry

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Summary

List of acronyms

A

ABDAN - Brazilian Association for the Development of Nuclear Activities

ABEN - Brazilian Nuclear Energy Association

AIEA - International Atomic Energy Agency

ANEEL - National Agency of Electric Energy

ANP - National Petroleum Agency

B

BESS - Battery Storage System

BTU - British Thermal Unit

BCG - Boston Consulting Group

C

CAPES - Coordination for the Improvement of Higher Education Personnel

CBio - Decarbonization Credit

CCEE - Electric Energy Commercialization Chamber

CCS - Carbon capture and storage

CCUS - Carbon capture, use and storage

CDE - Energy Development Account

CDTN - Center for the Development of Nuclear Technology

CNPQ - National Council for Scientific and Technological Development

CO_2 - Carbon dioxide

COGEN - Energy Cogeneration Industry Association

CNEN - National Nuclear Energy Commission

CRCN-NE - Northeast Regional Nuclear Science Center

E

EPE - Energy Research Company

EU - European Union

EU ETS - European Union Emission Trading System

F

FAPERJ - Carlos Chagas Filho Foundation for Research Support in the State of Rio de Janeiro

FIRJAN - Federation of the Industries of the State of Rio de Janeiro

FPSO - Floating, production, storage and offloading

G

GDP - Gross Domestic Product

GHG - Greenhouse Gases

GLP - Liquefied Petroleum Gas

GNA - Açu Natural Gas

CNG - Compressed Natural Gas

GNL - Liquefied Natural Gas

GNV - Vehicular Natural Gas

GSF - Generation Scaling Factor

GW - Gigawatts

H

H_2 - Hydrogen

HPP - Hydroelectric Plant

I

IBAMA - Brazilian Institute for the Environment and Renewable Natural Resources

IEA - International Energy Agency

IEN - Nuclear Engineering Institute

IMO - International Maritime Organization

INCT - National Institute of Science and Technology

INEA - State Environmental Institute

IPEN - Institute for Energy and Nuclear Research

L

LABGENE - Nuclear-Electric Energy Generation Laboratory

LDES - Long Duration Energy System

M

MME - Ministry of Mines and Energy

MP - Provisional Presidential Decree

MW - Megawatts

O

ONS - National Electricity System Operator

P

P, D&I - Research, Development and Innovation

PL - Bill

PPSA - Pré-Sal Petróleo S/A

PROPDI - Research, Development and Innovation Program

PRIS - Power Reactor Information System

R

REDUC - Duque de Caxias Refinery

S

SAF - Sustainable Aviation Fuel

SEB - Brazilian Electricity System

SENAI - National Industrial Learning Service

SESI - Industry Social Service

SIE - Integrated Flow System

SIN - National Interconnected System

SIP - Integrated Production System

SMR - Small Modular Reactors

T

TEP - Ton of Oil Equivalent

U

UENF - State University of Northern Rio de Janeiro

UEP - Stationary Production Unit

UERJ - Rio de Janeiro State University

UESC - State University of Santa Catarina

UFF - Fluminense Federal University

UFMG - Federal University of Minas Gerais

UFRJ - Federal University of Rio de Janeiro

UFRGS - Federal University of Rio Grande do Sul

UHR - Reversible Hydroelectric Plant

UPGN - Natural Gas Processing Unit

UTE - Thermal Power Plant

UTGCAB - Cabiúnas Gas Treatment Unit

USP - University of São Paulo

W

WFER - World Forum on Energy Regulation

Editorial

The energy transition we are experiencing is not a recent process, but the result of factors and desires from the society that have accumulated over the years until it can be implemented gradually. Technological evolution takes place through knowledge that is gradually added and improved until the technology becomes accessible and safe to use. Large-scale solar energy as we use it today, for example, has been gaining more and more ground in the global energy matrix, but its foundations are based on knowledge accumulated since the 19th century with the discovery of the photovoltaic effect by Alexandre-Edmond Becquerel in 1839. Subsequently, technologies were developed, but still without the necessary efficiency for commercial use, until 1954 when the first practical silicon solar cell was developed. With society's growing desire for low-carbon energy sources, the industry's interest has intensified since the 21st century, achieving technological advances that have made it possible to expand its scale and commercial use.

This solar energy cycle is an example of how the adoption of an energy source can take time, the speed at which it is implemented being determined by technological advances and the society. It is with this concept in mind, with the aim of maximizing the best that each technology and energy source can offer us, that Firjan externalizes its vision of the energy transition: a journey of construction and collaboration between the different actors and segments of society, bringing not only technological solutions, but considering that they can, in fact, improve people's quality of life.

Understanding this concept leads us to make the energy resources of the state of Rio de Janeiro and Brazil available in a sustainable, accessible and safe way, contributing to the governmental spheres so that energy is the engine that will drive our development as a state and a nation.

The exploitation of local energy potential, the development of technologies, the decarbonization of energy and industrial activities, the importance of operational safety and workforce training, as well as the impacts on society's quality of life, are part of the broad context of the energy transition, which we have sought to develop and explore through the views of important industry players in this publication.

With the second edition of our publication dedicated to the theme of energy transition, now entitled Firjan's Journey for Energy Transition in Industry, we hope to make a contribution that can add qualified knowledge to building a better future for industry and companies, in synergy with our areas of technology, sustainability, education, health, and energy. Have a nice read!

Luiz Césio Caetano

President of Firjan

Acknowledgments

The second edition of Firjan's Journey for Energy Transition in Industry, previously entitled Energy Transition and Integration at Rio, is the result of a collaboration between the main players in the energy market, bringing together different views from industry and institutions of great relevance and outstanding performance in favor of the development of this market. With internal and external partnerships, Firjan SENAI SESI is pursuing its goal of building a better business environment through its activities, actively listening to industry and its agents in order to overcome the future challenges facing the entire local energy ecosystem.

We would like to thank our external partners, who have contributed significantly to this publication:

To **ABEN - the Brazilian Nuclear Energy Association**, for its fundamental role in promoting science, technology and innovation in the nuclear sector, contributing to Brazil's energy development.

To **ABDAN - the Brazilian Association for the Development of Nuclear Activities**, for its work to strengthen nuclear energy as a necessary source for diversifying Rio de Janeiro's energy matrix.

To **ANEEL - the National Agency of Electric Energy**, for its technical contribution to promoting the integration of different energy sources in the electricity sector.

To **CCEE - the Electric Energy Commercialization Chamber**, for coordinating and facilitating energy transactions, ensuring balance and transparency in the electricity market.

To **COGEN - the Energy Cogeneration Industry Association**, for its strategic role in promoting energy efficiency and technological innovation in the country's electricity sector.

To **Enel Brazil**, for its leading role in the electricity sector and for promoting sustainable energy solutions.

To **EPE - Energy Research Company**, for its work in planning the energy sector, whose production of technical analyses contributes to the diversification and development of the energy matrix.

To **Engie**, for its work in promoting a fair and comprehensive energy transition, strengthening the integration of innovation and sustainability in the sector.

To **Light Energia**, for the experience and strategic planning that strengthen the supply of energy, supporting the development of Rio de Janeiro's industry.

To **Mattos Filho**, for its outstanding performance in resolving important issues pertaining to multiple markets, including energy.

To **Petrobras**, for its importance in the Brazilian energy scenario and for its decisive contribution to the advancement of the energy transition.

To **Transpetro**, for working with excellence in the logistics of the oil and gas production chain, strengthening the efficiency and sustainability of the energy sector.

Presentation

The process of transforming the global energy sector towards greater diversification of sources and the decarbonization of industrial processes is part of a dynamic ecosystem that combines increasing energy demand, technological development, efficiency gains, emissions reductions and meeting social and environmental targets, as well as improving society's quality of life.

The Firjan's Journey for the Energy Transition in Industry seeks to translate this ecosystem into a vision of the agents who experience these challenges in their daily operations, bringing a collaborative approach from different market players.

In the national context, renewable sources have been on a consistent path of expansion in the Brazilian energy matrix. According to the National Energy Balance for 2025, published by the EPE, in 2024 these sources would account for 50% of the total energy supply, a significant improvement on the 39.4% recorded in 2014, as presented in the National Energy Balance for 2015. This performance shows the growing predominance of these sources and the strengthening of less carbon-intensive technologies, positioning the country as one of the leaders in global decarbonization goals.

One of the country's most important energy hubs, Rio de Janeiro is further consolidating its relevance by combining its historical leadership in oil and gas production with its potential in low-emission production. The state is advancing in the incorporation of new energies, with investments in offshore wind, solar photovoltaic and hydrogen projects standing out, signaling a path of transformation towards a more sustainable and diversified economy.

This publication brings together contributions from different strategic players in the energy transition, exploring scenarios and complementary approaches to the challenges and opportunities of the energy transition.

The publication begins with a contribution from Firjan, which presents a diagnosis of local opportunities and challenges, mapping initiatives, projects and the potential of renewable sources and new technologies in the state of Rio de Janeiro, positioning it as a strategic player in the national energy transition.

In the field of public policy, regulation and planning, ANEEL shares its regulatory vision on the challenges and opportunities of the energy transition in Brazil; CCEE addresses energy trading, highlighting its obstacles and opportunities in the face of the energy integration process; and EPE highlights the technological routes and the role of efficiency gains in the transition.

From a sectoral perspective, ABDAN presents the progress of SMRs, consolidating the new frontier of nuclear energy, while ABEN deals with the training and qualification of the workforce needed for the future of nuclear energy in Brazil. COGEN then highlights the contribution of cogeneration to the reliability and resilience of the energy sector.

Subsequently, Enel discusses the impacts of the future of energy on society's quality of life, and Engie analyzes how natural gas projects can contribute to the transition. Light Energia emphasizes the strategic importance of reversible hydroelectric plants as a pillar of Brazil's energy transition. For its part, Mattos Filho presented its vision of the recent Legal Milestones and the ANP's Regulatory Agenda, which are fundamental for guiding and consolidating the progress of the country's energy transition.

Finally, Petrobras details its work in offshore innovation and the transformative potential of the carbon capture and storage (CCS) pilot project in Cabiúnas-São Tomé, while Transpetro explores the technological perspectives aimed at decarbonizing maritime transport.

In this way, this edition reaffirms Firjan SENAI SESI's commitment to promoting debate and sharing experiences on the routes to decarbonization, efficiency and energy integration, reinforcing Rio de Janeiro's strategic role as a protagonist on the Brazilian energy scenario.

The Energy Transition Journey and the State of Rio de Janeiro

Overview of new energies in the State of Rio de Janeiro

It is well known that Brazil and the State of Rio de Janeiro are in a very favorable position with regard to global targets for a cleaner energy matrix. This puts us at an advantage when it comes to the desire for an energy transition to a low-carbon matrix, especially with regard to the use of renewable energies.

According to data from the Energy Institute (2025)[1], Brazil has 35% renewables in its energy matrix. Among the 15 countries with the highest energy demand, only four have a share of more than 10%, and none of them exceed 15%.

If we also consider nuclear energy as a low-carbon primary source, only France would have a higher share than Brazil, while the other countries would not come close to our level. The evaluation of the electricity matrix alone further reinforces our country's prominent position, with 87% of the national electricity matrix made up of renewable sources, rising to 89% when we add nuclear energy.

This scenario shows us that the energy issue is not a problem for the country, but a competitive advantage when we think of a decarbonized matrix model and its use by industry in the production of goods and execution of services with less impact on emissions, as discussed in previous Firjan publications[2].

The State of Rio de Janeiro plays a leading role in the national energy agenda, consolidating its tradition based on its potential and the innovative capacity of its industry, which has led it to be recognized worldwide as an important offshore energy hub.

The path to the sea began naturally with the first oil discoveries in the Campos Basin at the end of the 1970s, and to this day it is the main driving force behind our economy.

The construction of this energy development environment in the state has allowed Rio de Janeiro to develop infrastructure associated with this market, concentrate a large number of skilled workers with operational know-how, establish a high-tech industrial base, develop universities and industry in the search for innovative solutions, creating an environment conducive to the advancement of new energies, especially those linked to the sea.

Currently, the state accounts for more than 85% of national oil and gas production, with the leading role shifting from the Campos basin to the Santos basin - especially with the large volumes developed from the pre-salt. However, despite the migration of production hubs, the coast of Rio de Janeiro has remained at the forefront of this market, contributing to the generation of wealth and knowledge for the state and the country.

The combination of energy potential and a consolidated business environment, with important infrastructure already in place, such as structured ports, refineries, natural gas processing units, gas and oil pipelines, as well as research centers, has allowed the state to attract some of the largest energy companies in the world, generate opportunities for the growth of Petrobras and develop local suppliers, ensuring a robust and integrated production chain.

The mapping of the oil, gas, energy and marine industrial base carried out by Firjan identified that the integrated oil and gas chain in Rio de Janeiro has more than 5,500 active CNPJs. It is important to note that many of these companies are already able to meet the demands of the current energy transition scenario, contributing to the local development of new energies. The role of the oil industry in this scenario and in the gains in competitiveness of new energy sources is also noticeable when analyzing the large sums allocated to P, D&I in the country dedicated to this subject.

In this sense, it is also worth highlighting the role of Firjan SENAI as an institution that makes an important contribution to the historical development of the local energy market, whether through the training and qualification of labor or through its Technology Insti-

[1] 2025 Energy Institute Statistical Review of World Energy

[2] Anuário do Petróleo no Rio 2022 e Panorama Naval no Rio de Janeiro 2022.

tutes, whose examples of success stories, demonstrated throughout this article, reinforce the institution's ability to boost our industry.

The expertise acquired in the oil and gas market paves the way for diversifying the energy matrix and reducing carbon emissions from the sea, with an emphasis on renewable sources such as offshore wind, low-carbon hydrogen and CCS.

Together, the existing onshore projects and those under development in the areas of photovoltaic solar energy, hydroelectric power and nuclear energy reinforce the importance of energy integration in order to make the best use of our potential and the best that each source can offer. In this sense, it is important to note that the state of Rio de Janeiro is the only one in the country to have a nuclear thermoelectric power plant, which has been in operation since 1985, when the Angra I Plant began its activities.

This integration is fundamental when considering the impacts of the growth of distributed generation and the multiple and diverse intermittency that many renewable sources present, strengthening energy security in Brazil. The technical, regulatory and operational skills of the oil industry can and should be transferred to these new fronts, accelerating their maturity and competitiveness.

Large national and international companies have been developing studies, pilot projects and new energy solutions on the Rio de Janeiro coast, such as the 12 companies that have applied to IBAMA for environmental licenses to install offshore wind farms. As an example, Equinor, which is responsible for the Aracatu project, is also the operator of the Raia project, which will provide natural gas processed directly on the platform, in addition to the partnerships of various companies with the Port of Açu for possible hydrogen production projects. Linked to the current energy context, the issue of decarbonization is also part of the set of unprecedented solutions that are being or will be implemented in the state's projects, such as the electrification of platforms and the CCS project in the north of Rio de Janeiro, by Petrobras.

The presence of global players and centers of technological excellence guarantees an ecosystem conducive to innovation, integrating industry, government, educational institutions, and society.

Firjan, through its consolidated work on the "Energy Projects Panel" has identified potential projects which, if unlocked, could generate investments of more than BRL 1 trillion over the 2035+ horizon, contributing even more to the diversification of the state's energy portfolio. The realization of such a portfolio of projects could lead to new highly qualified jobs, an expansion of the industrial base and strengthen the state's position as a leader in Brazil's energy transition and integration.

Recently, some regulatory advances have been approved and tend to contribute positively to the future realization of energy projects, as in the cases of the so-called "Fuel of the Future"[3], hydrogen[4] and offshore wind farms[5]. These advances, linked to positive signals from environmental agencies, are fundamental to ensuring greater legal certainty and attracting companies interested in making investments.

According to IBAMA (2025), the Brazilian coast has a potential of more than 247 GW of offshore wind generation, of which approximately 15% is concentrated in offshore areas off the coast of Rio de Janeiro, with 16 projects applying for environmental licenses. To get an idea of this offshore wind potential, if we consider only the projects located in the state in terms of installed capacity, they would be equivalent to around 2.6 Itaipu hydroelectric plants.

[3] Law no. 14,993, of October 2024. Establishes the National Program for Sustainable Aviation Fuel (ProBioQAV), the National Green Diesel Program (PNDV) and the National Program for Decarbonization of Natural Gas Producers and Importers and Incentives for Biomethane.

[4] Law no. 14,948, from August 2, 2024. Establishes the legal milestone for low-carbon hydrogen; provides for the National Low-Carbon Hydrogen Policy; establishes incentives for the low-carbon hydrogen industry; establishes the Special Incentive Regime for Low-Carbon Hydrogen Production (Rehidro); creates the Low-Carbon Hydrogen Development Program (PHBC).

[5] Law No. 15,097, from January 10, 2025. Regulates the use of offshore energy potential.

Firjan's assessment, even eliminating the overlap of areas with licensing requests, still shows significant potential, totaling 28 GW - around twice the installed capacity of Itaipu.

When we also envision the production potential of low-carbon hydrogen from these projects, we have in the existing port infrastructure a strong ally for consolidating the state as a future hub for the production and export of green hydrogen, which would contribute to better indicators for our trade balance.

It is also feasible to conjecture that, in the future, the large number of reservoirs depleted by oil and gas production in the state will present themselves as very plausible alternatives for large-scale CO_2 storage, a solution for decarbonizing the energy and industrial sector.

Faced with these opportunities, we have the challenge of translating this potential into results for local industry, maximizing the generation of added value along the production chain. In the initial phase of implementing and building energy assets, a series of demands are generated in a chain that involves everything from engineering and other services to the manufacture of dedicated machinery and equipment.

However, the importance of these projects goes beyond the construction period, extending over the medium and long term. In terms of operation, energy projects generally have a life cycle for their assets for more than 20 years, guaranteeing the continuity of the demands of an entire chain linked to operation, repair and maintenance throughout this period.

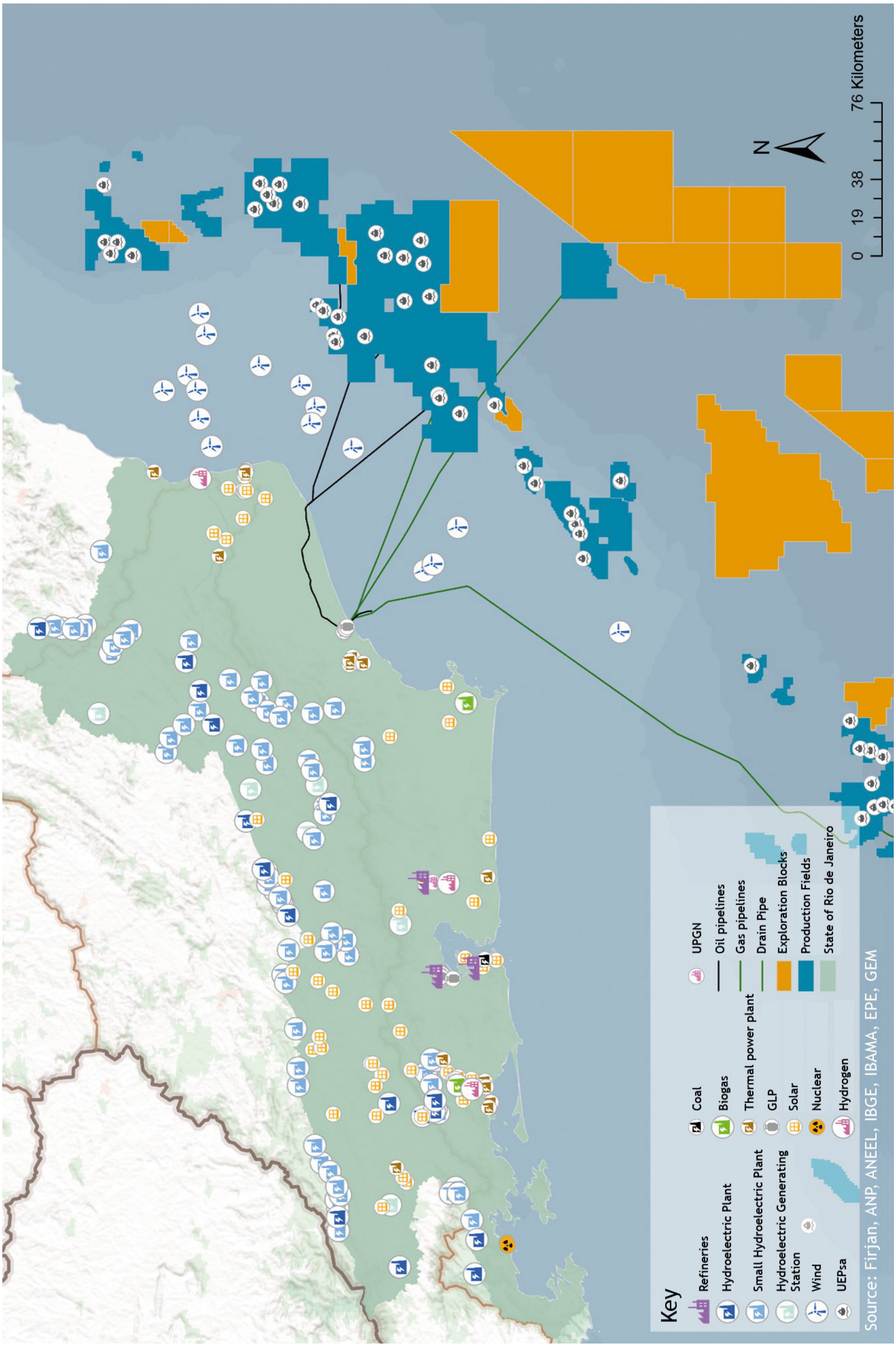
The feasibility of the new energy projects presented on the **"Rio de Janeiro Energy Hub"** Map has the potential to generate a series of new highly qualified jobs on various fronts, such as technicians, engineers and related activities, bringing additional prospects to oil and gas for increasing wage levels in the state, generating jobs and income and industrial development, as well as generating new resources for increased revenue in the different government spheres.

The consolidation of Rio de Janeiro as a national energy hub naturally involves its strategic location in view of its enormous energy production potential, the large presence of installed infrastructure and its proximity to the country's main consumer markets, thus reducing the need for additional investment in infrastructure dedicated to energy logistics between production facilities and the end consumer, as well as technical losses due to long-distance energy transportation.

We are facing a great opportunity for the state to lead the country's energy transition in a fair, sustainable, safe and efficient way, in a journey that must be worked on so that the state can leverage its resources in favor of economic development and improving the quality of life of its inhabitants, transforming it into a global benchmark that includes energy markets other than offshore oil.

The publication Firjan's Journey for Energy Transition in Industry is one of Firjan's initiatives to promote qualified information on the energy scenario in Rio de Janeiro and its potential, highlighting the challenges and opportunities from the perspective of the main players in this market. The digital version of this document, as well as the Dynamic Panel of Energy Projects and the interactive Map of Rio de Janeiro Energy Hub, can be accessed on Firjan's website, in the environment dedicated to the topic: www.firjan.com.br/firjan/empresas/competitividade-empresarial/petroleoegas/integracao-energetica/

Figure 1: Rio de Janeiro Energy Hub



Source: Firjan

*Rio de Janeiro Energy Hub presents power generation projects in operation, under construction and in the projects

Rio de Janeiro Energy Hub: Map of Energy in Rio de Janeiro

In Rio de Janeiro offshore environment there are 65 oil and gas UEPs in operation, distributed over more than 50 fields, which are responsible for more than 85% of the country's oil production, amounting to around three million barrels per day. There are also plans for 16 new oil and gas UEPs, the expansion of pre-salt production in the Santos Basin, the revitalization of mature fields in the same basin and the development of the Raia project. Only in Petrobras' assets, the estimated potential is for an increase of 2.5 million barrels of oil per day by 2035, and 35 million cubic meters of natural gas from offshore production in Rio de Janeiro.

To serve all of Rio de Janeiro oil and gas production, Rio de Janeiro's pipeline infrastructure has approximately one hundred interconnections mapped out from the north to the south of the state, in addition to the network dedicated to the transportation and flow of natural gas, which already operates with the Route 2 and Route 3 systems, while Route 5 is planned to serve the Raia project. The pipelines are connected to the three refineries in operation in the state - Cabiúnas, Manguinhos and Reduc - with plans to integrate them with the Boaventura Complex in Itaboraí. This complex also expands the gas processing capacity with the recently opened UPGN and refining capacity with the Refinery under construction, which adds to the processing units located in Macaé, at the Cabiúnas Terminal, and in Duque de Caxias, at Reduc.

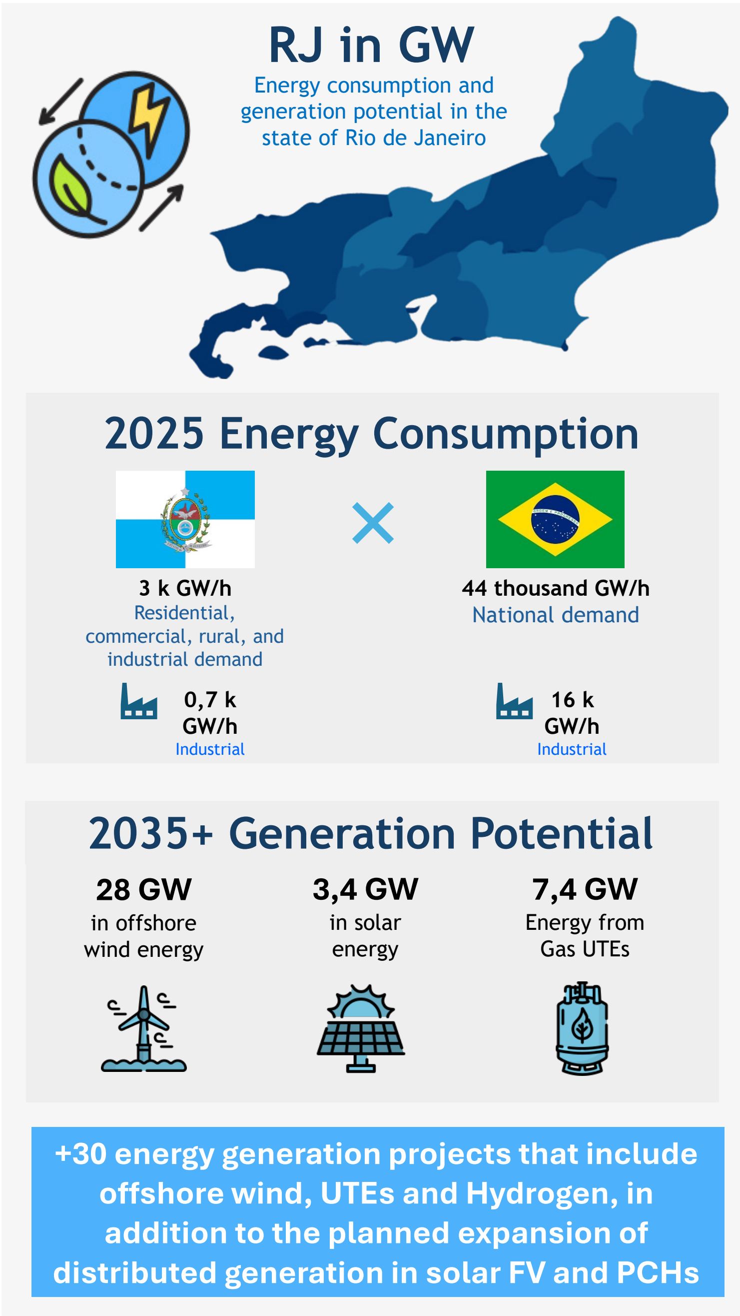
The natural gas infrastructure in the state also includes the distribution network that supplies homes, businesses, GNV stations and industries, with a demand of approximately 25 million cubic meters per day. Other industrial plants are also supplied by GNL and GNC at points where the distribution network has not reached, reinforcing the need for expansion. Rio de Janeiro's thermoelectric plant is one of the most robust in the country, taking advantage of the availability of natural gas to guarantee energy security. There are more than 40 thermoelectric plants between installed and confirmed projects, with an installed capacity of more than 1000 MW, as well as large projects such as GNA I and II, considered the largest thermoelectric plant of natural gas in Latin America, generating 3000 MW. At the same time, the addition of GNA III to the planned thermoelectric projects adds almost 2000 MW to the base of the Brazilian energy system, complementing intermittent sources and ensuring national supply, but already prepared to operate with low-carbon hydrogen, like the previous ones. At the same time, the thermoelectric plant in the state continues to expand, with projects planned at the Macaé thermoelectric complex and two UTEs at the Boaventura Complex in Itaboraí.

In the field of low-carbon hydrogen, Rio de Janeiro is strengthening its position as a national energy hub, with six projects in progress, including pilots and commercial projects. The focus is on meeting the demands of energy-intensive sectors such as maritime transport and the steel industry, known as hard to abate. Despite the potential, its implementation requires great energy availability and a robust distribution infrastructure, both factors in which Rio de Janeiro is a pioneer. Among the various major projects under development to diversify the matrix, offshore wind stands out, with 16 projects in the process of being licensed by Ibama, totaling 28 GW of power mapped according to geographical overlaps. The expectation is that auctions will begin in 2026, attracting major global players such as Equinor, Total and Shell. Petrobras is also conducting a pilot project at the Port of Açu, creating a test site that aims to speed up investment decision-making, ensuring security and predictability in the financing of larger-scale projects.

The state's energy integration also involves diversifying sources. More than 60 solar photovoltaic generation points and around one hundred small hydroelectric plants have already been mapped. SMRs are emerging as an alternative for the future of smaller-scale nuclear generation in conjunction with already widespread sources, combining energy security and low carbon. Rio de Janeiro nuclear matrix should also be strengthened by the completion of the third plant in Angra dos Reis, increasing the region's installed capacity.

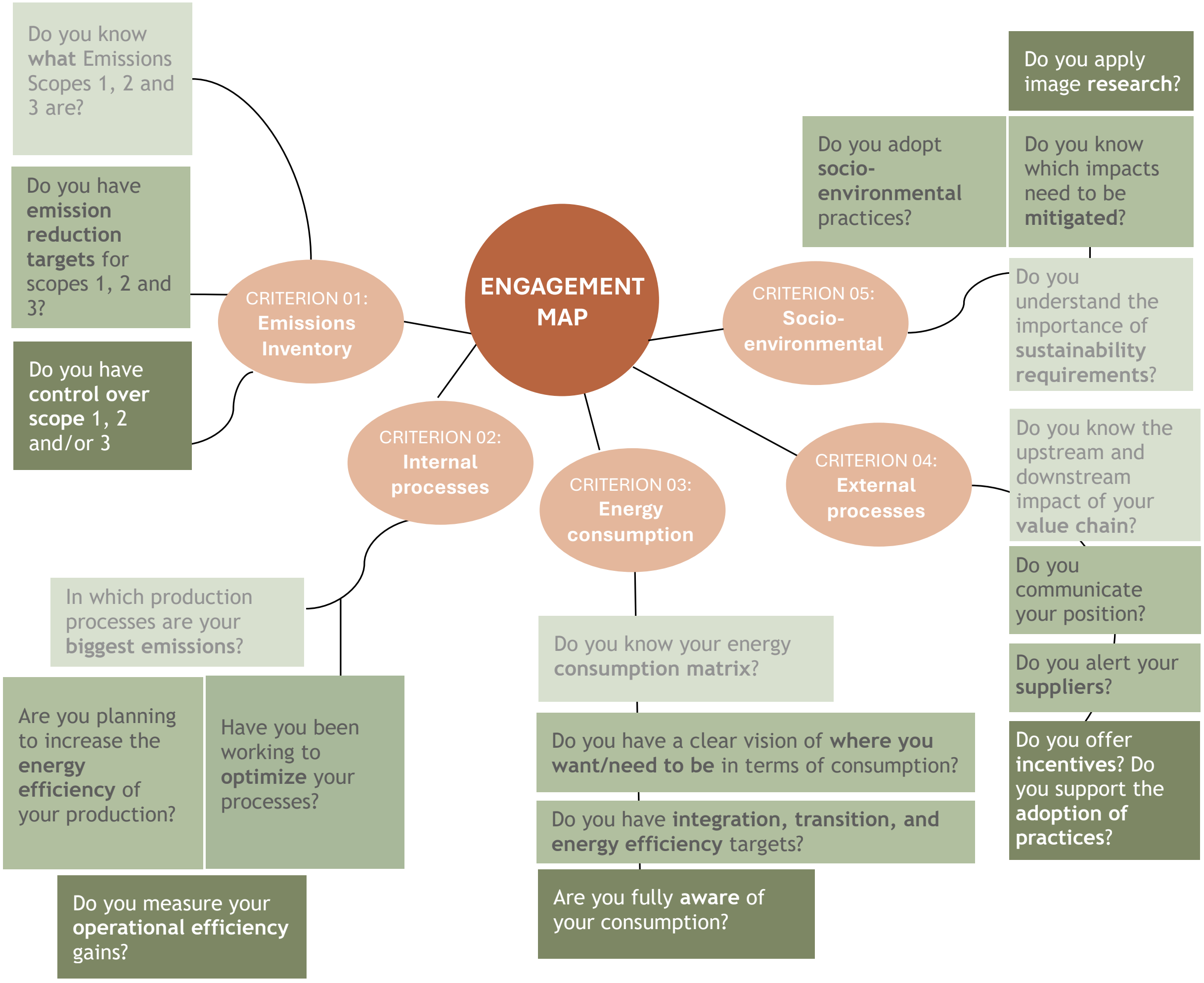
In addition to generation initiatives, other technologies are essential for the state to move towards a cleaner matrix, in line with global carbon neutrality targets. These include CCUS projects, which are considered essential for reducing emissions in fossil sectors that will remain important in the energy matrix. This perspective, combined with the already highly renewable nature of Rio de Janeiro's electricity grid, strengthens Rio de Janeiro's position as an oil and gas producer with one of the smallest carbon footprints in the world. Finally, the development of the supply chain will be decisive in meeting the sector's new demands, especially in terms of raw materials, technologies and skilled labor. The production and supply of critical minerals, for example, is gaining relevance in the context of the energy transition, due to the central role they play in expanding storage capacity and manufacturing batteries.

Figure 2: Rio de Janeiro in Gigawatts



Source: Firjan

ASSESS YOUR COMPANY'S LEVEL OF ENGAGEMENT IN THE ENERGY TRANSITION JOURNEY



LEVELS OF ENGAGEMENT

AWARE (UNDERSTANDING)	ADHERENT (COMMITMENT)	ENGAGED (MEASUREMENT)
0 TO 9 POINTS	9 TO 16 POINTS	17 TO 19 POINTS

FIND OUT HOW TO ACHIEVE BETTER RESULTS BY CONTACTING US!

ENGAGEMENT MAP FORM

SOLUTIONS MATRIX FOR YOUR COMPANY

LEVEL OF ENGAGEMENT	Firjan SENAI SESI IEL CIRJ Firjan CIRJ	Firjan SENAI	Firjan SESI	Firjan IEL
AWARE	Sustainability Advisory Energy Efficiency Advisory Economic Studies	Professional Training SENAI Technical Courses - Electrical and Renewable Energy - Mechatronics - Mechanics	Health Diagnosis and Mapping Training in Regulatory Standards (NRs) Certifications	Casa Firjan Courses and Workshops
ADHERENT	Commercial Intelligence Advisory Participation in international missions	Education SENAI mobile units - SENAI service in your company Technological Services - Firjan SENAI Institutes of Technology and Innovation	Absenteeism Management Occupational Safety: Technical Reports (Noise, Heat, etc.) NR Compliance Advisory	Training in Sustainability Program for Managers (Executive Training)
ENGAGED	Advisory on Foreign Trade, Credit and Financing, Legal Conecta Business Defense of Interests	Professional Development SENAI mobile units Firjan SENAI Institutes of Technology and Innovation Applied Research Projects	Integrated Corporate Health Management (SESI Viva+ Platform) Check-up for Executives Strategic SST Consultancy	Workshops to integrate the ODS into business strategy Leadership development consultancy

FIRJAN HAS THE IDEAL SOLUTION FOR YOUR COMPANY!
FIND OUT HOW WE CAN SUPPORT YOU

Firjan PEQ

What is it?

Firjan_PEQ is a specialized platform for small businesses in Rio de Janeiro, where entrepreneurs who already have a business or are starting a new challenge have direct contact with an exclusive service center made up of Firjan technicians and specialists and learn about products and services specially designed for MPEs.

Pillars of the Program

Firjan Small Business Portal

Information and services in strategic areas.

- PEQ Radar | What's next?
- Latest information for small businesses

Small Business Service Center

Specialized, problem-solving-oriented service and access to services.

Partnerships to support business growth

Development of the "PEQ Ecosystem", with the establishment of partnerships with institutions that can contribute to the development of very small and small businesses.

Access the Firjan Small Business Portal | Firjan_PEQ

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The Energy Transition Journey: Reflections from the Perspective of Regulation and Planning

ANEEL's vision for the energy transition

Prepared by ANEEL

Climate change is a direct consequence of the increase in GHG emissions. Since the Industrial Revolution, the concentration of CO_2 in the atmosphere has grown exponentially, a phenomenon widely recognized by the scientific community. Even subtle rises in the global average temperature have the potential to destabilize the balance of the Earth's climate system, intensifying the frequency and intensity of extreme events such as prolonged droughts, heat waves, severe storms and tropical cyclones.

For the energy sector, climate change has two main implications. The first is the **need to create or adapt systems to make them more resilient to climate change**. For the electricity sector, this includes dealing with changes in the generation patterns of renewable sources, impacts on infrastructure due to storms, precipitation and more intense winds, and limitations on energy transfer capacity. The second implication is related to the **need to transform the energy sector, promoting a transition to a configuration that reduces GHG emissions**.

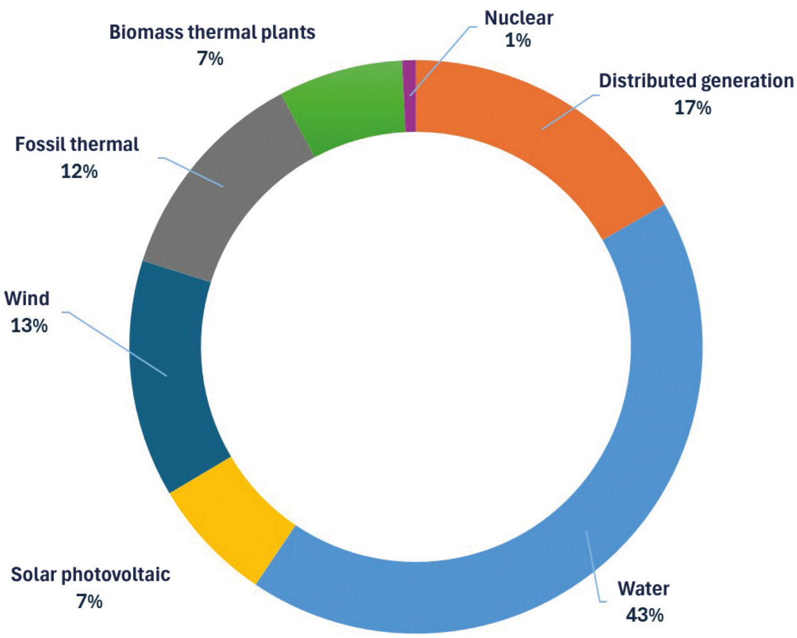
In this context, the **energy transition** is defined in Brazil as the process of transforming the infrastructure, production and consumption of energy by the different sectors, with the aim of contributing to the neutrality of the country's net GHG emissions (CNPE, 2024). This process is not limited to replacing fossil fuels with renewable ones; it involves adopting a new energy management paradigm, with an emphasis on digitalization, energy storage and the use of technologies that increase the efficiency and resilience of systems.

The electricity sector is a global **protagonist in the decarbonization** process due to its ability to incorporate renewable sources and, through the electrification of economies, reduce the consumption of fossil fuels in other sectors such as transport and industry.

The IEA's 2021 report highlights seven key pillars for achieving climate neutrality by 2050: 1. Energy efficiency; 2. Behavioral change; 3. Electrification; 4. Expansion of renewables; 5. Hydrogen and derived fuels; 6. Sustainable bioenergy; 7. Carbon capture, utilization and storage (CCUS). Among the pillars listed, electrification is one of the most striking trends in the energy transition. Also according to the IEA (2025), global demand for electricity will grow by around 4% a year until 2027, driven by three major factors: electrification of transport and buildings; expansion of data centers; and growth in energy-intensive industrial production. In Brazil, this trend is enhanced by the high share of renewables in the electricity matrix, allowing the expansion of demand to occur with lower emissions intensity, reinforcing the strategic role of the electricity sector in decarbonization.

In Brazil, the 2025 EPE's National Energy Balance (BEN) points out that in 2024, approximately 88% of all electricity generated in the country came from **renewable sources**, an extraordinarily higher rate than the global average, which in 2022 reached just **30%**. Since 2004, the share of clean sources in the Brazilian electricity matrix has remained consistently above **70%**, a high level that demonstrates a **solid and long-lasting energy transition process**, consolidating Brazil as an international benchmark in energy sustainability.

Figure 3: Diversity of electricity sources in Brazilian electric matrix (installed power)



Source: Own elaboration. Data from ANEEL's Generation Information System - September 2025

This high degree of renewability drives the so-called **powershoring**, a phenomenon in which energy-intensive industrial activities migrate to regions that offer **clean, affordable and reliable electricity**. With a mostly renewable electricity matrix and significant availability of **strategic minerals for the energy transition**, Brazil is in a privileged position to **attract investment and foster sustainable industrial development**. Even so, the country faces **structural challenges** that cannot be neglected, such as the rapid growth in demand for electricity, the need for greater **flexibility in the electricity system** to accommodate variable renewable sources such as **wind and solar**, and the **effects of climate change** on renewable sources. Added to this is the impact of **extreme weather events**, which test the resilience of the energy infrastructure and reinforce the urgency of **investments in innovation, modernization, and robustness of the system**.

Faced with these challenges, **regulatory agencies play a strategic role**. They need to identify the relationships and impacts of regulation on the energy transition and tackling climate change, acting in an integrated way, creating regulations that remove barriers to modernize the sector, stimulate investment and guarantee security, reliability, and fairness in the transition. This includes removing regulatory barriers to modern technologies, adjusting tariffs and creating economic incentives for the expansion and modernization of the system, as well as ensuring that the transition is fair and inclusive for society as a whole. This was even the main message of the last World Forum on Energy Regulation (WFER) conference held in Lima, Peru, in 2023, where energy regulators from around the world debated their role in decarbonizing the global economy, transcending sectoral and national regulatory issues. ANEEL is the regulatory body responsible for regulating and supervising the generation, transmission, distribution, and sale of electricity in Brazil.

In the energy transition, ANEEL acts by promoting regulatory innovation and removing barriers, with a view to promoting the electrification of the economy and the expansion of low GHG emission technologies, while preserving the safety and reliability of the electricity system with fair tariffs. If Brazil's electricity matrix has undergone a transition to a low GHG emission configuration, the electricity sector needs to transform its infrastructure to meet the demands of an increasingly digital society, which demands safe and reliable energy services and requires sustainability practices to be adopted by companies in the sector. In this context, ANEEL's Regulatory Agenda contains a series of activities that are essential to promoting the energy transition that society wants, such as regulating energy storage systems, modernizing electricity tariffs and promoting the resilience of transmission and distribution networks.

In turn, even though it is a regulatory agency for the electricity sector, Strategic Objective 1 (SO1) of its Strategic Planning already directs efforts so that the regulatory activity acts towards the energy transition with a fair allocation of its effects and with social responsibility. This is because ANEEL's purpose is to guarantee universal access to energy at fair and affordable prices. To this end, the energy transition process must consider the impacts on the most vulnerable consumers, in order to ensure that the benefits of the transition are widely shared with a reduction in social, regional and economic inequalities.

In this context, ANEEL has been working to modernize electricity tariffs and to better communicate what justifies the amount of the electricity bill that reaches Brazilian homes. In the field of communication with society, an important transparency tool is the "Subsidiometer", which shows, in real time, the total amount that electricity consumers are financing, via tariffs, in sectoral public policies, with legal provisions, especially those funded by the CDE.

Understanding that this is a complex journey that requires integration between public policies, technological innovation and efficient regulation, ANEEL has been discussing with society how to incorporate into its processes measures and actions to tackle climate change and promote the energy transition, through the preparation of the Practical Guide on Climate Change, Energy Transition, and Regulation.

Among the concepts covered in the Guide is the need to consider local specificities in the energy transition process. In the case of the state of Rio de Janeiro, the electricity matrix is characterized by a strong presence of gas-fired thermoelectric plants and nuclear energy, which can be complemented by a growing potential for offshore wind and solar generation, and for the production of hydrogen.

ANEEL recognizes the importance of the state of Rio de Janeiro as a strategic hub for energy transition in Brazil. The Brazilian regulator contributes through modern regulation, fostering innovation and research, public education and rigorous supervision, balancing safe expansion with climate sustainability. The start-up of the GNA II plant, which has the potential to use hydrogen, demonstrates the potential of our ability to support innovative and pioneering technological solutions.

In this regard, ANEEL plays a central role in promoting innovation in the electricity sector through its Research, Development and Innovation Program (PROPDI). The aim of this program is to encourage and guide electricity companies to invest part of their revenue in PDI projects aimed at technological progress, efficiency and sustainability in the sector.

In the state of Rio de Janeiro, Petrobras carried out strategic projects aimed at offshore wind generation, marine energy, the use of hydrogen and the efficiency of processes in thermoelectric plants, with investments of more than BRL 30 million. For its part, Enel Rio de Janeiro has been carrying out smart grid and distributed generation integration projects, with costs expected to exceed BRL 50 million. Furnas invested more than BRL 70 million in both innovation in transmission lines and renewable sources.

In the city of Rio de Janeiro, Light Distribuição has developed robotic inspection of lines and shielded transformers, at a cost of tens of millions of Brazilian Reais. The **Trafo Blindado** has brought greater resilience to urban networks by reducing damage caused by external impacts, with communication integrated with smart grids. **SmartReader**, based on artificial intelligence, allows remote reading and analysis of meters, increasing billing efficiency. The **Airline Inspection Robot** carries out inspections in real time, reducing costs and increasing operational safety. The projects show that PROPDI is generating real innovations that have already been applied in everyday life in Rio de Janeiro, with gains in reliability, quality and a reduction in electricity losses.

The energy transition in Brazil is an essential process in the face of the challenges posed by climate change and the growing demand for electricity in an increasingly digitalized and sustainable society.

In this scenario, ANEEL's role as a regulator is important for balancing technological innovation, security of supply and energy equity and sustainability, creating a regulatory environment capable of stimulating investment and promoting efficiency throughout the electricity sector chain.

The examples of initiatives developed in the state of Rio de Janeiro - involving generation, transmission and distribution agents - show that modern regulation, combined with research, development and innovation, is already bringing concrete results for society. The strengthening of this agenda, through instruments such as the Regulatory Agenda, the Practical Guide on Climate Change, Energy Transition and Regulation and PROPDI, consolidates the vision that the energy transition must be conducted in an inclusive, transversal, transparent, and collaborative manner. ANEEL therefore reaffirms its commitment to contributing to this movement, ensuring that Brazil maintains its position as a world leader in energy sustainability, while guaranteeing universal access to clean, safe and fairly priced energy for all citizens.

Energy trading from the perspective of energy transition and integration: challenges and opportunities

Prepared by CCEE

The global energy transition is no longer a future ambition, but a reality. The world is facing the consequences of climate change at an accelerating pace, and the energy sector needs to occupy a central position in the debate if we really intend to evolve towards a low-carbon economy. We need to move towards a model that brings together sustainability, competitiveness, safety and, above all, accessibility and consumer empowerment. In Brazil, this movement has taken on peculiar characteristics, but with a certain advantage. Our country has one of the cleanest electricity matrices in the world, with more than **90% of generation coming from renewable sources**, and this differential, added to the consolidation of a robust market and a journey towards expanding our free contracting environment, puts the country in a leading position in building a more sustainable future for all. This achievement did not happen spontaneously. In addition to our geographical characteristics, this is the result of decades of consistent public policies, regulatory improvements and investment in infrastructure. In the early 2000s, more than 90% of the country's energy was generated by hydroelectric plants. While this was excellent from an emissions point of view, it raised concerns about security of supply, due to the dependence on rainfall patterns. However, in the last 25 years, the country has diversified its matrix, introducing new sources and expanding the share of wind, solar and biomass sources. We currently have more than 187 GW of installed capacity from clean sources - which is eight times the power of the world's largest hydroelectric plant, the Três Gargantas, in China.

The progress is visible: the average production of both wind and solar farms increased by 19.8% and 24.9% respectively in 2025 alone, which means that the transition is not just talk, but reality. However, we mustn't forget the importance of other sources in the context of energy security. This history is directly linked to the development of the free energy market, in which consumers can choose their own supplier, negotiate supply on demand, set deadlines and conditions that best suit their needs, and can achieve savings of up to 35%, according to industry estimates. And the most interesting thing: you can choose the type of source you want to hire. It has the power in its hands to only buy electricity from renewable plants, reinforcing its decarbonization goals and desires.

Countries such as the United Kingdom, Germany, Chile and several American states have already implemented similar practices that allow the same benefits to residential and small consumers. In Brazil, thirty years ago, when we started to open up the market, it was hard to imagine how much it would expand. The process advanced gradually from the 1990s onwards and gained consistency with the creation of the Electricity Trading Chamber (CCEE), responsible for operating the market and guaranteeing security, predictability and transparency in negotiations. Today, there are **more than 80 k consumer units on the free market**, which represents more than half of the total national load. And that number continues to grow exponentially.

This is due, in particular, to regulatory advances that gradually opened up the market and allowed, from the beginning of 2024, the segment to no longer be exclusive to large industries and business groups, but also to be an option for small and medium-sized businesses - including bakeries, supermarkets, pharmacies, butchers and all others connected to high voltage.

As a result, in the period from **January to August 2025 alone, the CCEE migrated 16,900 new consumers in a simple, fast, transparent and secure manner**, who can now customize their service and seek a more efficient and cleaner operation.

The advantages are evident and serve as a beacon, pointing us toward what is to come. As well as being an important instrument for reducing costs, attracting investment, innovation and technological development, the free market is an important driving force for the energy transition, stimulating competition within the electricity sector and opening up opportunities for agents to devote themselves to developing new products and services for their customers. At the same time, the empowerment of consumers has opened the door to greater alignment of energy supply with Brazil's green agenda, a move that automatically creates conditions for balancing supply and demand and for new renewable generation projects to be made viable.

It is in this dynamic space, with the consumer at the center of the business, that the way is being paved for the next important and most awaited step: the complete opening up of the energy market, covering all consumers connected at low voltage, as initially planned in **Provisional Presidential Decree No. 1,300/2025**, published this year by the MME. The MP defined governance rules so that this process takes place in an organized, predictable and transparent manner. And the discussion was not limited to this decree, but extended to **MPs 1,304/2025 and 1,307/2025**, which broadened the scope of the debate, addressing relevant points about the sustainability of the CDE, a Brazilian sector fund created to finance public policies in the sector; the incentive for small hydroelectric plants; and the insertion of natural gas in strategic regions and mechanisms for valuing renewables. These are instruments that not only reinforce the agenda of opening up the free market, but also link the liberalization of the sector to a broader energy strategy aimed at diversification and security of supply.

Of course, the changes are taking place with the broad participation of society.

On this point, it is important to mention the MME's **Public Consultation No. 196/2025**, which deals with the regulation of opening up the electricity market to all Brazilian consumers, including residential ones.

The consultation concerned also discusses deadlines for returning to the regulated market, measurement requirements, contractual guarantees, scanning of procedures and awareness campaigns to reduce information asymmetry among consumers. The discussion received contributions from associations, companies, regulators and civil society organizations, which reflects the relevance of the issue for all links in the sector.

At the same time as this mechanism is being implemented, the CCEE, in close collaboration with ANEEL, is working to simplify market operations and create tools to facilitate migration and information management, to provide a simple, fast and secure experience for all new consumers, at no extra cost. And we can say that we are completely ready for this new phase. We will assume additional responsibilities in real-time monitoring of consumption, ensuring that this dynamic of openness is supported by accessible, standardized, and transparent information. We are investing in security, technological modernization, automating processes and expanding our capacity to handle an exponentially greater volume of data and transactions.

We estimate a potential of more than 90 million consumer units with the arrival of low voltage, considering homes, small businesses and commercial establishments that, for the first time, will have the right to choose who to buy electricity from. At the same time, through our latest initiative, the CCEE Academy, we are expanding our work in the area of development and training, creating a true knowledge hub, with projects, courses and educational materials that enable professionals and consumers to understand the electricity sector, the free market, sectoral advances and opportunities to be explored.

We are facing an unprecedented structural milestone in the Brazilian electricity sector, which democratizes benefits and paves the way for new businesses, from storage technologies and smart grids to the growing electrification of strategic sectors of the national economy, such as the automotive sector, as well as actions to effectively guarantee and enhance the sustainability attributes of this energy integration.

An important example is the Brazilian Platform for Renewable Energy Certification, developed by the CCEE and launched in 2024, to ensure that the origin of the energy used to create the assets is in fact renewable, guaranteeing the completeness of its environmental attributes. The platform verifies the absence of double counting (i.e. the use of the same amount of energy to issue more than one certificate), ensuring the credibility and traceability of certifications. In less than a year of operation, all national issuers have already been integrated into the solution, establishing a standard of trust and transparency that strengthens Brazil's image as a global benchmark in clean energy and attracts investors.

It is clear, however, that the moment we are going through, with advances of such magnitude, needs to be conducted with responsibility and balance. In addition to being predictable and sustainable, opening up the market must guarantee fair tariffs, preserve the financial health of distributors and ensure that no consumer is harmed by remaining in the regulated environment. And we have the technical capacity and expertise to make it happen.

The work carried out by the CCEE, in conjunction with the MME, ANEEL, associated agents and the National Congress, has proved to be an important instrument for implementing structural actions to bring stability, reduce risks and protect consumers. An example of this is the success of the competitive mechanism to reduce GSF liabilities, which took place last August and brought us closer to solving one of the biggest challenges ever faced by the Brazilian electricity sector.

And the same spirit should guide the implementation of the current provisional presidential decrees, as well as the regulations resulting from Public Consultation 196. The challenges remain significant: dealing with the variability of intermittent sources, improving transmission planning, modernizing pricing models and ensuring investor and consumer confidence. But the opportunities are even greater and unquestionable. Brazil has already shown that it is capable of transforming its electricity matrix in less than three decades, becoming a world reference. It is now in a position to lead an even more ambitious process, in which clean energy, technological innovation, equity and justice go hand in hand.

We are therefore living in a historic moment. The country can consolidate its position as a protagonist in the global energy transition, combining a renewable matrix, total market openness and institutional strengthening. And the success of this trajectory undoubtedly requires an environment of cooperation. The entire governance of the sector, including the MME and ANEEL, EPE, ONS, sector associations, investors and consumers must continue to work together to build an increasingly efficient, fair and competitive sector. CCEE, for its part, will continue to fulfill its mission with technical rigor, independence and a vision of the future, developing innovative, efficient and sustainable energy markets for the benefit of society.

We're ready. The next chapter in the history of the Brazilian electricity market will be written with more freedom, more renewability and more power for all consumers.

Technological routes and the role of efficiency gains in the energy transition

Prepared by EPE

Introduction: energy transition, climate change and sustainability

Energy transitions are, above all, historical processes. The world has already undergone deep transformations - from biomass to coal, and from coal to oil - all of them characterized by being long, gradual and non-linear processes, shaped by economic, social and technological factors.

The current transition, however, has unprecedented characteristics. Unlike the previous ones, it is driven not only by technological advances or changes in the availability of resources, but above all by the urgent need to tackle the climate crisis. Global climate change adds a sense of urgency that didn't exist in past transitions and puts the issue of sustainability in its economic, social and environmental dimensions at the center of the debate. This creates an unprecedented dynamic: we need to accelerate decarbonization on a global scale, reduce vulnerabilities to extreme weather events and, at the same time, guarantee social inclusion and energy security.

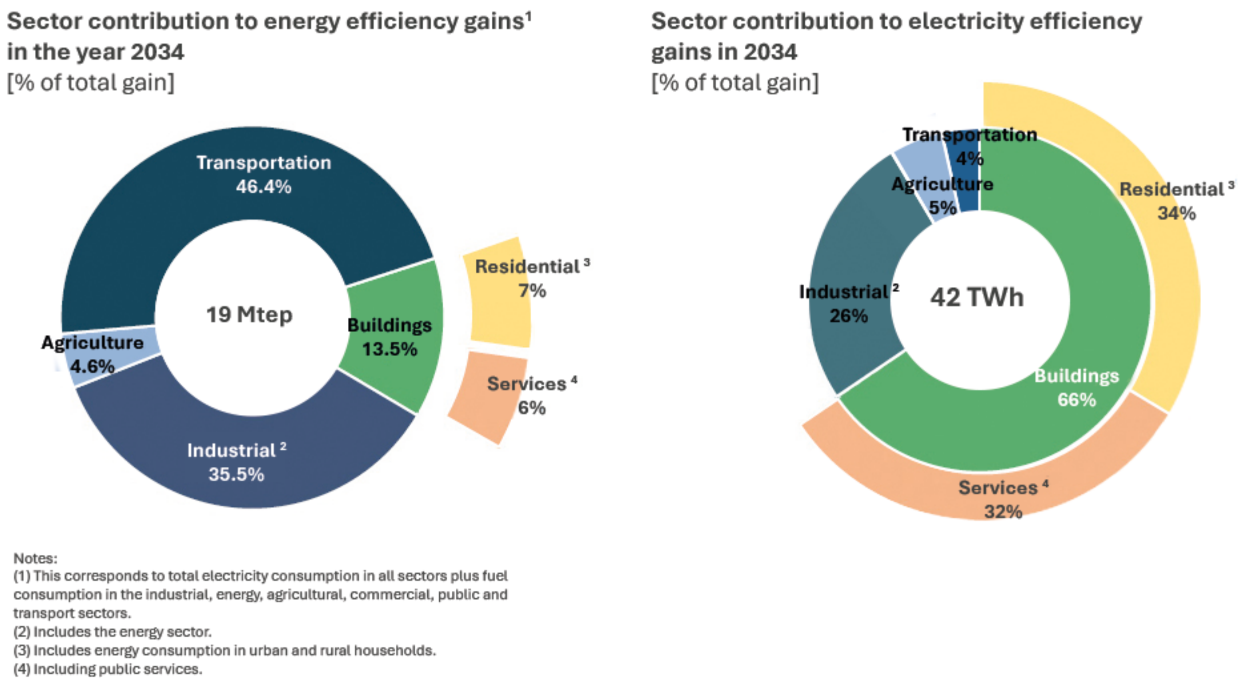
The challenge, therefore, is to balance development, competitiveness and the reduction of inequalities with the decarbonization of the energy matrix. The concept of common but differentiated responsibility, enshrined since Rio-92, is still relevant: all countries need to move forward, but at a pace compatible with their realities. For Brazil, this means taking advantage of comparative advantages, such as the high share of renewables in the electricity matrix, the long tradition in the use of biofuels and the potential in new energy sources, while at the same time having to face relevant challenges, especially the reduction of emissions in industry and transport. The future, in this scenario, is uncertain. There is no single path, but multiple possibilities that will depend on the quality of the decisions made today - in public policies, technological innovation and investments. In this context, energy efficiency is a strategic axis. As highlighted in the Ten-Year Energy Expansion Plan 2034 (PDE 2034), efficiency gains reduce costs, increase energy security and help make economic growth compatible with sustainability. In other words, efficiency is the "first fuel" of the transition, capable of delivering immediate results while new technologies mature.

The reflection proposed by the Firjan Journey for the Energy Transition is therefore strategic: inserting Rio de Janeiro and Brazil into a debate that goes beyond cyclical energy management, positioning the sector as a vector for sustainable development, innovation and global competitiveness. As a hub for energy and industry, the state of Rio de Janeiro brings together both the greatest challenges and the greatest opportunities to boost integration between different sources, sectors and public policies, consolidating its strategic position in Brazil's energy transition - and reinforcing the country's role as a protagonist in the global decarbonization effort.

Efficiency as the basis for transition

Energy efficiency is the foundation of a successful energy transition. It is not limited to final consumption, but is expressed in systemic gains throughout the chain: from the modernization of hydroelectric plants to the expansion of renewable sources, from greater transmission reliability to the reduction of losses, to the appreciation of distributed micro and mini-generation, self-production and behind-the-meter storage. These elements strengthen the system's resilience and make the consumer an active part of the transition.

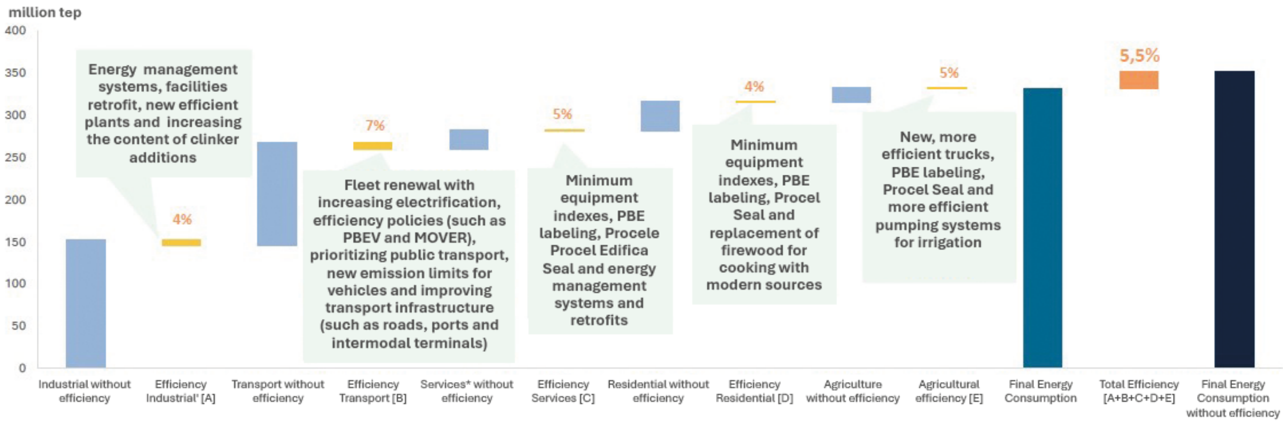
Figure 4: The importance of energy efficiency in the ten-year scenario



Source: Ten-Year Energy Expansion Plan 2034 (PDE 2034)

In end use, efficiency translates into lower energy intensity in the economy, allowing GDP growth not to be converted into a proportional increase in energy consumption It is a strategy that generates immediate environmental, economic and social benefits, becoming a bridge between short-term needs and the long-term objectives of the transition.

Figure 5: Sector contribution to total energy efficiency gains (% in each sector)



Source: Ten-Year Energy Expansion Plan 2034 (PDE 2034)

In transportation, efficiency gains are seen in the consolidation of liquid biofuels, the introduction of advanced fuels such as HVO and SAF and the gradual electrification of the light fleet. Logistical improvements are also important, with the expansion of public transport, railroads and cabotage.

In buildings, which are expected to account for more than half of the country's electricity consumption by 2034, the challenge is to disseminate more efficient building standards, low-consumption air conditioning equipment and greater use of solar thermal energy. Although the impact of each individual home or building is small, in the national aggregate the savings are significant, especially when associated with load management mechanisms.

Efficiency and industry: the heart of the energy transition

It is in the industrial sector, however, that energy efficiency reveals its full transformative potential. Industry accounts for around a third of final energy consumption and a large part of the emissions associated with the use of fossil fuels. In this sector, efficiency gains not only mean reduced operating costs, but can also redefine entire production processes, open up space for innovative technologies, and create new markets.

The PDE 2034 projects significant changes in the structure of industrial consumption, with a greater share of electricity and natural gas and a relative drop in the use of oil derivatives. This trend stems both from the rise of more electro-intensive industries and the modernization of traditional segments. The figures are impressive: electrical efficiency contributes to a 3% reduction in industrial consumption in 2034, or 11 TWh (an amount close to the total current electrical consumption of the ferro-alloys segment, for example), and energy efficiency gains reduce 7 million tep of the industry's potential consumption in 2034 (PDE 2034), comparable to the current consumption of the cement segment.

And we can still go further. The combination of existing efficiency mechanisms in the country, such as the implementation of policies affecting Brazilian industry, as well as autonomous actions by industries, linked to aspects such as facilities retrofit, new, more modern and energy-efficient industrial units (greenfield), and energy use management actions, among others, are some of the possible contributions of energy efficiency.

Over the next decade, the cement sector, for example, is expected to increase the use of additions to clinker, reducing the intensity of emissions, while the chemical industry replaces obsolete technologies, such as mercury cells, with cleaner processes. The steel industry is expected to invest in more efficient blast furnaces and is already preparing to incorporate less carbon-intensive fuels as a vector for decarbonization.

In pulp and paper production, biomass has become a central energy input, enabling cogeneration and increasing systemic gains.

These advances also illustrate how efficiency in industry goes beyond saving energy: it is an agenda of technological transformation and competitiveness. Companies that adopt more efficient practices reduce costs and, at the same time, prepare themselves to meet the demands of international markets that link trade to carbon emissions. For Rio de Janeiro, whose industry focuses on activities such as steel, petrochemicals, and pulp and paper, this is an opportunity to lead the transformation, consolidating the state as a benchmark in industrial decarbonization.

It is important to note that, in addition to long-term energy planning, efficiency has also been recognized as a pillar in the National Climate Change Plan (Climate Plan), which structures Brazil's path towards neutrality by 2050. The Climate Plan highlights efficiency as one of the most cost-effective ways to reduce emissions, in line with the principles of climate justice and sustainable development.

In the case of the Industry Sector Plan, energy efficiency is one of the most important impact actions, especially the goals of electrifying production processes, industrial digitalization (Industry 4.0) and achieving energy efficiency gains of 2% by 2030 and between 4% and 8% by 2035 compared to 2023. These initiatives reinforce that efficiency goes far beyond reducing costs: it is an instrument of competitiveness, a means of aligning Brazilian industry with international low-carbon requirements and a condition for a just transition, by preventing costs from falling disproportionately on the most vulnerable segments of society.

Energy efficiency is therefore both a strategic lever for competitiveness and a fundamental tool for reducing inequalities and ensuring a just transition. Solutions that involve disproportionate costs or exclude low-income consumers not only slow down the process, but also increase social vulnerabilities.

This perspective is particularly relevant in Brazil, where transition needs to go hand in hand with social inclusion. The alignment between innovation, efficiency and social justice is a necessary condition to ensure that the benefits of the transition are widely distributed and consolidate a sustainable path to development.

Opportunities for Rio de Janeiro

Rio de Janeiro concentrates strategic assets that place it in a central position in Brazil's energy transition. As the largest oil and gas hub in the country, with refineries, thermal power plants, ports, research centers and a diversified industrial farm, the state has unique conditions to be a protagonist in this process. This position means not only decarbonization challenges, but also great opportunities for transformation.

The state can lead industrial decarbonization projects, modernizing chains such as steel, petrochemicals and pulp and paper. It also has the potential to become a national hub for low-carbon hydrogen, taking advantage of its natural gas infrastructure, its ports and its technological base. CCUS projects can be developed on the basis of the experience accumulated in the oil and gas sector, creating new routes to competitiveness for local industry. In addition, Rio can integrate renewable sources more intensively into its matrix, taking advantage of onshore and offshore solar and wind potential in combination with the expertise already consolidated in wind generation in the Northeast and large-scale transmission.

By combining its industrial and energy base with innovation, adequate regulation and consistent public policies, Rio de Janeiro can become a laboratory for Brazil's transition, attracting investment, stimulating technological innovation and generating quality jobs. This leading role not only strengthens the state's competitiveness, but also projects its leadership onto the national and international stage.

Brazilian Greenhouse Gas Emissions Trading System - SBCE

What is the carbon market?

Mechanisms that aim to reduce GHG emissions through a system of emission quotas and mechanisms so that companies that exceed these limits can purchase emission permits or carbon credits, in order to offset their exceeding emissions.

1 credit = 1 tCO_2eq

Law 15,042, passed in December 2024, establishes the SBCE - the Brazilian carbon market

It applies to activities on national territory that emit or may emit GHGs. It will have its own management body, linked to the Interministerial Committee on Climate Change and a Permanent Technical Advisory Committee.

Operators of activities that issue:

over than • 10.000 tCO_2eq/year or over than • 25.000 tCO_2eq/year

They should present in stages:

Monitoring plan	Reporting GHG emissions and removals	Other obligations defined by the SBCE	Reporting periodic reconciliation of obligations
••	••	••	•

Implementation phases

I in 2025: the publication of the regulation of Law 15,042

II in 2026: for the operationalization of companies of the **emissions reporting**

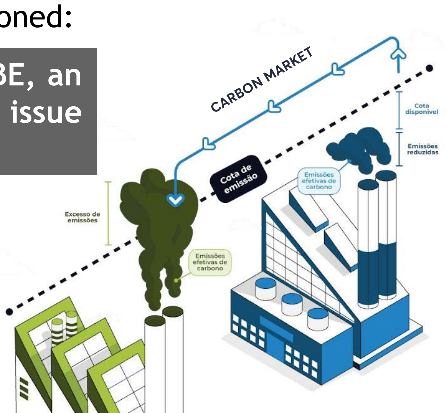
III in 2028: operators submit Emissions Monitoring and Reporting Plan

IV and V: first National Allocation Plan and implementation of the SBCE

The following assets will be transitioned:

Brazilian Emissions Quota, the CBE, an asset representing the right to issue $1tCO_2e$

Certificate of Verified Reduction or Removal of Emissions, or CRVE, an asset representing an effective reduction or removal of GHG $1tCO_2e$



The Energy Transition Journey: Paths for Industry and Society

SMRs: The new frontier of nuclear energy

Prepared by ABDAN

Nuclear energy once again occupies a central role in the global energy debate. With low CO_2 emissions and the ability to supply electricity continuously, the technology is emerging as a strategic solution for the energy transition - especially with the advance of Small Modular Reactors, or SMRs. According to PRIS data, of AIEA, there are currently 416 nuclear power reactors in operation around the world, spread across 31 countries, with a total capacity of 375 GW(e). Another 59 are under construction. Nuclear energy already accounts for around 10% of the world's electricity and is the second largest low-carbon source, behind hydroelectric power. The demand for electricity is growing rapidly, driven by the advance of technologies such as Artificial Intelligence. Giants such as Microsoft, Amazon and Google see SMRs as an alternative to guarantee clean and stable energy for their data centers, which operate 24 hours a day. The appeal also lies in the possibility of installing them close to urban centers, reducing losses and increasing energy security.

More than electricity

Designed to generate up to 300 MW(e) per unit - around a third of the capacity of a traditional reactor - SMRs can be produced and transported as ready-to-assemble modules. This feature reduces costs, shortens deadlines and allows for diverse applications, such as water desalination, industrial heat supply and hydrogen production. In countries like the United States, Poland and Romania, the technology is already being used to replace coal-fired power plants, taking advantage of existing infrastructure and preserving jobs. One example is the project by TerraPower, Bill Gates' company, which is building a sodium SMR in the state of Wyoming. Studies show that converting coal-fired plants to SMRs can reduce implementation costs by up to 30%.

In Brazil, although the electricity matrix is predominantly renewable, there is still around 3 GW of installed coal power. According to a technical study by ABDAN, many of these plants could be converted to modular technology, reducing emissions and diversifying the matrix.

Security and flexibility

SMRs offer three central advantages:

- **Flexible operation:** they can adjust power according to demand and operate in conjunction with seasonal renewable sources such as solar and wind.
- **Intrinsic safety:** they have passive and inherent systems, which reduce the need for large emergency planning zones and allow greater proximity to urban centers.
- **Economic viability:** although they lose the economy of scale of large reactors, they have lower initial costs, less financial risk and the possibility of modular expansion according to demand.

Today, the AIEA has 81 SMR projects under development around the world, with different applications and stages of maturity. For the nuclear community, this is an opportunity to combine technological innovation, safety and sustainability, positioning nuclear energy as a key player in the transition to a clean and stable matrix.

Figure 6: Conceptual vision of an SMR project integrated with electricity generation

Source: ABDAN

The challenges of training and qualifying the workforce for the future of nuclear energy in Brazil in the context of the energy transition

Prepared by ABEN

Introduction

The global energy transition has highlighted the need to diversify energy matrices, with a focus on reducing carbon emissions, increasing security of supply and integrating new technologies. In this scenario, nuclear energy, especially SMRs, is emerging as a strategic alternative to complement intermittent renewable sources, contribute to the decarbonization of industry and provide heat and cogeneration services to critical sectors.

However, the viability of this transition depends decisively on the training and qualification of specialized human resources. Brazil, with a consolidated nuclear tradition since the 1960s, faces the dual challenge of preserving accumulated knowledge and preparing a new generation of professionals capable of dealing with the technological and regulatory innovations of the new nuclear age.

The importance of nuclear energy in the energy transition

According to recent AIEA estimates, the number of reactors in operation worldwide is expected to grow from 377 GWe in 2025 to between 514 and 950 GWe in 2050. SMRs could account for up to 153 GWe of this total, standing out as a flexible and scalable solution for developing countries.

In addition to electricity generation, nuclear reactors offer additional benefits:

- Production of hydrogen and synthetic fuels;
- Desalination of seawater;
- Industrial heat supply;
- Support for isolated power grids and offshore applications.

Brazil, for its part, has important comparative advantages: mastery of the nuclear fuel cycle, experience in operating research and power reactors, and high-level research institutions. However, to turn this potential into reality, it is necessary to invest heavily in human resources and nuclear know-how.

The challenge of training human resources

The development of nuclear programs requires highly qualified personnel in multiple areas, such as: nuclear engineers, specialists in reactor physics and thermal hydraulics, physicists, chemists, nuclear safety professionals, energy economics and public communication. International experience, compiled by the AIEA, shows that the implementation of SMRs and new plants requires the creation of a National Human Resources Plan involving government, regulators, universities, research centers and industry. Current gaps:

- Ageing technical staff;
- Low attractiveness among young engineers;
- Insufficient integration with the demands of the energy transition.

AIEA experiences and recommendations

The AIEA has emphasized that capacity building for nuclear programs must be systemic, encompassing four pillars:

1. Education and training;
2. Human Resources Development;
3. Nuclear Knowledge Management;
4. Education and Knowledge Networks. The recommendations include:

» Updating technical and university education programs to include state-of-the-art nuclear topics;

» Implementation of knowledge transfer programs to ensure that accumulated expertise is preserved;

» Long-term national planning, including quantitative modeling of the need for professionals;

» Participation in international training schools and programs.

Opportunities for Brazil

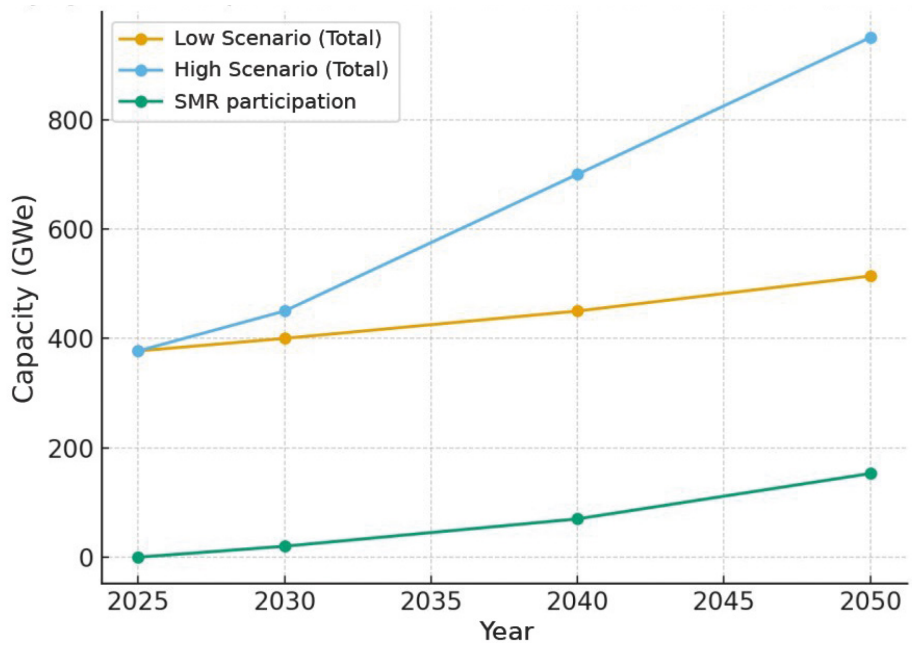
Brazil is already developing cutting-edge nuclear energy projects, which place it in a strategic position in the energy transition scenario. Highlights include the Brazilian Navy's Nuclear Program, with advances in LABGENE - the land-based prototype of the nuclear propulsion system - and in the development of the Brazilian nuclear submarine; CNEN's initiatives, through its research institutes, such as IPEN, IEN, CDTN and CRCN-NE, which develop technologies, innovation and the training of strategic human resources. In the academic field, the INCT on Modular and Innovative Reactors, promoted by CNPq in partnership with CAPES and FAPERJ, which brings together universities and institutes such as UFRJ, UFMG, UESC, UFF, UFRGS, UERJ, IEN, IPEN, among others, and cooperation with international research centers, should be highlighted.

This solid base of research and innovation creates the conditions for Brazil to explore opportunities in the context of the energy transition:

- Integrating SMRs into industrial and port hubs for the simultaneous production of electricity and heat;
- Using nuclear energy for desalination, especially in semi-arid regions;
- Apply microreactors in isolated locations, reducing dependence on fossil fuels.

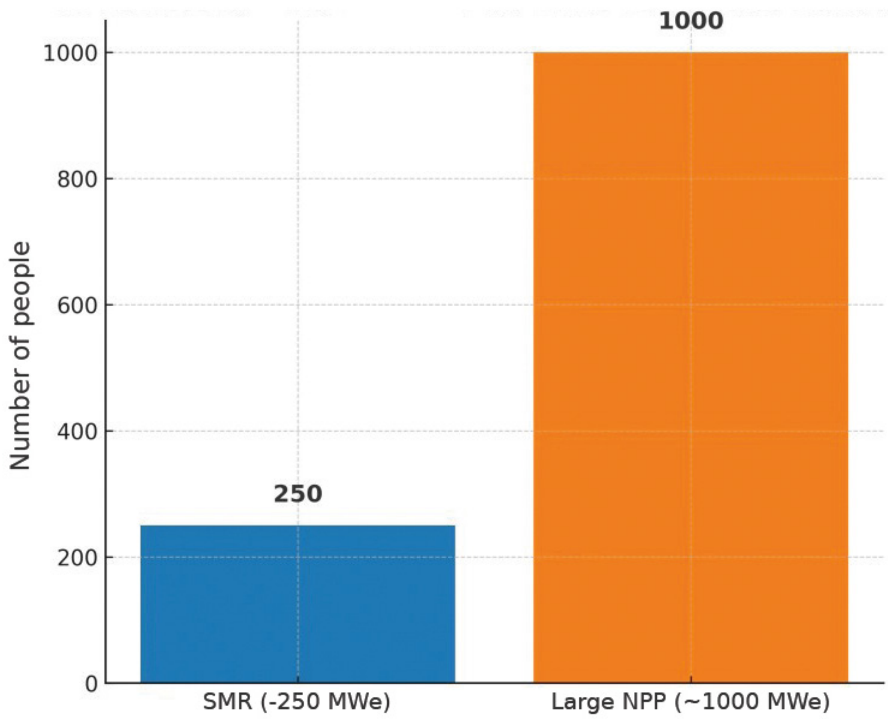
For these applications, it will be essential to have professionals trained in multiple areas, from engineering to economics, public policy and social communication.

Figure 7: Projection of global nuclear capacity growth until 2050 (IAEA, 2024)



Source: ABEN

Figure 8: Comparison of personnel needs for SMRs and large nuclear power plants (IAEA, 2025)



Source: ABEN

Priority actions

In order to meet the challenges of training and qualifying the nuclear workforce, we recommend:

1. Creation of a National Nuclear HR Plan;
2. Strengthening undergraduate and graduate programs in the nuclear area;
3. Training for regulators and public policy makers;
4. Establishing and strengthening Centers of Excellence for research into new technologies;
5. Programs to attract young talent;
6. Nuclear knowledge management, with methodologies for capturing the tacit knowledge of senior specialists.

Final Considerations

The energy transition in Brazil will not only be technological, but also human and institutional. Without training a new generation of highly qualified professionals, the country risks losing competitiveness in a strategic sector for decarbonization and energy security.

Nuclear energy, alongside renewables, will play an essential role in building a sustainable future. To this end, it is imperative that the education, training and retention of skilled labor be treated as a state priority, in line with international best practices and Brazil's specific needs.

The contribution of cogeneration to the reliability and resilience of the energy industry

Prepared by COGEN

Energy efficiency and security of electricity supply, especially from cogeneration, are attributes that need to be increasingly valued.

A recent report in the newspaper O Globo (*"Data center market experiences boom with use of AI"*, published on 07/03/2025), shows that the artificial intelligence industry is driving a wave of data center projects in the country.

And what does this have to do with cogeneration? These facilities, boosted by the emergence of chatbots etc., require a lot of energy to process, store and distribute data. In order to function properly, computer rooms need powerful climate control equipment and a reliable power supply.

It's no coincidence that global energy demand is set to rise above the levels recorded over the past decade.

A BCG report entitled *"Breaking Barriers to Data Center Growth"* projects that global demand for data center energy will grow at an annual rate of 16% between 2023 and 2028.

This is a window of opportunity for Brazil, where the governments of many states and city halls, including Rio de Janeiro, are very interested in the possibility of attracting investment in these technological infrastructures, centers capable of generating quality jobs and increasing revenue.

Among the various criteria that investors evaluate, one is inescapable: we need secure, reliable and resilient energy, which combines environmental gains with energy security.

All of these are attributes linked par excellence to cogeneration systems.

Explaining cogeneration

It is one of the most intelligent, stable and efficient forms of energy production.

Cogeneration, in short, is the result of producing two types of energy (electrical and thermal, with heat or cold) from a single source - biomass, natural gas and biogas, for example.

This use of thermal energy can produce complementary applications such as steam and chilled water, i.e. air conditioning.

Precisely because it is generated directly at the center of consumption, cogeneration avoids losses that naturally exist in the transmission and distribution processes, which is good for the country. And in the event of an interruption in the SIN, the establishment served by cogeneration has much more stability and autonomy.

Historically, Brazil woke up to cogeneration in the early 2000s. In August 2025, the date of this article, the segment already had 21.9 GW of installed capacity in commercial operation, which at that time represented 10.3% of the national electricity matrix (212.7 GW), considering only centralized generation.

In addition to the sugar-energy and pulp and paper mills, which together account for 77.1% of cogeneration, other important industrial sectors are served: petrochemicals, wood, food and beverages, steel, sanitation and automobiles, among others.

The most interesting thing is that cogeneration allows each location to benefit from the energy source of its energy vocation - sugar cane biomass in the interior of São Paulo, waste from pulp and paper production in Três Lagoas, Mato Grosso do Sul, and natural gas in the metropolitan region of Rio de Janeiro, to name just a few examples.

In a large metropolis like the one that gravitates around the capital of Rio de Janeiro, natural gas cogeneration can be extremely useful.

Firstly, because in the metropolitan region there is a notable capillarization of the natural gas distribution networks of the concessionaires CEG and CEG-Rio (the result of decades of investment by companies controlled by Naturgy Brasil), which makes one of the basic factors for the start of any project viable in advance - supply.

Secondly, the existence of these networks can serve as an entry point for the injection of biomethane — a renewable gas obtained through the purification of biogas derived from the use of agricultural, forestry, and livestock waste, as well as urban solid waste, whose production is growing and boosted by the Future Fuel Law Law No. 14,993/2024, which establishes the National Decarbonization Program for Natural Gas Producers and Importers and the Incentive Program for Biomethane.

The production of biogas and biomethane, moreover, could be, with scalability, an additional vector to arouse the appetite of data centers and other businesses that are interested in combining the safety of natural gas with the renewability of biomethane. Rio de Janeiro plays a leading role on both fronts, as one of the largest producers of natural gas and biomethane - with Gás Verde's plant in Seropédica standing out.

In addition, businesses increasingly need the certainty of continuous supply, come rain or shine, something that has been a recurring problem in the country, given the not always predictable weather - Brazilians spent an average of 10 hours and 14 minutes without power due to supply interruptions in 2024, according to ANEEL. The frequency of outages was 4.89 per consumer.

Challenges and opportunities for cogeneration in Rio de Janeiro

Rio de Janeiro has pioneering cases in the use of natural gas cogeneration in emblematic industries in the beverage and textile sectors, and this potential could be even more significant if the country advances in gas competitiveness.

Data released by EPE, the MME's planning arm, shows that the final cost of natural gas in Brazil could fall by half (from USD 16.10 to USD 7.67) per million BTU, if the costs still charged for investments in assets that have already been depreciated and duly remunerated in links in the chain such as Flow and Processing and Transportation through gas pipelines were eliminated.

In order to increase this competitiveness, opening up the market and carefully reviewing these costs are a desire of industry in Rio de Janeiro and throughout the country - which depend on natural gas to optimize their production processes in sectors considered hard-to-abate.

Many are calling for more competition in supply - and in Brazil, despite some progress, there are still states where the gas distributed comes from a single supplier, which has a strong dominance in shaping the price of the molecule.

A good example of how the opening up of the market is positive is in the state of Bahia. Benefiting from the abundant supply of onshore gas, the local concessionaire has more than ten suppliers and supplies gas at around USD 11 per million BTU.

To resolve this type of issue, the ANP, now having two new directors in its composition, appointed after being questioned and approved by the National Congress, has a preponderant role. The tariff review of gas carriers, with a thorough examination of the regulatory asset base, is a process that deserves a lot of attention from the five directors who make up the ANP.

There is also a lot of expectation about the PPSA auctions, whose original schedule is delayed, but which could be decisive for negotiated and non-discriminatory access to infrastructure - the current costs of access to the infrastructure of the Integrated Drainage System (SIE) and Production System (SIP). Taking care of these processes with due diligence is fundamental for Brazilian industry to be able to invest more in cogeneration, especially in the state of Rio de Janeiro, which had a significant GDP growth in 2024, of 3.9%, surpassing that of the national GDP by 0.5 percentage point, according to data from the Firjan System.

Valuing the attributes of gas cogeneration is fundamental

There is considerable potential for growth in cogeneration.

A study carried out with 12 segments by Cogen, in partnership with Promon Engenharia, back in 2018, identified that the greatest potential for producing electricity from natural gas cogeneration is in the chemical activities, hospital, shopping mall and textile sectors, mainly in the states of São Paulo and Rio de Janeiro. Approximately 5,500 new enterprises could use this alternative form of energy self-production, which would triple gas-fired cogeneration, which remains stable at 3.2 GW. This sum of new projects, the survey reveals, could reach 7.2 GW, which is equivalent to half of Itaipu Binacional, the world's third largest plant in terms of installed capacity, with 14 GW.

For its part, the cogeneration industry has been playing its part, investing in innovation and improving the efficiency of equipment.

Even so, the development of new, more robust cogeneration projects, considering large industry, has been timid, which demonstrates a picture that requires the right incentives and appropriate public policies in view of all the benefits that this way of producing energy provides for more balanced, reliable and distributed energy and electricity matrices.

One of Cogen's requests to ANEEL is the pricing of the attributes of natural gas cogeneration, with gains in competitiveness that could bring more rationality to the electricity system instead of investments in centralized generation.

Brasília is dealing with various issues involving the energy sector and gas cogeneration definitely needs to be remembered, not only because of its more competitive cost compared to thermoelectric plants, but also because of its greater energy efficiency, among other economic and environmental externalities.

It is essential that these attributes are properly valued by regulators and public agents, for the benefit of a country that needs to attract not only data centers, but retain and stimulate businesses that generate income and jobs for Brazilians.

COGEN INFOGRAPHIC

August/2025 edition

COGEN Associação da Indústria de Cogeração de Energia

Sources: DataCOGEN, ANEEL, CCEE, EPE, MME, and ONS

A COGEN was set up to promote the advancement of Distributed Generation in Brazil, with an emphasis on Energy Cogeneration, acting on the sector's regulatory infrastructure.

3 vectors that guide COGEN'S activities: biomass, natural gas and biogas.

21 Years

81 members, which operate in the energy cogeneration chain, including companies that generate, transmit, distribute and sell electricity and natural gas; companies in the sugar-energy industry, manufacturers of equipment and materials; engineering, consultancy, and energy efficiency companies; service providers; integrators; law firms and cogeneration users.

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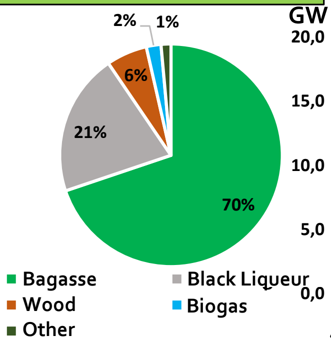
Total Cogen - 21.9 GW

	Power Plants	GW
Biomass	529	18,3
Natural Gas	94	3,2
Biogas	53	0,4

Fuel → Cogeneration → Electric E. / Thermal E. / Gases

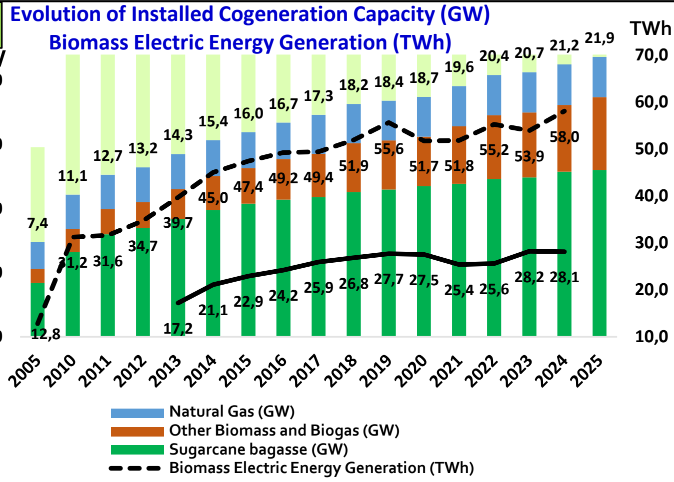
Centralized Solar	+450	18,0
Micro and Mini GD	+3700k	41,7

Biomass – 18,7 GW

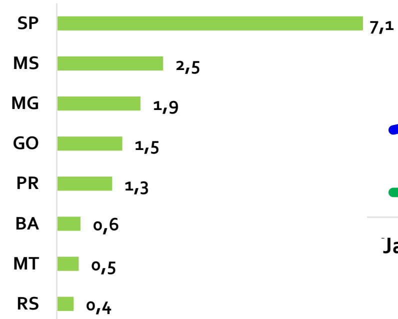


Sources: ANEEL, CCEE, EPE

Evolution of Installed Cogeneration Capacity (GW)
Biomass Electric Energy Generation (TWh)



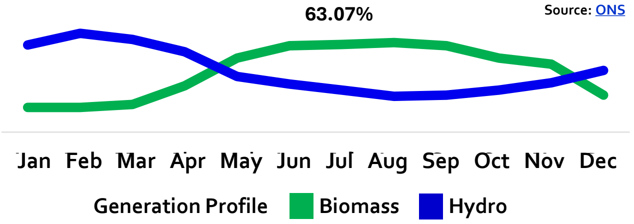
Ranking Estadual



In 2023, biomass generation will save **16%** of the SE/CO reservoirs

Level of the SE/CO Reservoirs on 07/31/25:
63.07%

Source: ONS



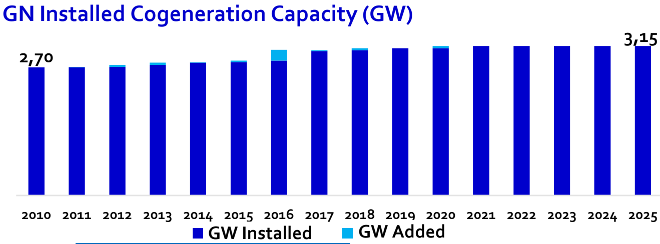
Fonte: COGEN

Natural Gas - 3.2 GW

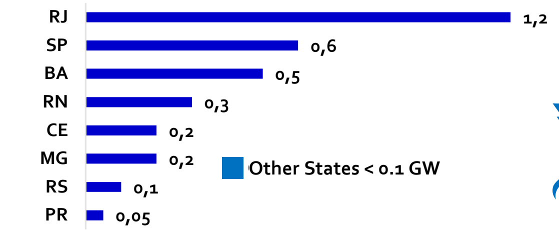
Cogeneration using natural gas is ideal for supplying electricity, heat and cooling, especially in large metropolitan centers.
The high efficiency, reliability and resilience of GN cogeneration brings several advantages inherent to this fuel.

COGEN Associação da Indústria de Cogeração de Energia

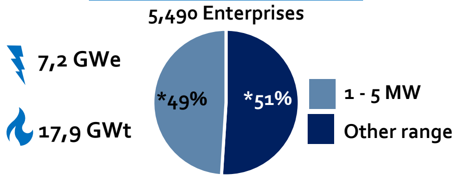
GN Installed Cogeneration Capacity (GW)



State Ranking



eBook - Potential

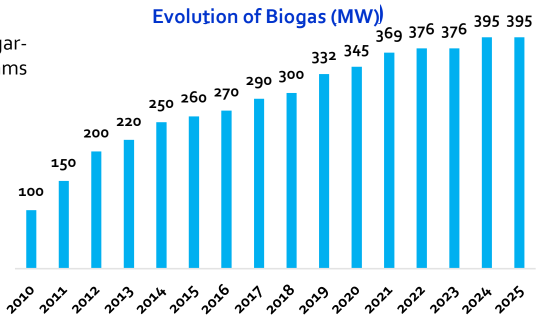


Benefit Simulator

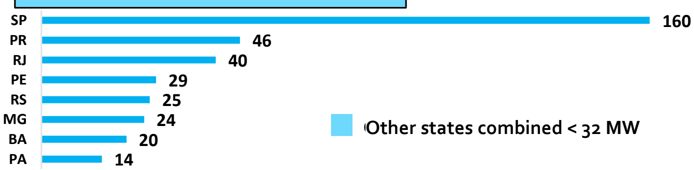
Biogas – 395 MW

Biogas, whether it comes from solid urban waste, agricultural waste or the sugar-energy industry, has enormous potential, especially with the advent of programs such as RenovaBio.

Evolution of Biogas (MW)



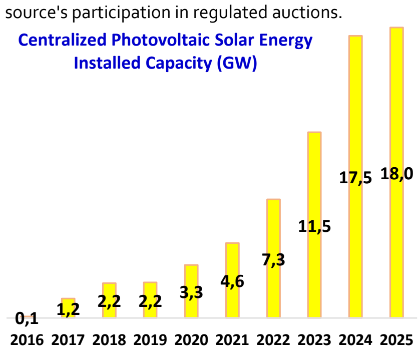
State Ranking



Centralized Solar Photovoltaic - 18.0 GW

Centralized solar photovoltaic generation has seen continuous growth since the beginning of this source's participation in regulated auctions.

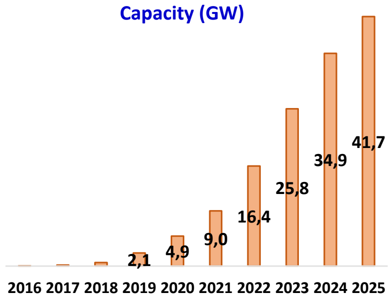
Centralized Photovoltaic Solar Energy Installed Capacity (GW)



Solar Photovoltaic MMGD - 41.7 GW

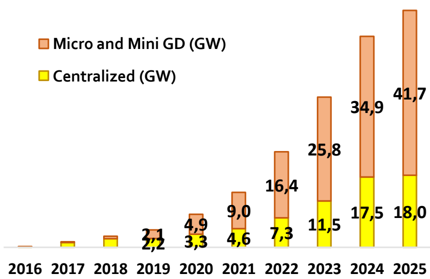
In the field of distributed micro and mini generation, this source is a leading player, accounting for 98% of MMGD.

MMGD Solar Photovoltaic Installed Capacity (GW)



Centralized Solar Photovoltaic + MMGD: 59.6 GW

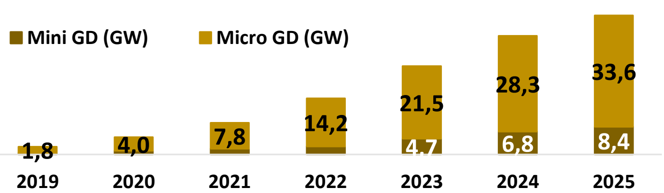
Centralized Solar Photovoltaic Installed Capacity + MMGD (GW)



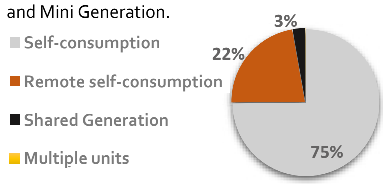
Distributed Micro and Mini Generation: 41.9 GW

Micro < = 75 KW: 33.6 GW
75 KW < Mini < = 5 MW: 8.4 GW

MMGD Installed Capacity (GW)



Generation of energy through renewable sources or qualified cogeneration, with a view to self-consumption or offsetting energy credits from the surplus exported to the electricity grid (netmetering). Regulated by Law 14,300/2022, the Legal Milestone for Distributed Micro and Mini Generation.



Source: ANEEL

Fonte: COGEN

The future of energy and its impact on society's quality of life

Prepared by ENEL

Energy: Pillar of development and citizenship

In a world in transition, nothing is more urgent - and more promising - than transforming the way we produce, distribute and consume energy. The challenge is immense, but the opportunity even greater: the energy transition is the way not only to mitigate climate change, but to build a fairer, more resilient and inclusive society.

Energy is not just about infrastructure. It's what connects people to opportunities, lights up homes and ideas, boosts economies and guarantees dignity. Talking about energy, therefore, is talking about quality of life, especially in a country like Brazil, where unequal financial access still compromises, in many cases, the full right to citizenship.

Over the last decade working in sustainability in the electricity sector, I have witnessed the transformative power of energy when it is thought of not as an end in itself, but as a means to develop people, territories, and the future.

To make this future possible, it is essential to modernize the infrastructure that supports this system. More intelligent, automated, and interconnected networks are becoming the fundamental pillars of this transformation. Technologies such as hybrid power plants, remote control and automation equipment, and thermographic inspections increase the resilience and capacity of the grid, preparing it to integrate new forms of consumption and greater active participation by society.

It is in this combination of purpose and innovation that the electricity sector finds the way to deliver not only energy, but also a quality service, support the decarbonization of the economy and reduce the emissions that aggravate climate change.

Brazil's commitment to neutrality by 2050

In 2024, Brazil submitted its NDC (Nationally Determined Contribution) to the UN, setting a target of reducing GHG emissions by 59% to 67% compared to 2005 in all sectors of the economy, reaffirming its commitment to climate neutrality by 2050.

In the energy sector, this means reducing dependence on fossil fuels by accelerating the electrification of end uses, further expanding the share of renewable sources, as well as advancing in grid digitalization and efficient energy use. These measures require robust investments in smart and digital grids, capable of integrating distributed generation, electric vehicles, storage, and new forms of energy consumption.

In addition to the transition of the energy matrix, it will be necessary to strengthen regulatory frameworks and offer clear economic signals to encourage private investment, with legal certainty and institutional stability. This regulatory environment is key to enabling technological innovation, new business models and digital solutions that guarantee greater reliability and resilience for the electricity system.

In this context, the state of Rio de Janeiro can become a national model capable of attracting new investments, combining new opportunities with industrial capacity and a changing distribution network, to demonstrate how public policies, companies, and society can converge to build a modern, inclusive energy sector in line with Brazil's climate goals.

Paths to the energy transition in Brazil: routes and opportunities

The study "Paths to the Energy Transition", developed by Enel in partnership with Deloitte, presents scenarios for Brazil's decarbonization path until 2050.
One of the central points is to reduce the consumption of fossil fuels, especially oil and gas, which today account for around 50% of Brazil's energy matrix. To achieve the climate neutrality scenario, the report projects that by 2050 this percentage will have to fall to less than 20%, with gradual replacement by electrification and advanced biofuels. According to the study, the electrification of end uses stands out in this context: it is estimated that the share of electricity in final energy consumption, currently close to 20%, could reach between 35% and 40% by 2050. This electrification will be distributed across different sectors:

- Industry: low and medium temperature thermal processes may migrate to electricity. Hard to abate heavy industry, such as steel, cement, and chemicals, could benefit from green hydrogen as an energy input and raw material, enabling low-carbon routes for steel and fertilizers.
- Transport: light vehicles will see increasing penetration of electric mobility, reaching 51% by 2050, while heavy transport, such as urban buses, trucks, and trains, will be served by 99% direct electrification by 2050.
- Residential and commercial: increased electrification through the expansion of more efficient equipment, such as water heating via heat pumps and high-efficiency electric air conditioning, will reduce dependence on natural gas.
- Agriculture: electric mechanization and the use of electricity can reduce diesel consumption and support the production of green fertilizers.

By integrating electrification, renewable generation and new clean energy sources such as green hydrogen, Brazil could reduce emissions from the energy sector by more than 70% by 2050, while increasing the competitiveness of industry and reducing costs for consumers.
According to the study, this scenario will require around BRL 1.6 trillion in investments in the energy sector. Although high, this figure is fully offset by the gains from the carbon pricing mechanism, the savings from greater energy efficiency and the benefit generated in terms of the social costs of avoided carbon, as well as the opportunity to generate a net balance of 8 million jobs, strengthening the national industry and Brazil's strategic positioning as a clean energy exporter.

Enel's strategy: mitigation, adaptation and innovation

Climate change impacts not only cities and people's lives, but also the operation of the electricity sector, requiring rapid and structured responses. For the energy industry, this means rethinking the way it plans, operates and invests, seeking not only to mitigate risks, but also to adapt its practices to the new scenario.
In Brazil, Enel already operates 6.6 GW of 100% renewable installed capacity, distributed between wind, solar and hydroelectric sources, reaffirming its commitment to climate neutrality and the decarbonization of the electricity sector. This matrix positions the company as one of the country's leading clean energy operators, while generating jobs and development in various regions.
In energy distribution, Enel has consistently increased its investments, allocating BRL 24 billion in the 2025–2027 three-year period, as announced in 2024, with the strategy of modernizing and digitalizing the electricity grid.
Mitigation actions, which act on the causes of global warming, concentrate a significant part of these investments in initiatives such as the installation of remote control equipment, reinforcement, and automation of the network, expansion of substations and modernization of existing lines. These measures bring efficiency to the network, reducing response times and bringing the

company closer to its climate neutrality targets, while ensuring a higher quality of energy supply.
Adaptation actions, on the other hand, are aimed at dealing with the inevitable impacts of climate change and seek to make the network more resilient to the increased frequency of storms, floods, and heat waves. The plan includes continuous weather monitoring, critical event management systems and seasonal programs such as the Summer Plan, for rapid response to emergencies. In addition, practices such as pruning and tree management reduce shutdowns caused by branches falling on the network, showing how adaptation is directly linked to the customer experience and operational resilience.
This movement is accompanied by a continuous cycle of innovation. Partnerships with research centers and initiatives such as Paths to the Energy Transition and Circular Cities make it possible to anticipate regulatory and climate trends and develop sustainable urban solutions. Thus, each investment strengthens not only the operation of the network, but also the contribution to a more resilient, efficient and inclusive society.

Rio de Janeiro: protagonist of the national energy transition

The state of Rio de Janeiro has one of the largest investment portfolios in the country. According to Firjan, the Investment Panorama 2025-2027 projects BRL 534 billion in new projects, almost 80% of which are in the energy sector. This volume could generate thousands of jobs, increase state and municipal revenue and consolidate Rio de Janeiro as a strategic hub for the energy transition, by combining traditional assets such as oil and gas with new low-carbon vectors such as green hydrogen, offshore wind and investment in digitalizing the grid.
In the state of Rio de Janeiro, Enel Distribuição Rio is at the center of this transformation. The company will invest around BRL 6.1 billion over three years - a 74% increase on the previous plan - to modernize the network in the 66 municipalities where it operates. By 2025 alone, the plan includes the construction, expansion, and modernization of substations, the construction of 80 km of high-voltage network, the reconditioning of 300 km of medium-voltage network, as well as the introduction of more than 2,000 pieces of remote-controlled equipment for remote management and increased reliability.
These investments in Rio de Janeiro are not limited to the physical infrastructure; they also involve expanding the team by hiring more than 2,000 employees by 2026, intensifying preventive maintenance through pruning and thermographic inspection, and improving customer service.
For society, Enel annually develops initiatives aimed at access to energy and social inclusion, such as the refrigerator exchange program, energy efficiency projects via public calls, education actions for conscious consumption and income generation initiatives, which contribute to combating energy poverty. Over the last five years, more than 40 energy efficiency projects have been carried out, benefiting hospitals, schools, public institutions and lighting systems. These actions have led to savings of 9,675 MWh per year, reducing costs and relieving public budgets, as well as reinforcing energy citizenship.
Together, these actions strengthen Enel's role as an agent of transformation in the electricity sector, aligned with efficiency, innovation, and quality service.

Fair energy transition: social impacts and improved quality of life

Climate change is testing the resilience of societies and showing that the impacts will fall hardest on the most vulnerable groups. Guaranteeing secure and stable access to energy is therefore more than an environmental goal: it is a question of social justice. The fair energy transition must ensure that the benefits of decarbonization, including clean energy, affordable tariffs and the creation of new jobs, reach everyone, reducing inequalities and preventing entire populations from being exposed to the risk of forced displacement, the so-called climate refugees, or energy poverty.

Investments in renewable energies, network digitalization and predictive maintenance are pillars of this transformation. These measures, in addition to avoiding gas emissions, make the electricity system more reliable, reduce losses, anticipate failures and strengthen resilience in the face of extreme weather events. At the same time, they enable homes, schools, hospitals, and businesses to have stable, quality energy, creating a solid foundation for social inclusion and human development.

The effects are noticeable in everyday life: lower electricity bills with energy efficiency, cleaner air with the electrification of the transport fleet, skilled jobs in the construction and operation of renewable assets and more resilient cities with smart grids. By reducing costs associated with health, improving mobility and increasing productivity, the energy transition contributes directly to raising people's quality of life and strengthening the right to citizenship for the entire population.

Ultimately, the future of energy will be all the more promising when it is able to combine purpose and technology. Consistent public policies, stable regulatory milestones and continuous innovation are essential elements for accelerating this agenda. The integration of renewable generation, digital networks and social participation is the path to a competitive, inclusive and sustainable energy system. It is in this convergence that the energy transition ceases to be just a response to climate change and becomes a real development strategy for society.

SENAI Institute for Innovation in Virtual Production Systems (ISI SVP)

Firjan SENAI SESI, through the **SENAI Institute for Innovation in Virtual Production Systems (ISI SVP)**, has established itself as a benchmark in the use of **Artificial Intelligence (AI)** to accelerate the **energy transition** and **digital transformation of industry**. Combining skills in **digital modeling, computer vision, signal analysis and advanced algorithms**, the institute develops solutions that promote **operational efficiency, waste reduction and sustainability**.

Among the highlights of the portfolio are:

- **Energy monitoring solutions with AI**, capable of analyzing consumption patterns in real time and indicating strategies for optimizing processes and reducing costs.
- **Non-intrusive energy disaggregation platforms** that use deep learning to measure and predict the consumption of industrial equipment, supporting energy efficiency and decarbonization goals.
- **Onboard predictive maintenance systems** that identify faults in real time, ensuring greater operational reliability and avoiding unscheduled shutdowns with an energy impact.
- **Advanced signal analysis tools** that identify patterns and anomalies in critical processes, contributing to safer and more energy-efficient operations.

Among these solutions, the **intelligent energy monitoring system** stands out, developed during the LabProcel Program (a partnership between Firjan SENAI and Eletrobras) to offer **remote management of electricity consumption** with precision. The technology combines AI, cloud architecture and data analysis, using a single meter to map and predict the use of multiple devices. This **non-intrusive** approach allows for efficiency gains, support for **decarbonization** targets and more assertive decision-making, with information accessible in real time via an app or web interface.

With a multidisciplinary team and a robust infrastructure, **ISI SVP** acts as a **hub for innovation in AI and energy**, supporting industries from different segments in the transition to a **smarter, more sustainable future aligned with the low-carbon economy**.

INSTITUTO SENAI DE INOVAÇÃO SISTEMAS VIRTUAIS

FIRJAN Innovation - Thermal Solutions for Solid Waste Recovery

The SENAI Institute for Innovation in Green Chemistry has developed a project to build an intelligent thermal conversion plant, on a semi-pilot scale, with the aim of valorizing solid urban and wet waste to produce biofuels. The project was structured on the basis of generating technological knowledge applied to the processing of different types of waste, ensuring the efficiency of the process and the viability of its use on an expanded scale.

Over the course of the project, processes using modified catalysts were evaluated, which led to significant gains in selectivity and thermal stability. An integrated semi-pilot system was also designed and built, capable of simulating real operating conditions and providing robust data for future industrial applications.

The main challenges faced included the need for proper waste segregation, the complexity of developing unit operations for wet streams and the adaptation of catalysts with superior performance in high severity environments.

As a result, expertise in thermal conversion technologies for solid waste has been consolidated, strengthening innovation capacity for bioenergy and sustainable industry. The legacy of the project was strategies applicable to integrated waste management in partnership with municipalities, as well as solutions that increased the sector's competitiveness and boosted progress in the circular economy. In this way, it has had a direct impact on the lives of Brazilians, supporting municipalities in building cleaner cities, stimulating the production of renewable energy and contributing to a society that is more engaged in the transition to a sustainable future.

Reactor used to increase the scale of oil production

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How can natural gas projects contribute to the energy transition?

Prepared by ENGIE

Introduction

The energy transition is one of today's most important issues. It represents the global effort to change the way we produce and consume energy, seeking cleaner, safer, and more sustainable sources. In Brazil, this process is taking place in a particular way: we are in a privileged position, with a relatively clean energy matrix and an abundance of natural resources, which allows the transition to take place not through abrupt substitution, but through the diversification of energy sources with intelligent use of the resources already available.

In this context, natural gas has become a strategic vector for Brazil's energy transition. It is a less carbon-intensive fuel compared to other fossil sources, capable of offering operational flexibility, security of supply and synergy with emerging technologies. Its already established infrastructure represents a competitive advantage: it enables market service at lower costs and can be used to offer new renewable gases.

Rio de Janeiro, with its significant industrial base, urban density and proximity to energy-producing centers, has the ideal conditions to lead this movement. The strategic use of natural gas and its infrastructure in the state can boost economic development, attract investment and increase the competitiveness of industry, while contributing to environmental and energy security goals.

In this article, we will explore the role of natural gas as a transition fuel, highlighting its contribution to the decarbonization of energy-intensive sectors and the use of its infrastructure in ensuring resilience and evolution towards an increasingly clean matrix.

The role of natural gas in Brazil's energy transition

Brazil has one of the cleanest energy matrices in the world, with around 50% of the total energy matrix and more than 80% of electricity generation coming from renewable sources such as hydroelectric, biomass, solar and wind power. This composition reflects decades of investment in abundant natural resources, positioning the country in a privileged position on the global energy transition stage.

Despite this favorable context, structural challenges remain that require complementary solutions. Electricity generation in Brazil, for example, is highly vulnerable to climatic variations, due to the high share of intermittent sources, which compromises the predictability and security of the energy supply. In addition, sectors such as industry and transportation still operate with high-emission fossil fuels such as coal, coal coke and petroleum products such as diesel, fuel oil, coke and GLP, among others. To meet these challenges and move towards decarbonization, natural gas is a technically and economically viable alternative, capable of promoting environmental, economic, and operational gains.

Natural gas has attributes that position it as a strategic solution in the energy transition. Firstly, its combustion generates significantly lower carbon dioxide emissions compared to other fossil fuels, as well as virtually eliminating the release of particulates and sulphur oxides, critical pollutants for public health.In addition to the environmental benefits, natural gas offers technical advantages that qualify it as a transition fuel: it is a dispatchable source, with high predictability and operational flexibility. Its wide applicability in different sectors and existing infrastructure reinforce its economic and logistical viability.

Natural gas: a strategic solution for key sectors of the economy

Let's look at some examples of how natural gas can be used to decarbonize sectors of the economy. As already mentioned, the Brazilian electricity matrix is mostly renewable, with a strong presence of hydroelectric generation and a growing share of solar and wind power. This evolution has changed the system's profile from a hydrothermal configuration to a structure more dependent on intermittent sources. In other words, the Brazilian electricity sector is not exactly in a low-carbon transition, but in a structural change that requires greater flexibility and power capacity to guarantee the stability of the system.

In this new arrangement, the thermal farm, especially the natural gas plants, plays an essential role as a technical reserve. Gas-fired thermoelectric plants are dispatchable sources with rapid response capacity and stable operation, which are essential for ensuring the reliability of the electricity system at times of low renewable generation or peak demand. Its operational flexibility contributes to energy security and allows the system to absorb the variability of renewable sources more efficiently and quickly, enabling it to expand in a safe and coordinated manner.

Natural gas is also emerging as a strategic solution for the energy supply of data centers, which are increasingly essential for sustaining digital services, data storage and critical operations in various sectors. These centers require firm, highly available energy sources to meet their growing consumption and need for continuous, reliable supply. The complementarity between renewable and thermal gas sources can guarantee the stability needed to attract investment in data centers in Brazil, transforming the country into a strategic hub of the digital economy.

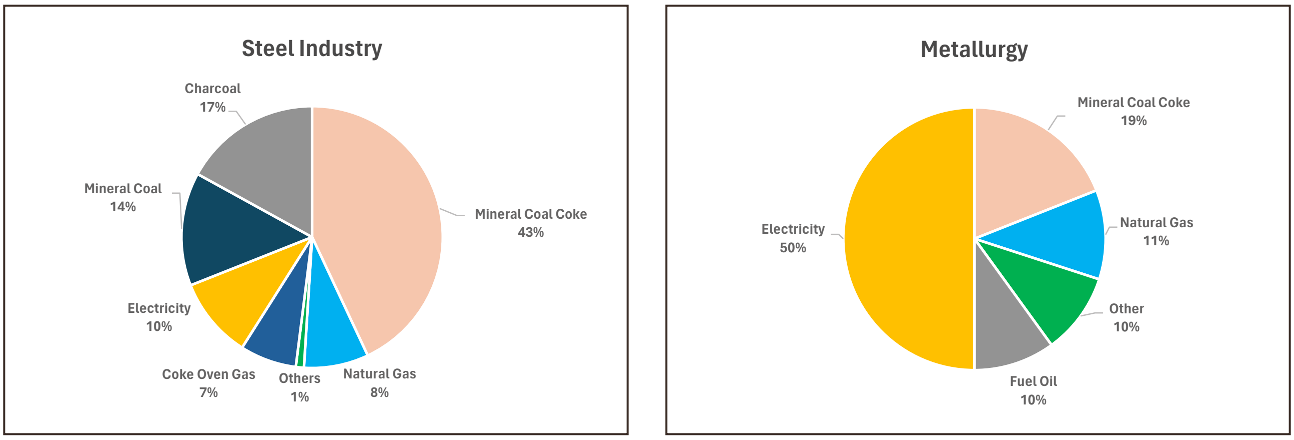
The main role of natural gas in Brazil's energy transition, however, is associated with the industrial and transportation sectors, which are responsible for around 65% of the energy sector's emissions in Brazil. Both hard-to-abate sectors depend on technological solutions for decarbonization, which should only happen in the long term, while gas stands as an economic solution for reducing GHG emissions in the short and medium term.

In industry, natural gas stands out for its versatility, as it can be used as a thermal source in production processes, as an energy input in cogeneration systems and as a raw material in the manufacture of fertilizers and other chemical products. Its stability of supply and predictability also favor gains in efficiency and industrial competitiveness.

This multiplicity of uses reinforces the role of natural gas as an efficient and more environmentally appropriate solution, capable of replacing high-emission fuels and contributing to the modernization of production processes.

In the steel and metallurgy sectors in particular, gas plays a central role in decarbonizing production processes, mainly due to the high share of more polluting and technically replaceable fuels. Figure 9 shows the energy matrix of both sectors. In the steel industry, natural gas can replace coal coke as an energy source and blast furnace reducer, substantially reducing GHG emissions, as well as improving the thermal efficiency of processes. In metallurgy, the high consumption of fuel oil and coal can also be replaced by natural gas, with direct benefits in reducing the carbon footprint and complying with international environmental requirements.

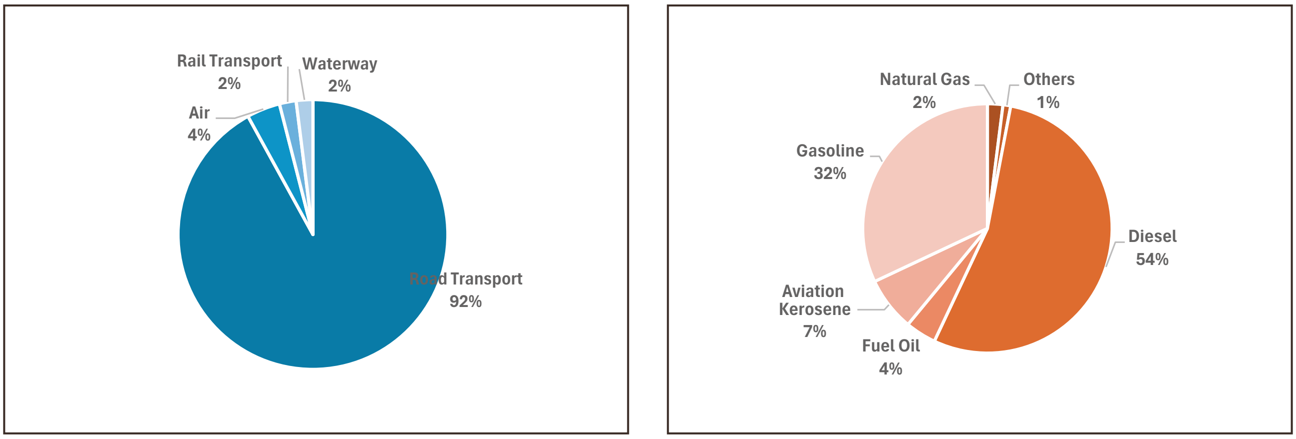
Figure 9: Energy matrix of the steel and metallurgy sectors, 2024



Source: Own elaboration with EPE data (2025)[1].

The transport sector, in turn, is one of the country's biggest GHG emitters, due to the predominance of diesel in road freight transport and gasoline in passenger vehicles, as shown in Figure 10. In 2023, the burning of diesel in the transport sector resulted in the emission of approximately 129 million tons of equivalent CO_2, and the consumption of this fuel has shown an upward trend in recent years, while the potential for replacing it with biodiesel remains limited, due to production scale restrictions. In this context, natural gas has emerged as a viable alternative for decarbonization in the short term.

Figure 10: Transport sector emissions by modal and fuel, 2023



Source: Own elaboration with SEEG/Observatório do Clima data (2024)[2].

GNV and GNL are alternatives that can significantly reduce emissions. GNV is already used in light vehicles and cabs in several Brazilian cities. It is cheaper than gasoline and ethanol and emits fewer pollutants. As GNL is stored in liquid form, it has a higher energy density and can be used in heavy fleets, maritime and rail transportation. The adoption of these solutions in logistics corridors and regions with high freight traffic represents a concrete opportunity, with immediate positive impacts on reducing operating costs and decarbonizing the sector.

In short, an analysis of the electricity generation, industry, and transport sectors shows that natural gas occupies a unique position in Brazil's energy transition. Its versatility and lower carbon intensity make it a practical solution with immediate impact for emissions-intensive sectors.

Natural gas infrastructure: strategic basis for transition

One of the main advantages of natural gas in Brazil's energy transition is its existing infrastructure. The national natural gas infrastructure includes production, flow and processing units, regasification terminals, and pipeline networks that connect the production centers to the consumption areas. This integrated chain allows natural gas to be available in a safe, continuous, and economically viable way in various regions of the country, making it feasible to use it as a large-scale transition fuel.

At the heart of this infrastructure is the network of transport pipelines, which plays an essential role in the security and efficiency of supply. In Brazil, this network is technically robust and strategically positioned, being integrated nationally from Rio Grande do Sul to Ceará, as well as connecting producing regions - such as the Santos Basin and the pre-salt - to consumer centers in different states. In Rio de Janeiro, for example, the transport infrastructure is an important asset for supplying industries, thermoelectric plants and urban centers, as well as enabling integration with logistics modes and regional expansion projects.

In this context, the expansion of the natural gas transportation infrastructure is an essential condition for consolidating the role of natural gas as a fuel for Brazil's energy transition. Although the country already has a significant network, new gas pipeline projects are essential to expand access to natural gas in regions that are not yet served, replacing more polluting fuels, reducing regional asymmetries in access to energy and promoting local development, while at the same time increasing efficiency in the use of national energy resources and increasing security of supply.

Therefore, the expansion of the transport network must be understood as a structuring investment for Brazil's energy future, in order to ensure that natural gas fully fulfills its role as a vector for decarbonization. With a more extensive and interconnected network, the country not only improves logistics and security of supply, but also strengthens its capacity to decarbonize energy-intensive sectors, sustains industrial competitiveness and ensures the reliability of energy systems.

In addition, investments in transportation infrastructure allow for the generation of multiplier effects in local economies, enabling greater access and stimulating the production and sale of domestic gas, generating a virtuous cycle of income and employment in the country.

The gas pipeline infrastructure represents not only a consolidated asset for the present, but also a strategic platform for the future of the energy matrix. With a gas pipeline network already installed, technically mature and operating to high safety standards, the country has a base capable of accelerating the introduction of new low-carbon fuels. This ability to leverage is a relevant competitive advantage, especially in a transition context that demands scalable, economically viable and rapidly implemented solutions.

Biomethane is a concrete example of this synergy. Produced from the anaerobic digestion of organic waste, this renewable gas has physical and chemical characteristics compatible with natural gas and can be injected directly into the existing network. With this possibility, the current natural gas infrastructure becomes a bridge between the present and the future, connecting solutions that are already available with an emerging renewable source. Sectors with high waste generation now have the opportunity to convert environmental liabilities into energy assets, with a direct impact on sustainability and the diversification of the matrix.

Another promising vector is green hydrogen, produced through the electrolysis of water using renewable sources. Although still in the technological and economic development phase, studies already indicate the feasibility of its gradual insertion into the natural gas network through controlled mixtures. This approach allows testing and validating technical, regulatory, and commercial solutions, using the existing infrastructure as an initial platform for offering to the market. The possibility of adapting pipelines to different gas compositions reinforces the system's flexibility and increases its relevance in the energy transition.

Conclusion

The role of natural gas in Brazil's energy transition is clear and strategic. With its lower carbon intensity and wide applicability, natural gas presents itself as a mature solution with an immediate impact, capable of replacing more polluting fossil sources and promoting environmental, operational, and economic gains. Its flexibility and compatibility with different sectors make it essential for meeting the challenges of decarbonization, especially in segments that are difficult to replace technologically.

In addition, natural gas is supported by a robust and technically consolidated infrastructure, which guarantees efficiency and security of supply. This network not only enables the current use of natural gas, but is also a platform for the introduction of renewable fuels such as biomethane and hydrogen. The adaptability of the gas pipeline network increases the system's relevance, making it a strategic asset for accelerating the energy transition.

In a country with the dimensions and complexities of Brazil, natural gas is not just a one-off substitute—it is a structural solution that fills technological and logistical gaps, connecting the present with the opportunities of the future. Its contribution to decarbonization, industrial competitiveness and energy security is decisive if the country is to make coordinated, efficient and sustainable progress towards a cleaner, more resilient energy matrix in line with global climate commitments.

We can say that natural gas is strategic today and guarantees a fair energy transition for a sustainable future.

Reversible hydroelectric plants: a strategic pillar for the energy transition

Prepared by Light Energia

The hydraulic heritage of the Brazilian electricity sector

Given the high availability of water resources in our country, the SEB began its history by structuring the supply of electricity from UHEs, whose engineering design predominantly provided for the formation of regularization reservoirs that allowed for the management of water resources, with various benefits to the system. Looking back and following the evolution that the SEB has undergone over the years (and will continue to undergo), it is possible to say, contrary to common sense, that the decision of our predecessors to encourage the implementation of hydroelectric projects should be considered one of the country's most important assets, sustaining the challenges brought about by climate change and creating opportunities for the inclusion of other sources of electricity generation, with benefits for society, consumers, and the economy.

New challenges for the electricity system

The fact is that the original functions of UHEs are undergoing a transformation due to climate change, the multiple uses of reservoirs, the need for flexibility, resilience, and storage to manage large amounts of intermittent power generation. Allied to this, the SEB is facing a new paradigm with the end of the construction phase for large hydroelectric plants: how to move forward with projects to generate renewable energy from intermittent sources, while maintaining the balance of the electricity system, without relying on additional dispatchable energy, such as that supplied by UHEs.
This paradigm is mainly motivated by two factors:

- There has been an exponential increase in the share of non-dispatchable renewable sources in the Brazilian electricity matrix, especially wind and solar photovoltaic, due to the lower cost and construction time, as well as the lower complexity of environmental licensing.
- High difficulty in implementing new UHEs with regularization reservoirs (or even those operated on a run-of-river basis) due to environmental and political issues, since a large part of the remaining hydroelectric potential is located in the Amazon River basin or in areas considered environmentally sensitive.

The need for flexibility and storage

Given the ongoing transformations in the Electricity Sector, it is natural that UHEs will gradually cease to perform their original function and begin to play a role that goes beyond conventional energy generation. Increasingly, these plants are taking on a strategic role in providing services that guarantee a balance between supply and demand, acting as true green batteries.
With their high energy storage capacity and rapid response to power injection needs, UHEs are valuable resources for providing the operational flexibility required by the ONS, contributing to the stability and efficiency of the electricity grid in a scenario of increasing complexity.
However, the changing context of electricity generation requires adjustments. The entry of intermittent renewable sources requires the delivery of intensive services, especially in terms of system flexibility and reliability. The capacity to supply maximum generation immediately is becoming increasingly necessary, mainly due to the intermittency of these sources. The supply of power capacity, not just energy generation, is essential for operational flexibility and resilience. It should be noted that many of the services mentioned are linked to the operational flexibility already offered by hydroelectric plants, as well as environmental, social, and economic benefits that are not yet monetized for generators, but which generate additional operating costs not initially considered in their business models.
All this transformation of the electricity matrix requires a change in the logic of sector planning and operation so that the new challenges can be adequately addressed. The institutional and commercial model of the Brazilian electricity sector needs to be rethought, with a view to preparing the system for sustainable expansion and resolving issues that are already very evident. These include the need for hydroelectric plants to be adequately remunerated for the additional services they provide to the system.
The question now is to understand how sector planning and hydroelectric projects can contribute to the challenges of the energy transition we are experiencing.

Reversible hydroelectric plants (UHRs): concept and operation

In the midst of all this comes the well-known figure of the reversible hydroelectric plant (UHR), a technology widely used in other countries and still unexplored in Brazil, given our high water availability without the need to adopt storage systems to optimize the use of this natural resource. Worldwide, UHRs already reach almost 200 GW of installed capacity, providing more than 90% of all long-term energy storage, with more than 400 projects in operation, and are currently the largest form of renewable energy storage.

The UHR operate with two water reservoirs at different altitudes: one above and one below. During periods of high electrical demand, water can be released from the upper reservoir into the lower one, driving turbines and generating energy. At times of lower demand, the process is reversed, pumping the water back into the upper reservoir, consuming energy from the grid. This cycle of charging and discharging allows UHR to operate like large hydraulic batteries, storing energy in the form of gravitational potential.

Benefits of UHRs for the electricity system

The intermittent and seasonal nature of resources such as wind and solar irradiation brings uncertainties that affect the operation of the electricity system. Although storage in the form of BESS chemical batteries helps to circumvent these effects, what is being sought as an effective solution are LDES long-term electricity storage systems, with UHR being the most mature technology with the greatest capacity and scale, thus configuring it as the best alternative for balancing the system, maintaining low levels of GHG emissions and providing other benefits. They are very efficient, have a fast response time and a longer service life than other alternatives.

It can be said that UHRs are the only long-term storage technology widely available at network scale capable of offering high reliability, fast operational response and support for system stability. They also help to make more efficient use of intermittent renewable sources, such as solar and wind, by compensating for their variations and guaranteeing a continuous supply of energy.

These plants contribute directly to energy management by storing energy in periods of low demand and supplying it at times of higher consumption, taking advantage of variations in price and availability, known in the market as energy arbitrage.

In addition, by reducing the system's peak loads through the release of previously stored energy, they perform peak-shaving, relieving pressure on other generating sources and improving the grid's operational efficiency. UHRs also provide ancillary services essential to the stability of the electricity system, such as rapid response to demand, voltage control, frequency regulation, black-start, acting as a spinning reserve and supporting reactive control.

Regarding supply management, UHRs increase the quality of the energy delivered and strengthen the reliability of the system. These attributes make them strategic elements for security and real-time operation. The fundamental role of these plants in the integration of intermittent renewable sources is also highlighted by offering firm capacity and shifting generation to times more suited to demand (time shifting). These plants enable the safe and efficient insertion of non-dispatchable energy, promoting the transition to a cleaner and more resilient electricity matrix.

That said, it can be said that this technology is essential for the expansion of the system and is an important resource available to meet the growing demands of the SIN.

Challenges and barriers to implementation in Brazil

Despite its enormous potential, there is an urgent need to update regulations to address the mismatch between the speed at which rules are approved and innovation and solutions that can provide flexibility and make it possible to attract investment in more efficient networks. In addition, it is essential to implement mechanisms that enable adequate remuneration for all the systemic attributes offered.

The implementation of these solutions still faces barriers due to regulatory complexity and the need for efficient coordination between private and government institutions.

Light's role and future prospects

Aware of the transformations in the electricity sector and faithful to its history of leadership, Light has strategically dedicated itself to the development of Brazil's first Reversible Hydroelectric Power Plant in the 21st century.

With a vision of the future and a commitment to innovation, the company has been investing in technical studies, institutional mobilization and regulatory improvements to make this pioneering venture viable.

The UHRs represent a robust solution to the challenges of the energy transition, and Light's initiative reinforces its role as a driving force behind the modernization of the national electricity matrix.

The storage capacity, operational flexibility and ancillary services provided by these plants are fundamental to guaranteeing the security, efficiency and sustainability of the SIN.

Light's actions in this context signal concrete progress towards a more resilient sector that is prepared for the future.

Recent legal milestones and the ANP'S regulatory agenda for Brazil's energy transition

Prepared by Mattos Filho

In recent years, Brazil has made significant progress in creating a robust legal framework to drive the energy transition, consolidating itself as a benchmark in renewable energies and decarbonization. Between 2024 and 2025, the National Congress approved and the Executive Branch signed a series of strategic laws establishing new types of energy supply, fostering clean and innovative technologies.

The main recent legal milestones include:

- Law No. 14,902/2024 - Green Mobility and Innovation Program (Mover), which encourages the production and use of low-emission vehicles.
- Law No. 14,948/2024 - Legal Milestone for Low-Carbon Hydrogen, which establishes the National Low-Carbon Hydrogen Policy.
- Law No. 14,993/2024 - Future Fuel Law, which creates a regulatory milestone for advanced biofuels, synthetic fuels, carbon capture and storage ("CCS"), and increases the share of ethanol and biodiesel in the transportation matrix.
- Law No. 15,042/2024 - Regulated Carbon Market, which structures the national emissions trading system.
- Law No. 15,097/2025 - Legal Milestone for Offshore Energy, which regulates the assignment of maritime areas for offshore wind power generation.
- Law No. 15,103/2025 - Energy Transition Acceleration Program (PATEN), which creates financing mechanisms and guarantees for low-carbon projects, with emphasis on the Green Fund, which aims to mobilize up to BRL 600 billion in investments.

These laws represent an improvement in national energy policy, bringing Brazil into line with international best practices and the goals of the Paris Agreement. However, the effectiveness of these laws depends on detailed regulation, to be carried out through executive decrees and normative acts by regulatory agencies, especially the ANP, with regard to hydrogen, CCS and low-carbon fuels.

The Executive Branch has been working on issuing the respective regulatory decrees, which include the regulation of the Biomethane Origin Guarantee Certificate (CGOB), the subject of Decree No. 12,614/2025, and the regulation of the Hydrogen Legal Milestone. In the same vein, the ANP has been working on relevant new regulations, such as the recent issuance of ANP Resolution no. 987/2025, which replaces ANP Resolution no. 734/2018 and establishes new requirements for the authorization of biofuel production activities. The new resolution, which was already valid for authorizing biomethane, ethanol, and biodiesel production plants, seeks to bring more flexibility to the granting process, as well as including new products such as green diesel and alternative aviation kerosene from biomass in its scope.

There are also other relevant initiatives in the ANP's Regulatory Agenda for the 2025-2026 biennium, which consolidates 56 initiatives - 28 inherited from the 2022-2024 agenda and 28 new ones - with a strong impact on the energy transition ("ANP Agenda"). Although the document was designed to cover all the segments under the ANP's competence, with regard to the energy transition, it focuses on natural gas, as a transition fuel, and biofuels. In the natural gas segment, most of the actions seek to operationalize the New Gas Law, prioritizing the migration from the concession regime to authorization in transport gas pipelines, the promotion of non-discriminatory access to essential infrastructures and the definition of more transparent tariff methodologies.. This predominantly pro-market approach reinforces the view of natural gas as an input for systemic competitiveness, leaving its role as a bridge fuel for decarbonization in the background. The only explicitly climate action is the forthcoming resolution on reducing methane emissions in exploration and production activities, which could change the carbon footprint of the upstream.

In the biofuels sector, the ANP Agenda presents nine new initiatives, highlighting efforts to regulate the Future Fuel Law and improve the National Biofuels Policy (RenovaBio). Noteworthy are the proposals on the certification of SAF routes, the creation of the CGOB, the review of RenovaBio's individual targets and sanctions, the regulation of sugarcane producers' participation in CBIO revenue and the updating of marine fuel specifications to allow the addition of biodiesel and other renewables. These measures combine technical regulation (quality, traceability, life cycle certification) and economic instruments (carbon credits, compulsory targets), signaling convergence between energy policy and climate policy.

Emerging technologies such as low-emission hydrogen and CCUS do not yet have a pre-defined regulatory timetable in the ANP Agenda, despite recent legal frameworks giving the ANP the power to regulate issues such as licensing and its criteria, certification, traceability, and classification by carbon intensity. The reason for not introducing these topics is based on different grounds, according to the ANP's position.

For CCUS, the lack of specific action in the Agenda is because the ANP has already taken a position on how it will act on this industry in the coming years in the "Report on the implementation of the CCUS regulatory milestone in the country", prepared by the Technology and Environment Superintendence (STM). In this report, the ANP carries out an analysis of the CCUS chain and concludes that, given the still incipient stage of these activities in Brazil, the most appropriate regulatory approach would be through experimental regulation, especially via pilot projects.

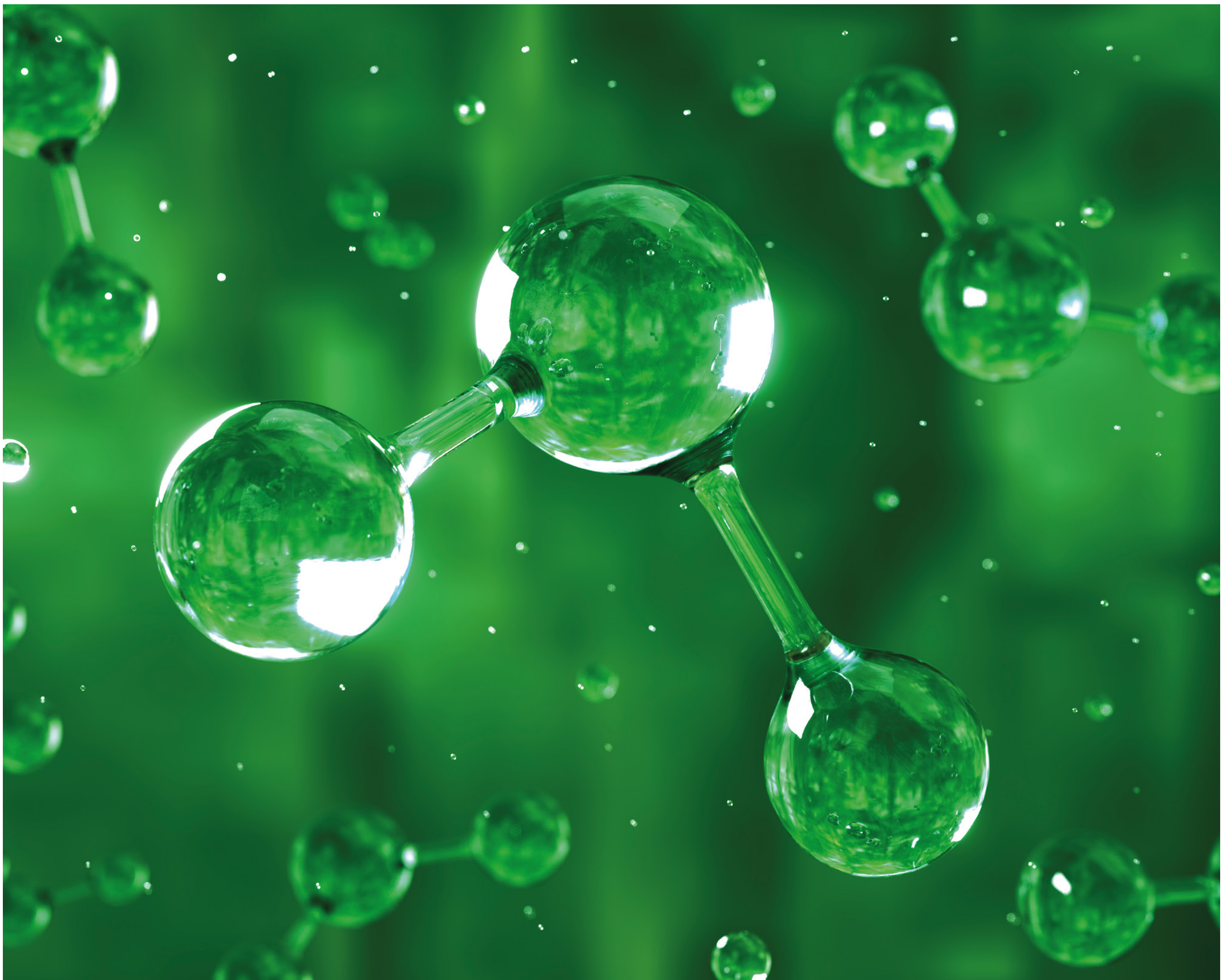
This technical guideline was the basis for Board Resolutions No. 256 and No. 859, both of 2024, which established that projects related to the CCS activity, in progress or in the implementation phase, will be authorized through experimental regulation via pilot projects, until the specific regulation process is completed.

In the case of low-carbon hydrogen, the lack of specific action in the Agenda is justified by the ANP's previous position, consolidated in the report "Implementation of the Regulatory Milestone for Low-Carbon Hydrogen in Brazil", prepared by the Hydrogen Working Group set up by Ordinance no. 148/2022. In this document, the Agency recognizes that, given the recent sanction of Law no. 14,948/2024, it is still necessary to wait for the Federal Executive Branch to issue the regulatory decree, which will define essential aspects for the ANP's regulatory action, such as the boundaries of competence between agencies and the criteria for authorizing the activities provided for. With a view to not delaying the implementation of projects and providing comfort to the market, the ANP has already indicated its intention to prepare a booklet of good practices to guide economic agents and foster the safe and efficient development of the low-carbon hydrogen industry, while infralegal regulations are discussed.

The ANP Agenda also reveals the ANP's favorable stance towards regulatory innovation in a broader sense, as evidenced by the proposal for a new action entitled "Innovative regulatory experiences: Standardize the concept of a regulatory sandbox and distinguish it from other types of exceptional authorization". This initiative is in line with the guideline of supporting innovative energy solutions not yet covered by current standards, through experimental regulatory instruments. This approach not only enables the development of new technologies, but also promotes legal certainty and regulatory flexibility, which are essential for the consolidation of disruptive energy solutions such as low-emission hydrogen and CCUS.

In short, between 2024 and 2025, Brazil built a solid and comprehensive legal basis to lead the energy transition. The Executive Branch and the ANP make progress in regulating biofuels and consolidate pro-market reforms in natural gas.

It is clear that the establishment of a robust legal framework is not the only barrier to the development of new technologies and projects for the energy transition. Other relevant issues need to be resolved, such as bottlenecks in the energy transmission network, restrictions on SIN connection requests and the expansion of gas transportation networks. However, we see Brazil in a strategic position to position itself as a relevant player in the transition and an effort by agents to create a secure regulatory environment.



Petrobras driving the energy transition: Offshore innovation and the transformative potential of the Cabiúnas-São Tomé CCS pilot project

Prepared by Petrobras

CCUS as a pillar of the energy transition

CCUS technology has established itself as one of the main tools for enabling deep decarbonization in emissions-intensive industrial sectors such as oil and gas, steel, cement and petrochemicals. In a global context marked by increasingly ambitious climate targets and growing regulatory pressure, CCUS offers a viable alternative to mitigate CO_2 emissions without compromising the operational continuity of strategic assets. By enabling the safe and permanent capture and storage of CO_2, CCUS preserves existing investments, enhances technical skills and extends the useful life of critical infrastructures. This is an essential technology for ensuring a safe, efficient and inclusive energy transition, especially in countries with a complex energy matrix and a strong presence of basic industries.

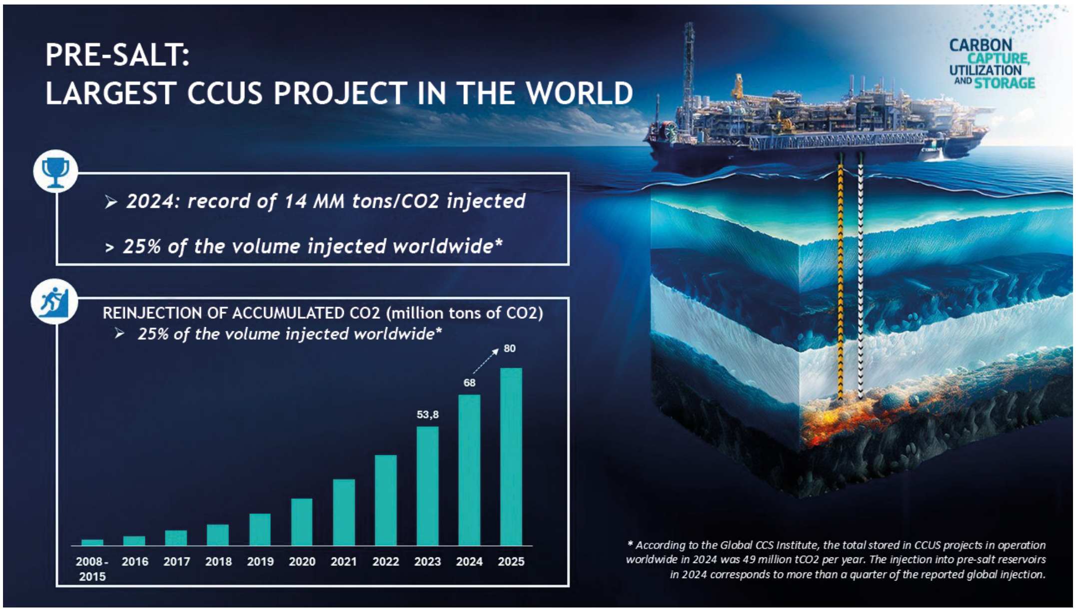
In Brazil, CCUS is also showing promise in segments such as bioenergy, especially sugarcane ethanol. The possibility of capturing biogenic CO_2 and storing it geologically increases the positive impact of the technology, positioning the country as a protagonist in building a low-carbon economy.

In this scenario, Petrobras plays a strategic role by aligning its decarbonization actions with the commitments defined in its Strategic Plan. The company seeks to lead the just energy transition, reconciling responsible oil and gas exploration with diversification into low-carbon businesses such as biofuels, sustainable petrochemicals and renewable energies.

Petrobras: pioneering and scaling up the capture, use, and storage of CO_2 in ultra-deep waters

Petrobras has played a central role in implementing CCUS solutions in offshore environments, establishing itself as a global benchmark in the application of the technology in ultra-deep waters.
The company currently operates the largest offshore CCUS cluster in the world, with CO_2 reinjection systems in 23 floating production, storage, and offloading units (FPSOs) located in the Brazilian pre-salt province, accounting for around 25% of all captured and reinjected CO2 in the world.

Figure 11: Information on the Pre-salt CCUS cluster



Source: Petrobras

By the end of 2024, Petrobras had reinjected more than 68 million tons of CO_2 into the pre-salt reservoirs, 14 million of which in the last year alone. The goal is to reach 80 million tons by 2025, which represents a significant milestone on the oil and gas industry's decarbonization path.

This infrastructure enables production in reservoirs located more than 2,000 meters deep and up to 300 km from the coast, in extremely challenging geological and operational conditions. Petrobras' success on this path is directly linked to its **capacity for technological innovation** and operational excellence, even in challenging scenarios such as the Santos Basin Pre-Salt Hub.

Technological innovations: unprecedented advances in CCUS in the offshore scenario

Petrobras' leadership in ultra-deepwater CCUS projects is the result of a series of pioneering innovations, including:

- **CO_2 capture by polymeric membranes:** The company was the first to apply this technology in offshore environments, enabling the efficient separation of CO_2 from natural gas produced in pre-salt reservoirs.
- **Application of the Water Alternating Gas (WAG-CO_2) technique:** Petrobras pioneered the use of this technique in deepwater offshore operations, promoting advanced oil recovery and the simultaneous reinjection of CO_2.
- **Drilling the world's deepest CO_2 injection well:** The company has drilled wells at depths of over 7,000 meters, demonstrating unique technical capacity in extreme environments.

These advances not only consolidate Petrobras' position as a global leader in CCUS in the offshore scenario, but also pave the way for new technological frontiers and business opportunities, including the formation of decarbonization hubs and the development of new business models in the country, such as CO_2 transport and geological storage services for other industries.

Cabiúnas-São Tomé CCS pilot project: a strategic milestone for Brazil

In this context, the Cabiúnas-São Tomé CCS pilot project represents a strategic and pioneering step in Latin America. This is a large-scale PD&I initiative, aimed at validating CCS technologies in deep saline reservoirs.
The transformative role of the Cabiúnas-São Tomé CCS project goes beyond technological and operational validation, with the potential to lay the foundations for the development of a CCS value chain in Brazil, creating concrete opportunities for both the generation of technological and scientific knowledge and the formation of new business models. By integrating the capture, transport and geological storage of CO_2 on a pilot scale, the project provides technical and regulatory support for the creation of industrial decarbonization hubs, enabling the provision of CO2 geological storage services and fostering new markets for decarbonized products and services.
In line with Petrobras' Strategic Plan, which foresees the expansion of investments in PD&I aimed at the energy transition and decarbonization, the project directly contributes to Brazil's positioning as a regional reference in climate solutions based on infrastructure and innovation. It also strengthens the country's capacity to develop proprietary technologies, train specialists and attract investment in low-carbon projects, consolidating Petrobras' role as an agent for inducing the country's energy transformation and competitiveness, in a context of pursuit of decarbonization.
The project is expected to capture approximately **100,000 tons of CO_2 per year** from UTGCAB, located in Macaé (RJ). The unit already has a capture system based on amine absorption, capable of generating a CO_2 stream with a purity of over 99%.
Before transportation, this stream will be dehydrated to ensure the integrity of the equipment and pipelines. The CO_2 will then be transported through the existing GASCAB II pipeline, which represents a strategic advantage for the project by reducing costs and speeding up the integrated demonstration of the CCS.

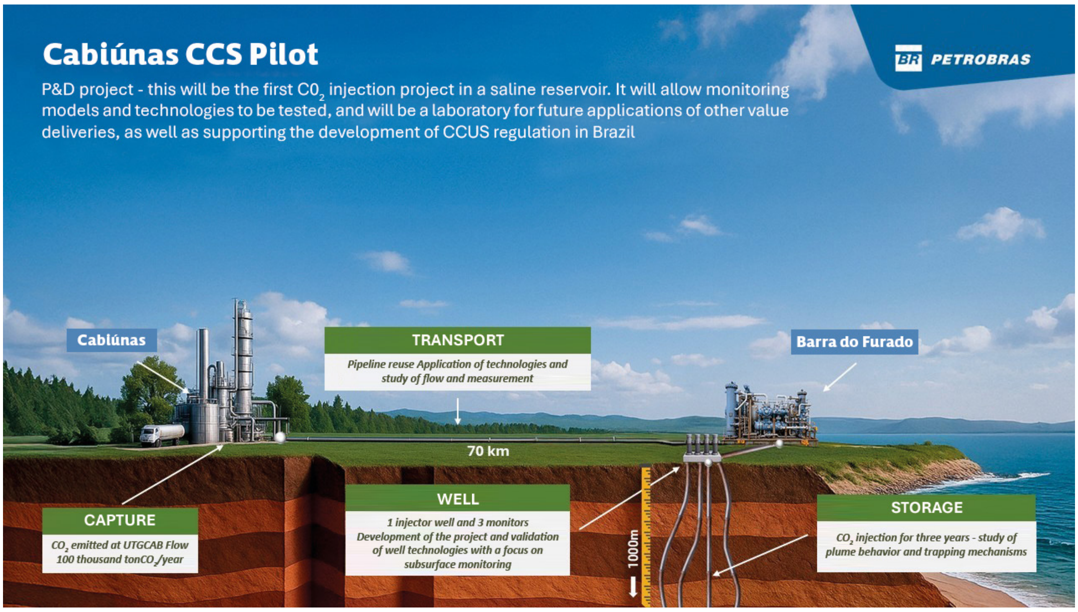
Geological storage: security, monitoring and innovation

At the Barra do Furado station, the CO_2 will be compressed and injected into a deep saline reservoir, located approximately 1,300 meters below the surface. This project has a carefully planned structure comprising:

- **One vertical injection well and three deviated wells for monitoring:** This configuration allows continuous monitoring of the integrity of the reservoir, the behavior of CO_2 within the reservoir and the area it will occupy throughout the operating period, with a further 3 years of CO_2 plume monitoring.
- **Robust monitoring plan:** It uses modern technologies, such as 4D seismic, to model the movement of CO_2, study the geological retention mechanisms and carry out numerical simulations to predict storage performance over the years.
- **Sensors distributed by optical fiber:** Installed in the injection and monitoring wells, this equipment, together with pressure and temperature sensors and fluid samplers at different depths, guarantees detailed monitoring of the reservoir's conditions.
- **Automated flow measurement system:** It provides precision and traceability of the volumes of CO2 injected, increasing the safety and reliability of operations.
- **Operational security systems:** They include pressure relief mechanisms, corrosion protection and continuous monitoring of the integrity of pipelines and wells, ensuring the stability and control of the entire system.

In addition, the project will be an important test site for emerging CCS technologies.

Figure 12: Schematic representation of the Cabiúnas - São Tomé CCS Pilot Plant



Source: Petrobras

Investment, partnerships, and scientific development

The Cabiúnas-São Tomé CCS pilot project is part of Petrobras' innovation strategy, which recognizes the central role of PD&I in enabling the energy transition. According to the company's Strategic Plan, by 2029 around 30% of the PD&I portfolio will be directed towards low-carbon initiatives, with an emphasis on CO_2 capture and storage technologies, renewable energies, and sustainable fuels.

Scheduled to operate between 2028 and 2031, the Cabiúnas-São Tomé CCS pilot project will be a catalyst for advancing the technological maturity and technical feasibility of CCS solutions in Brazil.

The project is being developed by Cenpes, in partnership with a network of national universities and research institutes, including: UENF, UFF, UFRJ, USP, and the National Observatory.

These institutions will be responsible for developing and applying methodologies for monitoring, characterizing the reservoir and validating technologies under real operating conditions, while also promoting the training of specialized human capital and the integration of academia and industry.

Regulatory impact and scalability

In addition to its technical and environmental relevance, the project will have a direct impact on the regulatory framework for CCS in Brazil. In partnership with the ANP and INEA, the project will provide concrete input for improving the rules and guidelines governing the implementation and operation of CO_2 capture and geological storage projects in the country.

Operating under real and controlled conditions will allow the validation of safety, monitoring and verification protocols, contributing to the construction of a robust regulatory environment, with legal certainty, attractiveness for investors and scalability for future initiatives.

Conclusion: a milestone for Brazil and the future of energy

The Cabiúnas-São Tomé CCS pilot project represents more than technological validation - it is a milestone for the country's industrial decarbonization based on innovation, scale, and responsibility. By investing in CCS technologies, Petrobras is reaffirming its role as a transforming agent in the just energy transition, promoting solutions that combine technical excellence, positive environmental impact and the generation of value for society.

Based on its experience in the pre-salt, its capacity for innovation and its links with academia, the regulatory sector and industry, Petrobras is positioned to drive decarbonization in Brazil - and the Cabiúnas-São Tomé CCS pilot project is a fundamental step in this direction.

Technological perspectives for decarbonizing maritime transport

Prepared by Transpetro

Summary

Decarbonization and a fair energy transition are linked. Transpetro has been committed to contributing to these processes, which have proved to be a complex challenge, seeking to balance logistics and oil transportation with emissions reduction, social development and environmental sustainability. Maritime transport is responsible for more than 80% of international trade by volume and has the lowest GHG emissions intensity per tonne-kilometer among long-distance modes. However, it is facing increasing regulatory pressure to decarbonize, led by IMO initiatives and regional regulations such as Fit for 55, EU ETS and FuelEU Maritime in the European Union. The revised IMO strategy establishes carbon neutrality by 2050.

The transition to low-carbon alternative fuels, such as biofuels, hydrogen and synthetic fuels, requires investments in port infrastructure, logistics, adaptation of engines and systems, as well as carbon capture and storage solutions. Energy efficiency measures and digitalization are emerging as essential strategies to mitigate costs and optimize operations during the transition. In Brazil, Transpetro is positioning itself strategically, integrating logistics assets and investing in fleet renewal with energy efficiency technologies, dual fuel ready and shore power, as well as testing drop-in fuels. These advances reinforce its potential to act as a low-carbon supply logistics hub. The next decade will be crucial for companies to combine innovation, infrastructure, and strategic partnerships in order to meet environmental targets and remain competitive in the global market.

Introduction

First of all, it's important to note that at Transpetro and throughout the Petrobras System, the just energy transition is a central theme. It's not just about switching to cleaner, renewable energy sources, but doing so in a way that ensures that aspects of energy security and social inclusion are also balanced. Our decarbonization processes are aligned with this balance in all of the above aspects.

To put this into context, it is important to note that maritime transport plays a central role in the global economy, accounting for more than 80% of international trade (UNCTAD, 2025). Despite having the lowest intensity of GHG emissions per tonne-kilometer among long-distance transport modes (Bilgili, 2023), the sector is facing increasing regulatory, social, and economic pressure to reduce its carbon footprint.

In 2018, the IMO adopted an initial strategy for the decarbonization of the maritime sector, with a target of reducing carbon intensity by 40% by 2030 and 70% by 2050. More recently, at meetings of the IMO's Marine Environment Protection Technical Committee (MEPC), the first revision of its GHG reduction strategy was completed. The ambitions for international maritime transport have increased significantly, with emissions neutrality expected by 2050.

The IMO's GHG reduction strategy now also addresses GHG emissions from the entire life cycle of maritime transport, with the aim of reducing them within the limits of the international maritime transport energy system and avoiding a transfer of emissions to other sectors.

At its last meeting of the Environment Protection Committee (MEPC 83), the IMO approved the GHG Fuel

intensity regulation, which sets emission intensity limits for the fuel used by vessels, penalizing shipowners who exceed these limits financially.
In the EU, the European Parliament launched the European Green Deal, which is a package of strategic initiatives aimed at putting the EU on the path towards an energy transition, with the ultimate goal of achieving climate neutrality by 2050.
Among the legislative acts of this strategic initiative, the EU ETS and FuelEU Maritime are the ones that establish rules for ships. The EU ETS is a cap-and-trade system in which a limited quantity of emission allowances is placed on the market and can be traded.
The FuelEU Maritime regulation aims to increase the share of low-carbon renewable fuels in international maritime transport. The regulation establishes requirements for average annual GHG emissions per unit of energy used by the ship.

Decarbonization in maritime transport

In order to achieve such an ambitious goal, it is essential that there is a real and possible transition to low-carbon alternative fuels in the use of the main on-board consumer equipment. The supply of these fuels will require large-scale production, with the industry adopting a variety of options. The production of these fuels is evolving, but large-scale supply is far from meeting total demand. Currently 93% of the world's fleet operates using only conventional fossil fuels (DNV, 2024).
International maritime transport requires bunkering infrastructure and fuels that are globally available and have good energy density, in order to maximize the space available for cargo on ships. Therefore, the choice of fuel for the sector requires careful analysis, given the impacts that can be generated in international trade.
From a purely technological point of view, there are several potentially carbon-neutral fuels of renewable origin that could be an alternative to the oil derivatives currently used (Carvalho, 2021). The possibilities range from the direct use of vegetable oils to the production of synthetic fuels from H2 and recycled CO2. It is worth noting that Brazil has potential advantages for the production of marine biofuels due to the availability of biomass resources and the country's existing experience in the production of liquid biofuels in a relevant manner, since the 1970s (Lima, 2013).
In addition, the presence of renewable resources and the low emission factors of the Brazilian electricity grid are a point in favor of the production of fuels involving hydrogen produced from electrolysis with renewable electricity.
Despite the technological differences, all these solutions present common challenges: adapting engines, combustion systems and on-board storage, investing in storage and supply infrastructure, guaranteeing supply at scale and cost competitiveness.
Carbon capture and storage (CCS) from the use of fossil fuels can also contribute significantly to the decarbonization of maritime transport. However, infrastructure for handling and storing CO2 needs to be developed.
Emissions can also be reduced by using electricity on land, connected to the ship. According to studies by the European Parliament, up to 7% of the total energy consumption of ships could be supplied by this type of electrical source, while docked in ports, if the electrical energy capacity on land was sufficient and all ships had the capacity to use it. Total electrification requires an increase in the supply of electricity in ports and, above all, technological advances in the production of more efficient batteries, given the low capacity for energy storage in the face of the demand to move large vessels over long distances.

Energy efficiency and digitalization

International regulations impose progressive decarbonization targets on the maritime sector, with a final horizon of 2050. However, the energy transition will have to take place gradually, probably at a slower pace than the regulatory requirements establish.

During this period of adaptation, it is expected that fuels - especially low-carbon fuels - will have higher costs, directly impacting companies' competitiveness and operations. In this context, the adoption of energy efficiency measures is essential not only to achieve the short-term targets set by the regulations, but also to mitigate the financial impacts of using more expensive alternative fuels.

Factors such as the operating condition of equipment, fouling on the hull and propeller, affect a ship's fuel consumption and, consequently, its GHG emissions.

Fuel consumption during a journey is also influenced by dynamic factors such as weather conditions, speed, route, and currents. The use of data from the ship and its systems, combined with sophisticated meteorological data and a greater capacity to process large data sets, can be used to enhance the voyage.

In addition to enabling route optimization, using the optimum propulsion power in different environmental conditions can reduce fuel consumption. In this case, the collection and processing of environmental and engine power data can predict and control the optimum propulsion power in real time, taking into account the environmental conditions ahead. It is also possible to diagnose inefficiencies caused by fouling on the hull and propeller in advance, resulting in corrective action to restore the ideal condition.

Transpetro in the context of the energy transition

Transpetro is the largest oil, gas, and biofuels logistics company in Latin America. It operates in fuel logistics in Brazil and in the import and export of oil and oil products, gas and biofuels, operating oil and gas pipelines, terminals, and ships. Its strategic objective is to expand its market share and, to this end, it launched the Petrobras System Fleet Renewal and Expansion Program (TP 25), which provides for the acquisition of 25 new vessels to expand Transpetro's logistical capacity in the oil and oil products cabotage activity.

For Transpetro, the energy transition is a strategic opportunity to expand its operations. The presence of terminals, pipelines, and tanks already integrated into the operation can be used to distribute different fuels, not only to serve the company's own fleet, but also to supply third-party vessels. In this way, the company can become a low-carbon supply logistics hub, strengthening its role in the domestic market and in global maritime trade, transporting fuels by ship.

Decarbonizing your operations

Transpetro has a vessel energy efficiency program. Since its inception, it has already invested BRL 35 million in energy efficiency projects and an additional investment of BRL 48 million is planned over the next few years. More than 100 energy efficiency devices have already been implemented on its 26 vessels in its own fleet, including energy saving devices, anti-fouling paint, trim optimization systems, and combustion optimization systems for main combustion engines.

Energy Saving Devices are devices/adjustments installed in the submerged part of hulls with the aim of improving flow, especially in the stern area, and increasing the efficiency of the propulsion system. These devices can be installed on the hull, the propeller, or the rudder and can produce a uniform flow to the propeller (increased efficiency) or reduce some of the resistance to the ship's progress.

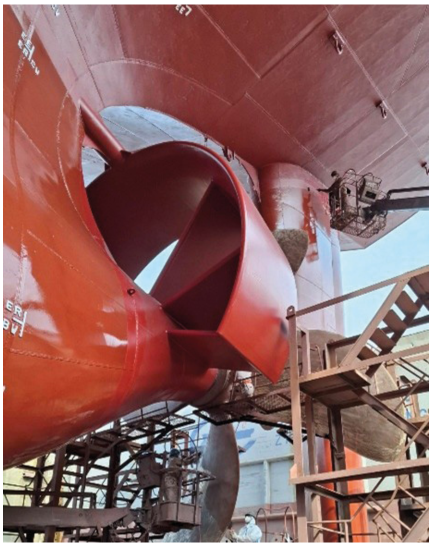
One of the main causes of the loss of energy efficiency in ships is the increased resistance to advancement caused by fouling. The main objective of anti-fouling paints is to effectively minimize the growth of biological fouling during the service interval between dockings. Depending on the type of high-performance coating, the surface preparation and the quality of the paint application, high-performance coatings can also improve a vessel's off-dock performance.

Trim optimization systems (inclination of the vessel to either end) are software capable of defining an optimum value, based on the conditions of the load plan, the vessel's draft (vertical distance between the water surface line and the lowest part of the vessel's hull) and the speed instructed by the charterer, which result in lower required power which, in turn, will result in lower fuel consumption, and thus lower GHG emissions.

Main combustion engines are the engines responsible for the ship's propulsion. Combustion optimization systems work to ensure optimum cylinder pressure by adjusting fuel injection timing and exhaust valve opening.

Figure 13: Propeller-type Energy Saving Device

Figure 14: Hull-type Energy Saving Device



Source: Transpetro

Through its energy efficiency department, Transpetro actively manages the efficiency of its vessels, instructing actions to correct deviations.
With the progress of the energy efficiency program, we will achieve 18,130 tons of CO_2 avoided in 2024, as opposed to 13,200 tons of CO_2 avoided in 2023, only taking into account the implementation of the technologies.
In the period between 2022 and 2024, absolute emissions in the fleet will fall by 8.4%.
For the ships in its current fleet renewal program, the construction specification relies on the best market practices in the implementation of energy efficiency technologies.
For the first class of own fleet ships to be built, as well as the new dynamic positioning ships that will be received, the project envisages main propulsion engines with Dual Fuel Ready Ethanol/Methanol class notation, which means that these ships will be prepared for conversion, making it possible to use these sustainable fuels.
The construction specification for the new fleet also includes a system for receiving electricity from land in the ports called Onshore Power Suply. This type of installation allows ships' generator sets to be switched off during operations, reducing emissions of polluting gases in port areas.
In addition, the specification includes the SMARTSHIP notation, focused on digital solutions designed to collect, store, process, analyze, and transmit ship data, promoting improved energy and maintenance management.
Additionally, in conjunction with other areas of the Petrobras System, Transpetro is betting on the use of drop-in fuel for its existing fleet. It recently used B24 fuel, a bunker with 24% Biodiesel, and is preparing to receive and use B30 in its next operation in Europe.

Conclusion

The fair energy transition and decarbonization have proven to be complex challenges. However, Transpetro, like the entire Petrobras System, is committed to leading this process, seeking to balance the oil business and transportation with emissions reduction, social development, energy security, and environmental sustainability.
The decarbonization of maritime transport is an important movement, driven by international regulations, market demands, and corporate commitments to sustainability. Achieving this goal will require an integrated approach combining low-carbon fuels, adapted infrastructure, energy efficiency technologies and digital solutions.
For Transpetro, this process is part of its business expansion strategy. The ability to integrate assets - pipelines, tanks, terminals and fleet - offers unique advantages for leading logistics and energy solutions in the new global scenario.
The next decade will be decisive. Organizations that invest now in technological innovation and strategic decisions will have a better chance of not only meeting environmental targets, but also consolidating their relevance and competitiveness in low-carbon maritime logistics.

Bibliographical Reference

ANP. Agenda Regulatória 2022–2024. Rio de Janeiro: ANP, 2022.

ANP. Agenda Regulatória 2025–2026. Rio de Janeiro: ANP, 2025.

ANP. Implementação do marco regulatório de hidrogênio de baixa emissão de carbono no Brasil. Rio de Janeiro: ANP, 2024.

ANP. Relatório sobre a implementação do marco regulatório de CCUS no país. Rio de Janeiro: ANP, 2024.

ANP. Resolução de Diretoria nº 256, de 25 de abril de 2024. Rio de Janeiro: ANP, 2024.

ANP. Resolução de Diretoria nº 859, de 19 de dezembro de 2024. Rio de Janeiro: ANP, 2024.

BRASIL. Lei nº 14.902, de 12 de junho de 2024. Institui o Programa Mobilidade Verde e Inovação (Mover). Diário Oficial da União: seção 1, Brasília, DF, 13 jun. 2024.

BRASIL. Lei nº 14.948, de 2 de agosto de 2024. Institui o marco legal do hidrogênio de baixa emissão de carbono e dá outras providências. Diário Oficial da União: seção 1, Brasília, DF, 5 ago. 2024.

BRASIL. Lei nº 14.993, de 28 de agosto de 2024. Institui o marco legal do Combustível do Futuro. Diário Oficial da União: seção 1, Brasília, DF, 29 ago. 2024.

BRASIL. Lei nº 15.042, de 18 de novembro de 2024. Institui o Sistema Brasileiro de Comércio de Emissões de Gases de Efeito Estufa. Diário Oficial da União: seção 1, Brasília, DF, 19 nov. 2024.

BRASIL. Lei nº 15.097, de 15 de março de 2025. Estabelece o marco legal da geração de energia elétrica offshore. Diário Oficial da União: seção 1, Brasília, DF, 17 mar. 2025.

BRASIL. Lei nº 15.103, de 5 de abril de 2025. Institui o Programa de Aceleração da Transição Energética (PATEN). Diário Oficial da União: seção 1, Brasília, DF, 7 abr. 2025.

CENERGIA. Prospects for carbon-neutral maritime fuels production in Brazil. Rio de Janeiro: UFRJ/Programa de Planejamento Energético, 2021.

CNEN. Relatórios institucionais sobre programas nucleares brasileiros. Brasília: CNEN, 2024.

CNPq; INCT. Reatores modulares e inovadores: projeto de pesquisa nacional. Brasília: CNPq/INCT, 2024.

CNPE. Resolução nº 5, de 26 de agosto de 2024. Brasília: CNPE, 2024.

DNV. Maritime forecast. Oslo: DNV, 2024.

ENEL; DELOITTE. Caminhos para a Transição Energética no Brasil. São Paulo: Enel/Deloitte, 2022.

ENEL. Relatório de Sustentabilidade 2024. São Paulo: Enel, 2024.

ENEL DISTRIBUIÇÃO RIO. Comunicados oficiais e plano de investimentos 2024/2025. Rio de Janeiro: Enel, 2025.

EPE. Balanço Energético Nacional 2015 (ano-base 2014). Rio de Janeiro: EPE, 2015.

EPE. Balanço Energético Nacional 2025 (ano-base 2024). Rio de Janeiro: EPE, 2025.

EPE. Balanço Energético Nacional (BEN): Relatório Síntese 2025 (ano-base 2024). Rio de Janeiro: EPE, 2025.

FIRJAN. Panorama de Investimentos 2025–2027. Rio de Janeiro: Firjan, 2025.

FIRJAN. PIB Rio de Janeiro 2024: Resultados e Perspectivas. Rio de Janeiro: Firjan, 2024.

IAEA. Energy, Electricity and Nuclear Power Estimates for the Period up to 2050 (RDS-1). Viena: IAEA, 2024.

IAEA. Human Resource Development for Small Modular Reactor Programmes. Buenos Aires: IAEA, 2025a.

IAEA. Global Status of Small Modular Reactor Development and Deployment. Viena: IAEA, 2025b.

IEA. Electricity 2025: Analysis and forecast to 2027. Paris: IEA, 2025.

IEA. Net Zero by 2050: A Roadmap for the Global Energy Sector. Paris: IEA, 2021.

IMO. International Shipping Facts. Londres: IMO, 2024. Disponível em: https://www.imo.org/en/About/Pages/Shipping-Facts.aspx. Acesso em: 15 ago. 2025.

IPT. Cidades Circulares. São Paulo: IPT, 2023.

MARINHA DO BRASIL. Programa Nuclear da Marinha – LABGENE e Submarino Nuclear Brasileiro. Brasília: Diretoria-Geral de Desenvolvimento Nuclear e Tecnológico da Marinha (DGDNTM), 2024.

OCDE. Shipping Emissions in Ports. Paris: International Transport Forum/OCDE, 2024.

ONU. Documentos oficiais das COP29 (Baku, 2024) e COP30 (Belém, 2025). Bonn: UNFCCC, 2024/2025.

ONU. Shipping data: UNCTAD releases new seaborne trade statistics. Genebra: UNCTAD, 2025. Disponível em: https://unctad.org/news/shipping-data-unctad-releases-new-seaborne-trade-statistics. Acesso em: 15 ago. 2025.

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