Energy Scenarios

Brazil's National Energy Plan 2055

TECHNICAL SHEET

(Positions on January 3, 2025)

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Rio de Janeiro, 2025

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INTRODUCTION

Brazil's Energy Research Office (EPE) main responsibilities include developing medium- and long-term plans for the national energy sector, such as the Ten-Year Energy Expansion Plan (PDE) and the National Energy Plan (PNE).

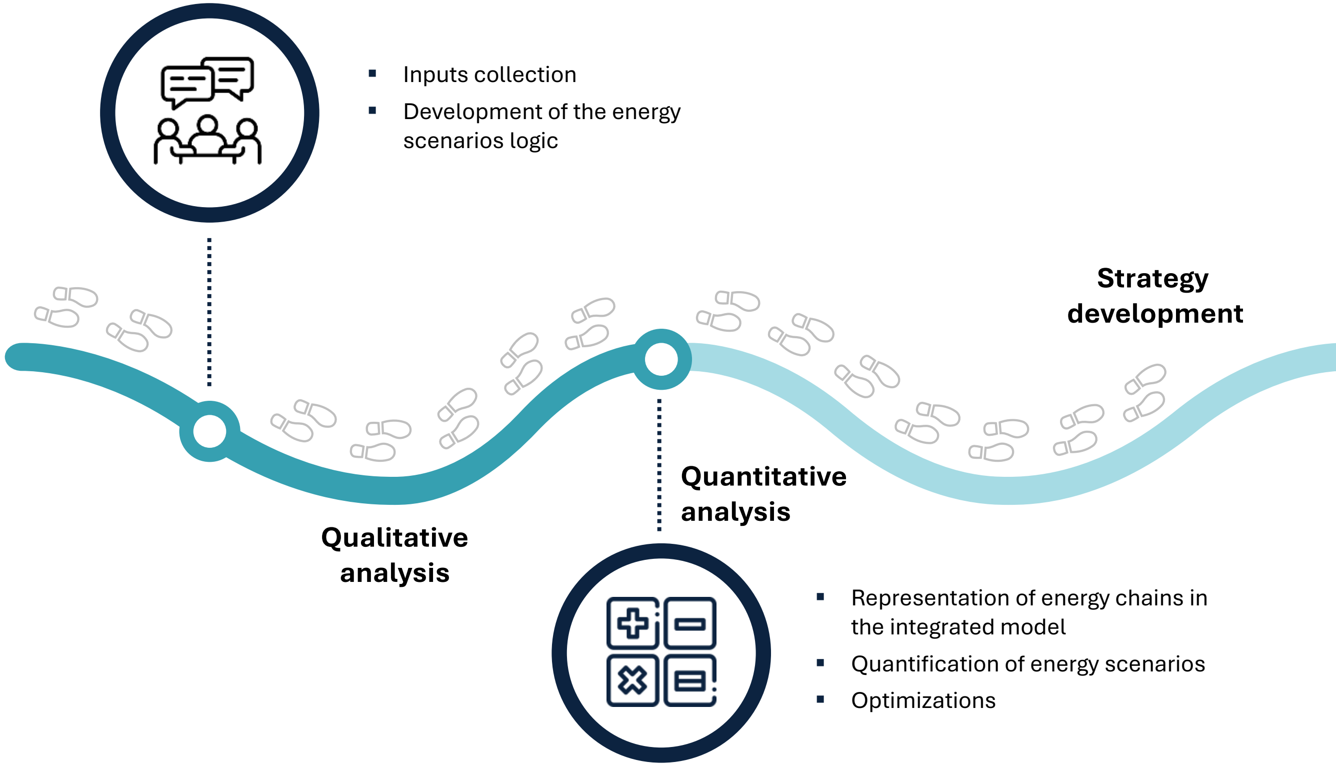
Through an innovative governance structure involving two working groups – one dedicated to the development of long-term energy scenarios (Scenarios Working Group) and another focused on coordinating the representation and optimization of energy chains in the integrated energy model (Models Working Group) – EPE has been leading the process of drafting the new National Energy Plan 2055 (PNE 2055). The PNE 2055 will be published in 2025, in compliance with the periodicity defined by Ordinance MME No. 6, dated January 7, 2020.

This document compiles the main inputs produced between March 2023 and June 2024 by the Scenarios Working Group, as part of the development of PNE 2055. The participatory process led by EPE, in collaboration with the Brazilian Ministry of Mines and Energy (MME), represents an innovative approach to the development of long-term scenario studies. The methodological quality and robustness of the results achieved during this process reflect not only the creation of a significant internal capacity but also the potential for contributing to other key ongoing initiatives, such as the National Energy Transition Plan (PLANTE), led by the MME, and the Brazil Strategy 2050, spearheaded by the Ministry of Planning and Budget (MPO).

It is worth highlighting that the qualitative and collaborative development of future scenarios serves as a fundamental starting point for PNE 2055. In the next steps, this will involve the quantification of these energy scenarios and the formulation of Brazil's energy strategy.

We wish you an enjoyable read!

PNE 2055 PROCESS



- Inputs collection
- Development of the energy scenarios logic

Qualitative analysis

Quantitative analysis

- Representation of energy chains in the integrated model
- Quantification of energy scenarios
- Optimizations

Strategy development

1

Scenario building for PNE 2055

Scenarios are not projections, but rather consistent stories about the future and practical tools to support decision-making under uncertainty

Energy systems, both at the global and national levels, are undergoing transformations that demand constant monitoring and a broadened long-term perspective. New themes are emerging, bringing with them a series of uncertainties – such as climate change, energy transition, evolution of technological innovations, and changes in consumption habits – further increasing the complexity of the external environment. This is the context in which the value of public policies, businesses, and organizations is defined or lost.

This environment, filled with uncertainties, makes strategy development and long-term planning particularly challenging, especially for those who believe the future can be predicted. The first step toward adopting a more effective approach is to understand that, by nature, **the future is multiple and uncertain**. As Taleb (2018) stated, 'Only the ordinary can be predicted, not the extraordinary.' This shift in mindset is essential for **embracing a prospective approach, which serves as a powerful tool for strategic positioning.**

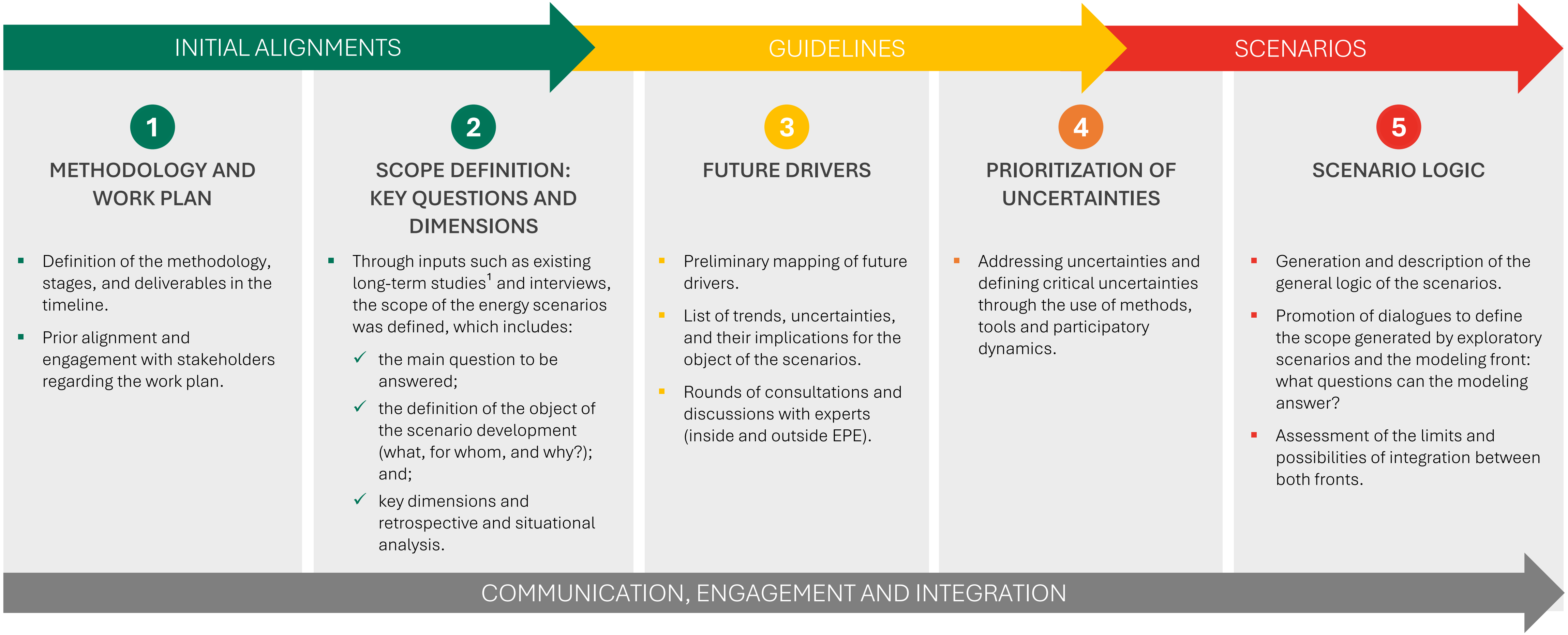
However, this change in mindset is not simple, as it ultimately implies a cultural shift in long-term analysis practices. While we cannot control the external environment or predict the future with precision, we can learn to deal with uncertainty by adopting a proactive stance and improving our ability to anticipate. This, in turn, supports the decision-making process.

For this to occur, beyond a change in mindset, it is necessary to adopt planning and management approaches that allow us to explore future possibilities and effectively deal with uncertainty. In this context, **foresight and scenario-building methods stand out as valuable tools, aiding in the understanding of this complex environment and facilitating long-term planning.** These methods not only help create a shared vision of the future among the various stakeholders involved but also contribute to achieving the desired future, adopting a systemic and non-linear approach.

Some of the questions that scenario-building helps us answer:

- What uncertainties are critical to the future (or to possible futures)?
- How feasible is a given objective?
- How flexible is our strategy?
- What are the potential regrets?

What were the steps taken in developing the scenarios for PNE 2055?



INITIAL ALIGNMENTS

GUIDELINES

SCENARIOS

1 METHODOLOGY AND WORK PLAN

- Definition of the methodology, stages, and deliverables in the timeline.
- Prior alignment and engagement with stakeholders regarding the work plan.

2 SCOPE DEFINITION: KEY QUESTIONS AND DIMENSIONS

- Through inputs such as existing long-term studies[1] and interviews, the scope of the energy scenarios was defined, which includes:
  - ✓ the main question to be answered;
  - ✓ the definition of the object of the scenario development (what, for whom, and why?); and;
  - ✓ key dimensions and retrospective and situational analysis.

3 FUTURE DRIVERS

- Preliminary mapping of future drivers.
- List of trends, uncertainties, and their implications for the object of the scenarios.
- Rounds of consultations and discussions with experts (inside and outside EPE).

4 PRIORITIZATION OF UNCERTAINTIES

- Addressing uncertainties and defining critical uncertainties through the use of methods, tools and participatory dynamics.

5 SCENARIO LOGIC

- Generation and description of the general logic of the scenarios.
- Promotion of dialogues to define the scope generated by exploratory scenarios and the modeling front: what questions can the modeling answer?
- Assessment of the limits and possibilities of integration between both fronts.

COMMUNICATION, ENGAGEMENT AND INTEGRATION

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[1] The long-term studies consulted were: BP (2023), CEBDS and PSR (2023), CEBRI, BID, EPE and CENERGIA (2023), DELOITTE (2020), EIA (2023), EPE (2007), EPE (2020), EPRI e GTI Energy (2023), IEA (2022), IRENA (2022), IRENA (2023a), IRENA (2023b), NREL (2022), Shell (2023) and Statkraft (2022).

… and the main differentiators of this process?

Participation of representatives from the MME and the three core departments of EPE

Participatory and dynamic meetings

Use of facilitation techniques such as Liberating Structures

Implementation of forms and interviews

Joint construction of the energy scenario logic

- **Institutional governance**, with the creation of a working group (Scenario Working Group) composed of members from EPE and MME, dedicated to the development of long-term energy scenarios.
- **Continuous process of communication, participation, and engagement** throughout all phases of scenario development: EPE Executive Board, MME, EPE Advisory Council (Concepe), PNE 2055 Executive Committee, and the PNE 2055 modeling working group (Models Working Group).
- Combination of **scenario-building methodologies**[2] **with the application of facilitation techniques, such as Liberating Structures**. This methodology helps foster greater participation, innovation, and effectiveness in meetings.
- Consultations with EPE and MME staff through **digital tools**, such as forms and interactive platforms, in addition to **interviews with EPE and MME leadership.**
- Decentralized planning and execution of **internal workshops focused on critical uncertainties in the energy sector**, along with discussions on relevant supply chains for the energy transition, engaging both internal and external experts.

[2] Since 2018, three training cycles on scenario-building methodologies have been implemented for EPE employees.

2

Scope definition and retrospective analysis

Initial alignments: general scope and key dimensions

SUMMARY FRAMEWORK OF SCENARIO ANALYSIS

Object and place
Energy system in Brazil

Time horizon
2055

Goal
Develop pathways for a decarbonized energy system as a driver of sustainable development

Key question
What are the challenges and opportunities in developing a decarbonized energy system that contributes to sustainable development?

Target audience
MME and society

KEY DIMENSIONS OF ENERGY SCENARIOS

- Energy Geopolitics
- Innovation
- Sustainable Development
- Energy Demand and the Role of the Consumer
- Resilience and Energy Security
- Public Policies, Governance, and Financing for the Energy Transition

Before thinking about the future, it is necessary to look at the past and the present and reflect on our main challenges ...

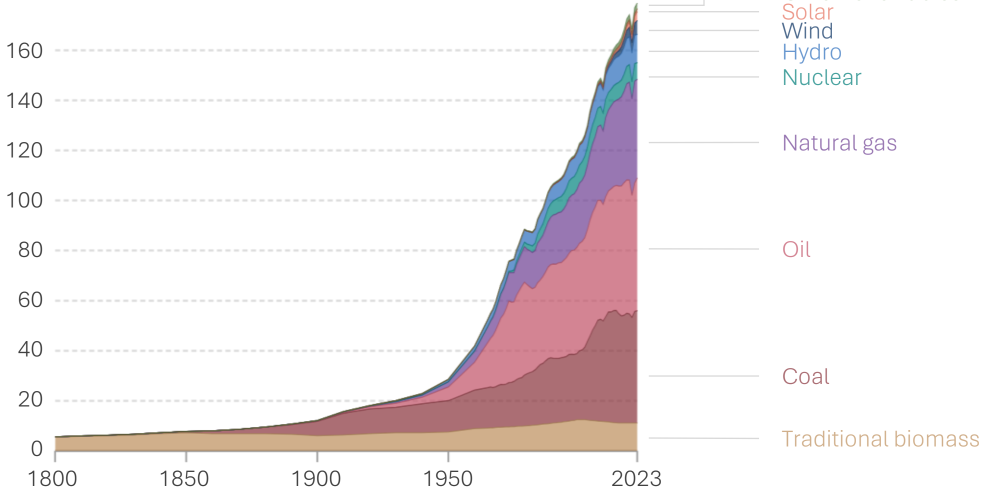
History shows that energy transitions are not a simple flip of a switch ...

Throughout history, **energy transitions have been gradual and complex processes rather than abrupt changes or 'flips of a switch'.**

The processes of replacing one dominant primary energy source with another have taken place over decades, reflecting not only the development of new technologies but also economic, social and political factors.

The transition from the predominant use of traditional biomass to coal in the 19th century, and later from coal to oil in the 20th century, did not necessarily result in an absolute reduction of the replaced energy sources.

Figure 1: Global Primary Energy Consumption by Source (thousand TWh)



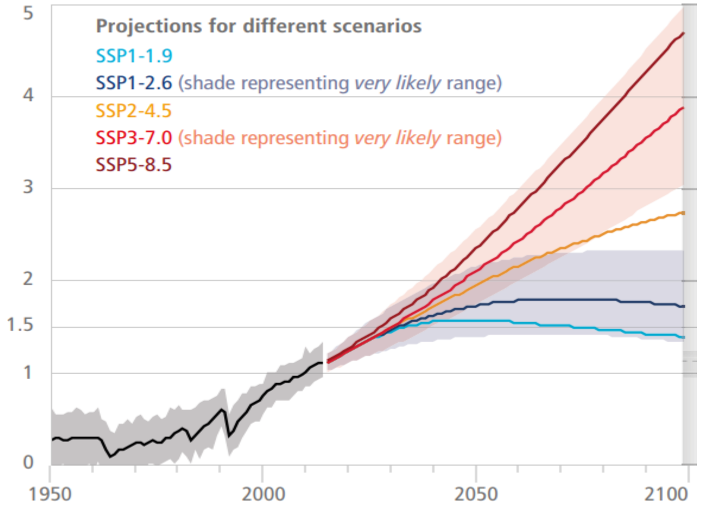
Source: Adapted from Energy Institute (2024) and Smil (2017).

... but the climate emergency and its impacts demand the acceleration of the current energy transition process

The climate emergency highlights the urgency of accelerating the current global transition process toward more sustainable, low-carbon energy sources.

The rise in average global temperatures, the intensification of extreme weather events and the pressure on ecosystems impose a new dynamic, reinforcing the need to rapidly reduce greenhouse gas emissions. This requires a coordinated effort from governments, businesses and civil society. **The challenge lies in balancing this urgent need with the economic and social realities of each region.**

Figure 2: Global surface temperature variation relative to 1850-1900 (ºC)



Source: Adapted from IPCC (2022).

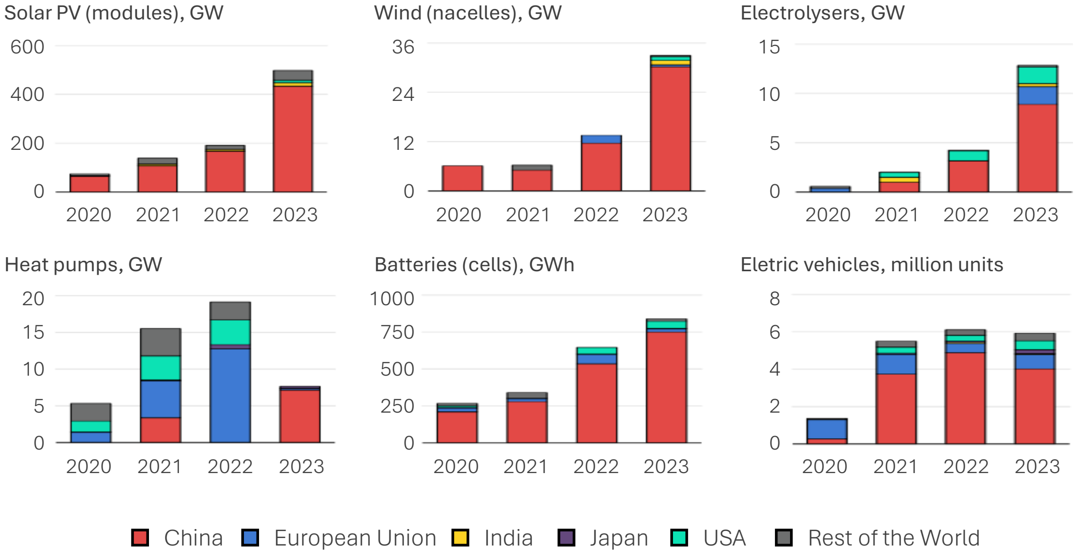
The social aspect of the energy transition in emerging countries is particularly challenging, given that millions of people still rely on traditional energy sources to meet their basic needs. This is because a significant portion of the global population does not have their basic needs met, reflecting a situation of energy poverty and strong unmet demand.

Therefore, **the global transition to low-carbon economies must consider social inclusion and the fight against energy poverty, ensuring access to more modern, sustainable and affordable energy sources.**

… bringing new contours to energy geopolitics

The acceleration of the energy transition is also reshaping energy geopolitics, shifting the axis of power from oil and natural gas-producing countries to new players that hold resource availability and technological dominance in low-carbon energy value chains. China, for example, plays a central role in this context, with its dominance in the supply chains of solar and wind energy, batteries and electrolysers, and strategic minerals.

Figure 3: Net manufacturing capacity additions for selected clean energy technologies by country/region (2020 – 2023)



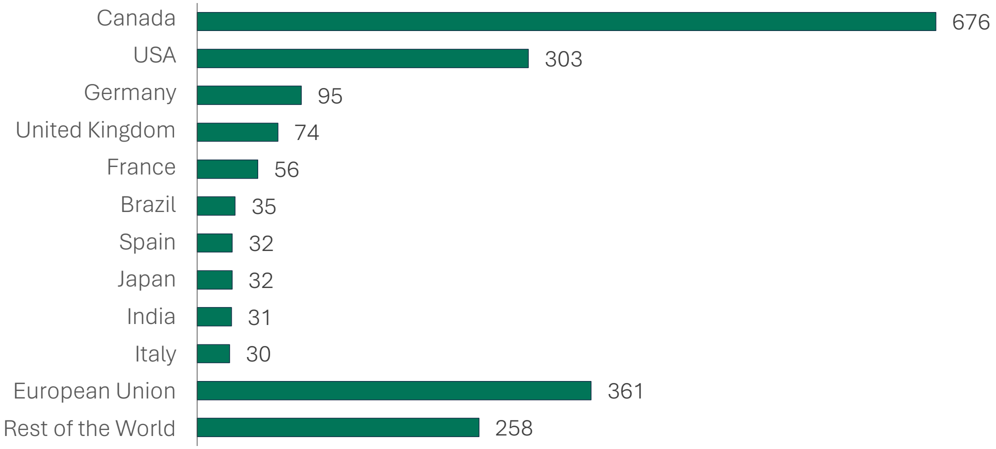
Source: Adapted from IEA (2024a).

... all of this within a context of changes in the global political and economic landscape

In this context, **major economies are adopting transformational policies to accelerate the energy transition process.** The United States launched the **Inflation Reduction Act (IRA)**, which encourages investments in clean technologies. In Europe, **RePowerEU** reinforces energy independence and the advancement of renewables, while China is driving its transition with ambitious decarbonization targets in its Five-Year Plans.

These efforts reflect the global competition for leadership in low-carbon technologies, while simultaneously addressing the challenges of economic and political transition in a context of a growing climate emergency.

Figure 4: Economies with the highest investments in energy transition in 2023 (US$ billion)



Source: Adapted from BloombergNEF (2024).

And how is Brazil positioned in this context?

We have numerous comparative advantages in terms of the availability of energy and mineral resources, as well as the profile of our energy mix ...

Brazil is widely recognized as one of the world's major energy powers, with abundant availability of energy and mineral resources. Additionally, the country has significant natural resources, including water resources, forests and the planet's greatest biodiversity.

The country holds **the largest water resources in the world** and is **the second-largest producer of hydroelectric power** (Energy Institute, 2024), with resources that support a predominantly renewable energy mix. Moreover, Brazil has the **seventh-largest installed wind energy capacity** (Energy Institute, 2024), with significant onshore and offshore potential that remains untapped and of high quality. Solar energy, the fastest-growing source in the country, is driven by excellent irradiation across its territory, offering high technical potential for photovoltaic generation.

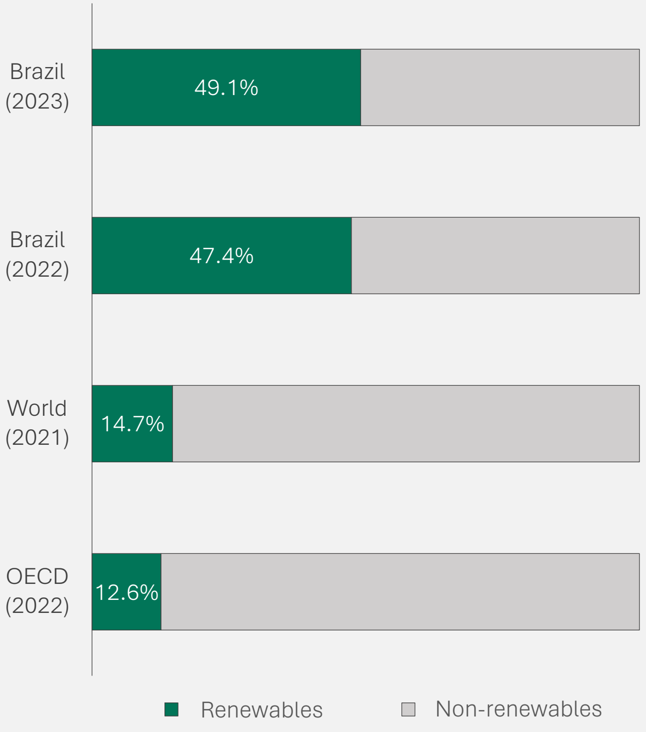
In the bioenergy sector, Brazil is the **second-largest global producer of liquid biofuels**, being the largest producer of sugarcane ethanol and the third-largest producer of biodiesel (Energy Institute, 2024). The country also has the potential to expand its production of biogas and biomethane, as well as advanced biofuels.

In the oil & gas sector, Brazil is currently ranked **eighth among the world's largest oil producers** (Energy Institute, 2024), with prospects of becoming one of the top five producers and exporters in the coming years (EPE, 2024b).The development of the pre-salt layer has been a key factor for this progress, solidifying the country as a major player in the global oil market.

Brazil is also recognized as a **leading producer and exporter in the global mineral commodities market**, especially in metallic minerals, thriving in the production of iron ore, copper, gold, aluminum, and niobium. Additionally, the country holds the eighth-largest uranium reserve (SGB, 2024), the second-largest reserve of rare earth elements, and the third-largest nickel reserve (USGS, 2024).

The country's significant renewable energy potential has ensured an energy mix with a high level of renewability, with approximately 50% of its energy derived from low-carbon sources, compared to a global average of around 15%, as shown in Figure 5. Among G20 countries, Brazil boasts the most renewable energy mix (IEA, 2024b), consolidating its leadership role in this regard.

Figure 5: Renewability of the energy mix: Brazil, the World, and OECD countries



Source: EPE (2024a).

... which contribute to the system's security. Even so, it is necessary to enhance its resilience to climate threats

In recent decades, Brazil has made progress toward energy self-sufficiency, gradually reducing external dependency, as shown in Figure 6. This progress has been coupled with increasing **diversification of the energy mix** (Figure 7), with the accelerated integration of renewable sources such as wind, solar and bioenergy, alongside a more robust National Interconnected System (SIN) that connects different regions of the country, enabling more efficient management of energy resources.

This energy diversity and system interconnection enhance flexibility and responsiveness to potential crises or fluctuations in energy supply. These factors provide Brazil with a solid foundation to face future challenges, especially in a context of global energy transition. Nonetheless, the intensification of extreme events in recent years demands additional actions to further strengthen the resilience of the energy system against climate threats.

Additionally, Brazil faces growing energy demand, driven by demographic growth, urbanization, and the need to improve access to essential services for the entire population.

As more Brazilians seek better quality of life and access to goods and services, energy needs are expanding in sectors such as transportation, buildings, and industry. This growing demand reinforces the importance of Brazil's comparative advantages, such as its abundance of renewable resources, to meet these needs sustainably and inclusively.

However, **addressing this demand sustainably requires significant investments and policies that encourage not only the expansion of energy infrastructure but also efficiency and accessibility.** These efforts must aim to integrate the most vulnerable segments of society and reduce energy poverty. These factors are essential for Brazil to maintain system security, promote inclusion, and ensure a **socially just energy transition.**

Figure 6: Brazil's external energy dependency (%)

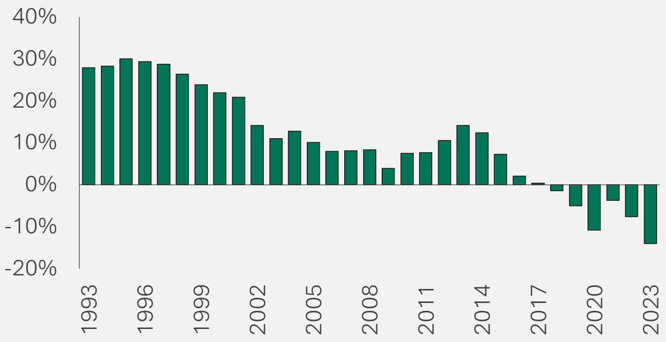


Figure 7: Brazilian energy mix in 2023

RENEWABLES ▶ 49.1%

Sugarcane biomass	16.9%
Hydro power	12.1%
Wind	2.6%
Firewood and charcoal	8.6%
Other renewables	7.2%
Solar	1.7%

NON-RENEWABLES ▶ 50.9%

Petroleum and oil products	35.1%
Natural gas	9.6%
Coal	4.4%
Uranium	1.2%
Other non-renewable	0.6%

Source: EPE (2024a).

How can the energy system serve as a driver for sustainable development and how can a just transition be achieved in Brazil?

And when we consider sustainable development, what is Brazil's true starting point?

To evaluate how Brazil is progressing in terms of sustainable development, it is essential to monitor the advancements related to the Sustainable Development Goals (SDG). Figure 9 illustrates that the country is achieving most of the targets related to SDG 7 – Affordable and Clean Energy – with notable growth in renewable energy and improved access to electricity.

However, many SDGs still face challenges to be fully achieved by 2030. In this context, **the energy system can serve as a catalyst for sustainable development, driving progress across other SDGs.**

Figure 8: Sustainable Development Goals

Source: ONU (2024).

Figure 9: Tracking progress on SDG 7 in Brazil

Targets	Global indicators	Evolution of indicators	Evaluation of goals
7.1 – By 2030, ensure universal, reliable, modern and affordable access to energy services.	7.1.1 – Percentage of the population with access to electricity.	✓	✓
	7.1.2 – Percentage of the population with primary access to clean fuels and technologies.	✓	
7.2 – By 2030, substantially increase the share of renewable energy in the global energy mix.	7.2.1 – Share of renewable energy in total final energy consumption.	✓	✓ 🎯
7.3 – By 2030, double the global rate of improvement in energy efficiency within the Brazilian economy.	7.3.1 – Energy intensity measured in terms of primary energy and GDP.	✓	✓ 🎯
7.a – By 2030, enhance international cooperation to facilitate access to research and clean energy technologies, including renewable energies, energy efficiency, and advanced and cleaner fossil fuel technologies. Promote investment in energy infrastructure and clean energy technologies.	7.a.1 – International financial flows to developing countries in support of clean energy research and development, as well as the production of renewable energy, including hybrid systems.	✕	✕
7.b – By 2030, expand infrastructure and modernize technology to provide modern and sustainable energy services to all developing countries, particularly the least developed countries, small island developing states and landlocked developing countries, in accordance with their respective support programs.	7.b.1 – Investments in energy efficiency, as a percentage of GDP, and the amount of foreign direct investment in financial transfers for infrastructure and technologies for sustainable development services.	✓	✓

✓ Positive evolution
⊖ No evolution
🎯 Global target achieved
⊗ Negative evolution
✺ Impacted by COVID-19
✕ No indicators or short/irregular data series

Source: IPEA (2024).

And when we consider sustainable development, what is Brazil's true starting point?

In this context, when analyzing Brazil's starting point for sustainable development, the environmental, economic, and social dimensions reveal challenges and opportunities.

Environmental dimension

Brazilian greenhouse gas (GHG) emissions differ from the global average, as the energy sector accounts for a smaller share of total emissions. **In Brazil, most emissions are related to land use, land-use change, and forestry** (including deforestation), **as well as agriculture**, as shown in Figure 10.

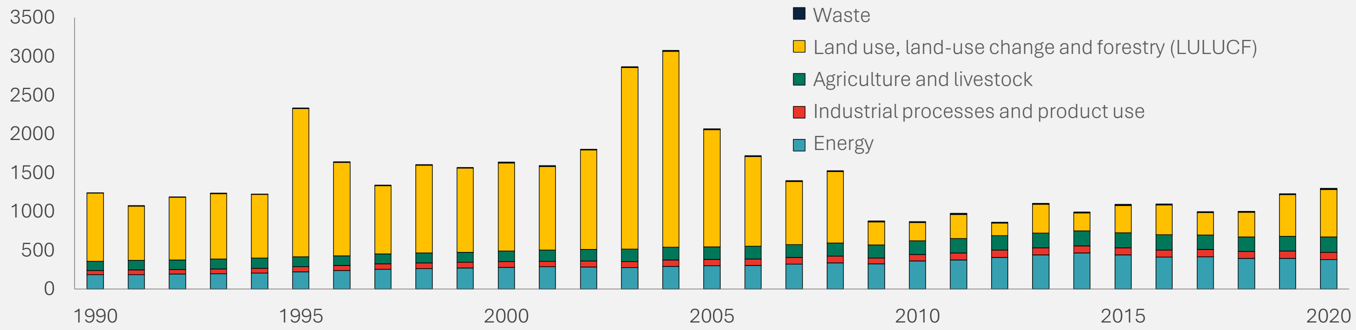
The increase in illegal deforestation has driven the growth of national emissions, compromising GHG reduction targets and highlighting the need for effective policies for environmental protection.

Economic dimension

From an economic perspective, **the country has faced a recent period of low economic growth, coupled with almost stagnant total factor productivity (TFP) for several decades**, as illustrated in Figure 11, with a loss of technological content in its export and production portfolios.

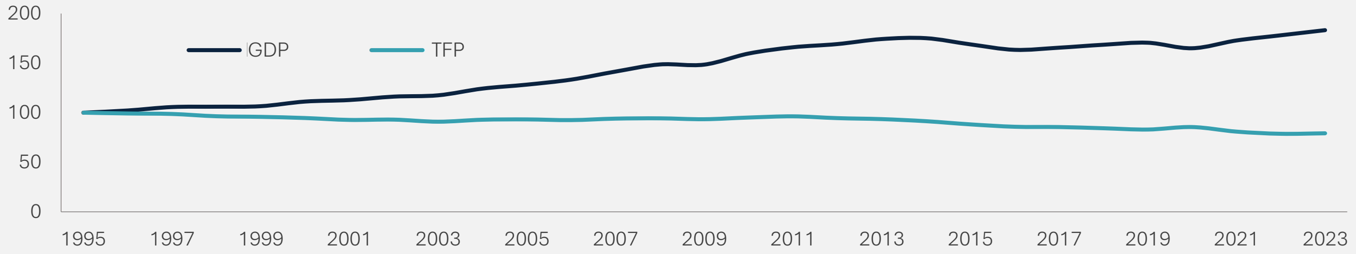
This scenario, to some extent, could limit the capacity to invest in modern and sustainable energy infrastructure.

Figure 10: Brazilian greenhouse gas emissions by sector (millions of tons of CO_2 equivalent)



Source: Own elaboration based on MCTI (2024).

Figure 11: Evolution of GDP and total factor productivity in recent years (1995 = 100)



Source: Own elaboration based on IBGE (2024) and FGV (2024).

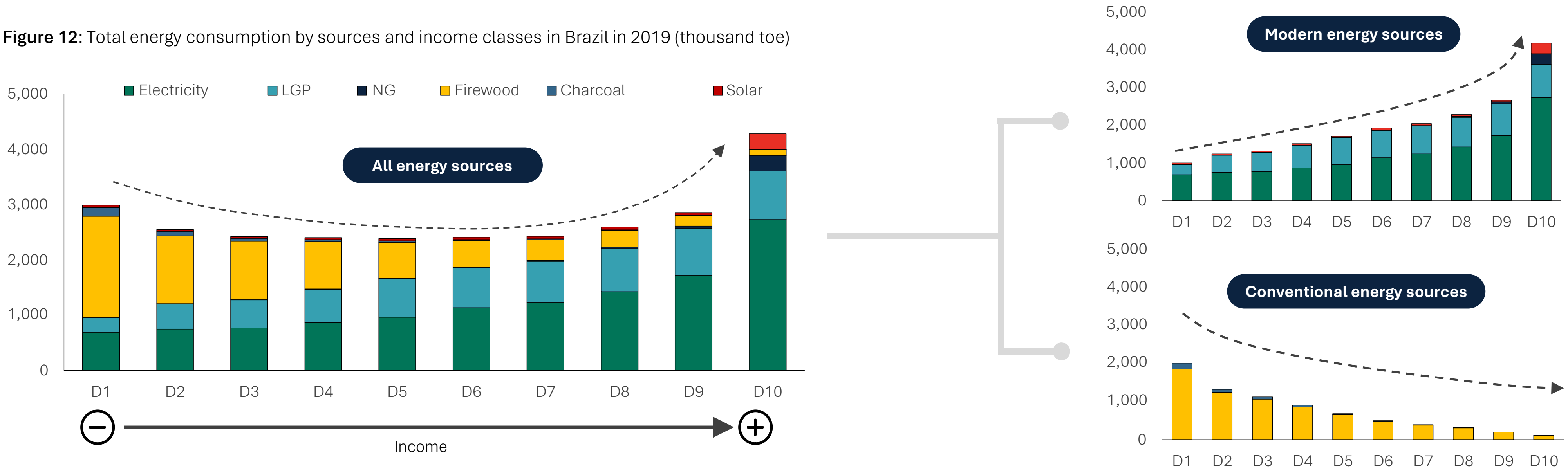
And when we consider sustainable development, what is Brazil's true starting point?

Social dimension

In the social dimension, Brazil exhibits high levels of poverty and income inequality, which are also reflected in the energy sector. Despite the recent decline, about 3.5% of the population lives below the extreme poverty line, according to the World Bank.

The country faces significant **challenges in reducing inequality in energy access and improving energy efficiency, especially among low-income populations.** The substantial use of firewood in residential energy consumption, particularly among lower-income families, highlights the issue of energy poverty, indicating that many households still lack adequate access to modern energy sources (Figure 12). These factors underscore the need for robust public policies to drive sustainable development while ensuring social inclusion and equity.

Figure 12: Total energy consumption by sources and income classes in Brazil in 2019 (thousand toe)



Source: EPE (2023).
Note: All classes from D1 to D10 contain the same number of people (10% of the population, or 20.9 million people). D1 represents the lowest income class, while D10 corresponds to the highest income class.

Difficult questions to answer, but the responses necessarily involve innovation ...

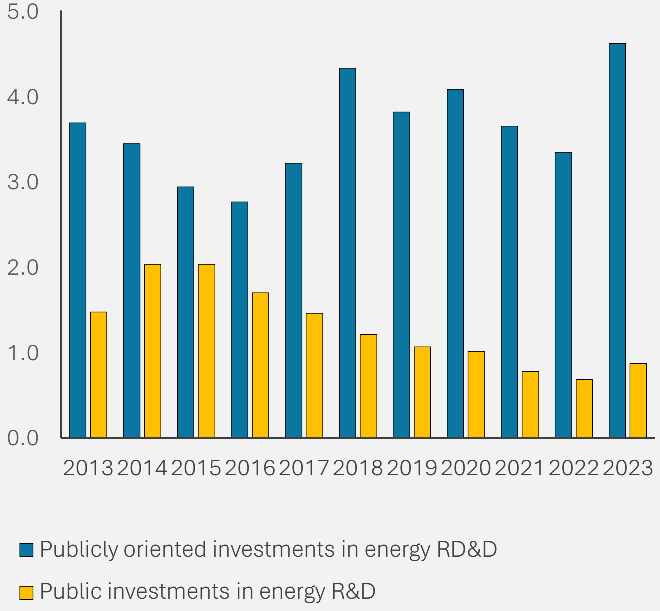
Innovation plays a crucial role in the development of emerging technologies and low-carbon solutions. According to the IEA (2023), a significant portion of these technologies are still in the early stages of maturity and development, making the acceleration of investments in innovation urgent.

However, in the Brazilian case, **public and publicly-oriented investments in energy sector research, development, and demonstration (RD&D) present a challenging scenario.** According to the Inova-e platform (EPE, 2024c), public investments in energy RD&D totaled R$ 2.0 billion in 2014 but decreased successively to R$ 683 million in 2022, a trend that began to reverse in 2023. Meanwhile, publicly-oriented investments have shown greater resilience over the years, reaching R$ 4.6 billion in 2023 (Figure 13).

A significant portion of these funds originates from legal obligations and is regulated by the National Electric Energy Agency (ANEEL) and the National Agency of Petroleum, Natural Gas, and Biofuels (ANP) through their research and development (R&D) programs. Under the ANP program, there has been a diversification of the oil and gas sector's investment portfolio in recent years, focusing on technologies aligned with the energy transition, such as renewables, hydrogen, fuel cells, energy efficiency and other cross-cutting technologies (Figure 14).

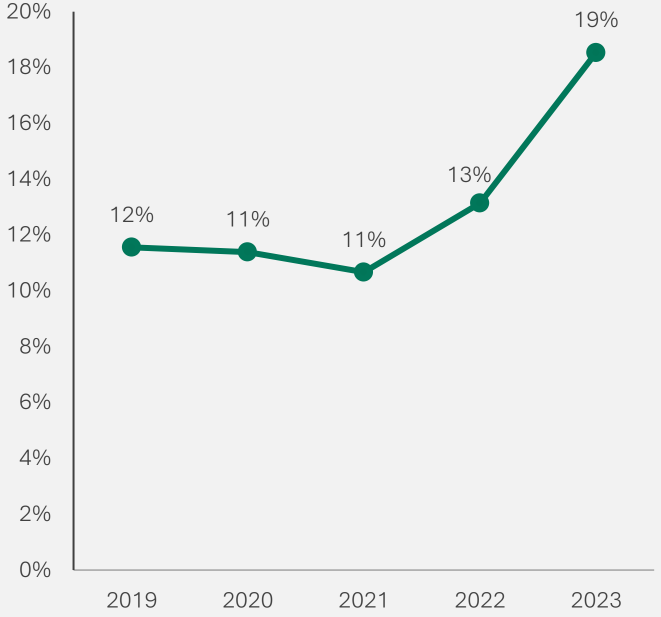
Note: The Brazilian real (R$ or BRL) is the official currency of Brazil.

Figure 13: Public and publicly-oriented investments in energy RD&D mapped by Inova-e (R$ billion)



Source: Own elaboration based on EPE (2024c).

Figure 14: Share of investments in RD&D for non-fossil technologies under the ANP program (% total)



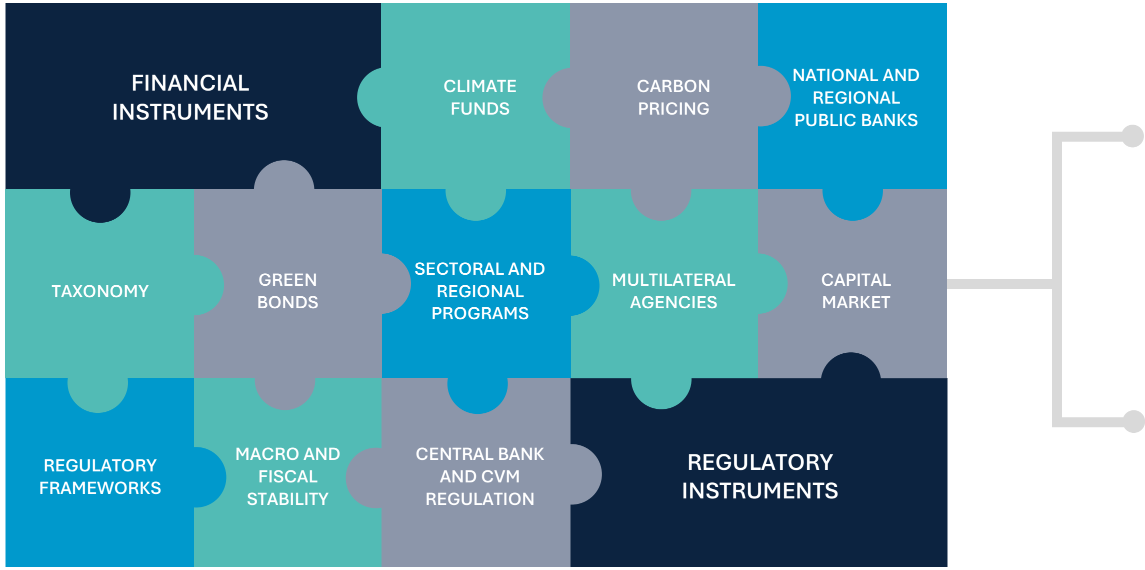
Source: Own elaboration based on EPE (2024c).

… in addition to instruments for financing the just energy transition …

The International Energy Agency (IEA, 2023) estimates the need to triple investments in clean energy by 2030 to achieve net carbon neutrality by 2050. Approximately 55% of these investments are expected to occur in emerging and developing countries, such as Brazil, requiring the mobilization of financial and regulatory instruments.

Another essential pillar for a just and inclusive energy transition is financing. In this regard, **Brazil has been adopting various financial and regulatory instruments to fund the energy transition and promote sustainable development.**

Climate funds and **green bonds** have been key tools, while carbon pricing and the **Brazilian Sustainable Taxonomy (BST)** will help align investments with climate goals. The Brazilian Development Bank (BNDES) has recently resumed its investments in renewable energies, while the volume of **incentivized infrastructure debentures in the energy sector** has been increasing, reflecting a more favorable environment for financing initiatives aimed at transitioning to a low-carbon economy.



FINANCIAL INSTRUMENTS

CLIMATE FUNDS

CARBON PRICING

NATIONAL AND REGIONAL PUBLIC BANKS

TAXONOMY

GREEN BONDS

SECTORAL AND REGIONAL PROGRAMS

MULTILATERAL AGENCIES

CAPITAL MARKET

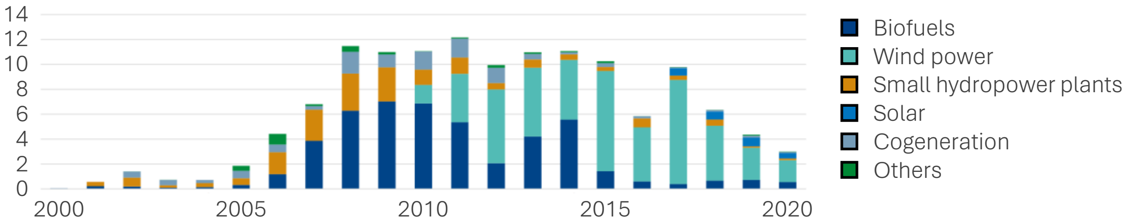
REGULATORY FRAMEWORKS

MACRO AND FISCAL STABILITY

CENTRAL BANK AND CVM REGULATION

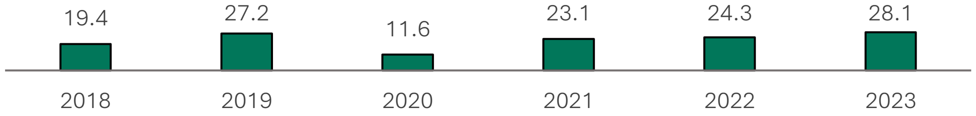
REGULATORY INSTRUMENTS

Figure 15: BNDES disbursements for renewable energies (R$ billion)



Source: Adapted from BNDES (2021).

Figure 16: Volume of incentivized infrastructure debentures in energy (R$ billion)



Source: Own elaboration based on ANBIMA (2024).

… and integrated public policies

In terms of public policies, **Brazil has developed solid institutions in the energy sector**, especially since the 1990s with institutional restructuring. The creation of entities such as National Electric Energy Agency (ANEEL), National Agency of Petroleum, Natural Gas and Biofuels (ANP), the National Council for Energy Policy (CNPE), the National Electric System Operator (ONS), the Electric Energy Trading Chamber (CCEE) and the Energy Research Office (EPE) marked a period of significant transformations, during which the country improved the governance and regulation of the energy sector.

Based on this solid institutional framework, **various public policies have been successfully implemented in the Brazilian energy sector over recent decades.** These have been decisive instruments in fostering energy security, expanding infrastructure and diversifying the energy mix. Examples include the Program for Incentives for Alternative Sources of Electric Energy (Proinfa), the National Electricity Conservation Program (Procel), the "Luz para Todos" Program and the National Biofuels Policy (RenovaBio).

In the climate area, Brazil has been engaged in global initiatives since the United Nations Conference on Environment and Development in 1992 (Rio 92), through the Paris Agreement, and the creation of national policies such as the National Climate Change Policy, as well as funds like the "Fundo Clima" and "Fundo Amazônia".

Examples of public policies in the Brazilian energy sector

1985	PROCEL PROGRAMA NACIONAL DE CONSERVAÇÃO DE ENERGIA ELÉTRICA
1997	Oil Law *(Law nº 9.478/1997)*
2000	Energy Efficiency Programs (PEE) *(Law nº 9.991/2000)*
2001	National Policy of Conservation and Racional use of Energy *(Law nº 10.295/2001)*
2002	PROINFA
2003	LUZ PARA TODOS
2005	A AGRICULTURA FAMILIAR PARTICIPA BIODIESEL COMBUSTÍVEL SOCIAL
2012	Micro and Mini Distributed Generation *(ANEEL Normative Resolution nº 482/2012)*
2017	RenovaBio
2023	PNH2 Programa Nacional do Hidrogênio
2023	ENERGIAS DA AMAZÔNIA
2024	COMBUSTÍVEL DO FUTURO
2024	National Energy Transition Policy (PNTE) *(CNPE Resolution nº 5/2024)*

Examples of initiatives, commitments, and climate policies

1992	RIO 92 Rio 92 - The United Nations Conference on Environment and Development (UNCED)
2009	Brazilian National Policy on Climate Change
2009	Fundo Clima
2015	PARIS 2015 Paris Agreement
2016	SIRENE
2021	Global Methane Pledge Global Methane Pledge
2023	Interministerial Committee on Climate Change *(Decree 11.550/2023)*

… around the priority and cross-cutting agenda that is Brazil's transition to a low-carbon economy

Brazil's agenda for the transition to a low-carbon economy integrates several priority and cross-cutting initiatives aimed at promoting sustainable development across various fronts. The National Energy Transition Policy (PNTE) and the Ecological Transformation Plan exemplify this approach, providing guidelines to reduce carbon intensity in strategic sectors and promote productive and technological development in key supply chains for the energy transition.

In parallel, Brazil recently revised its Nationally Determined Contribution (NDC), committing to a more ambitious goal for reducing greenhouse gas (GHG) emissions. The "Energias da Amazônia" Program is another essential action, aiming to integrate the Amazon Region into the national energy system sustainably through renewable energy, reducing reliance on fossil fuels. The "Combustível do Futuro" Law also represents a milestone for the national energy sector, introducing a series of initiatives to promote sustainable low-carbon mobility. These actions, when integrated, form a **solid foundation for Brazil to consolidate its position as a leader in the global energy transition**, preserving its natural resources, enhancing energy security and promoting social inclusion – key elements for ensuring that this transformation is both fair and inclusive.

Plano unifica ações de Estado para política energética mais verde e inclusiva

Com a presença de Lula, conselho aprova Política Nacional de Transição Energética, que vai integrar todas as ações do Governo Federal, com potencial de R$ 2 trilhões em investimentos

BNDES, Finep e MCTI lançam maior programa de inovação do país com apoio de R$ 60 bi e novas taxas

Presidente Lula sanciona Lei do Combustível do Futuro para promover a mobilidade sustentável

Norma estabelece a criação de programas nacionais de diesel verde, de combustível sustentável para aviação e de biometano, entre outras medidas

Brasil entrega à ONU nova NDC alinhada ao Acordo de Paris

Documento determina meta de reduzir as emissões líquidas de gases de efeito estufa do país entre 59% e 67% até 2035

Presidente Lula sanciona lei que cria mercado regulado de carbono no Brasil

Nova lei institui sistema de bonificação para empresas ou estados que reduzirem a emissão de gás carbônico na atmosfera

Novo Fundo Clima cresce e tem R$ 10,4 bilhões com novas condições para projetos verdes

BNDES busca projetos para financiar transição energética

Banco tem intenção de aprovar créditos de R$ 52 bi este ano, com maior parte dos recursos voltados para energia limpa

Transmissão de energia terá R$ 89 bilhões em investimentos no novo PAC

Novas linhas passarão por 15 estados e trarão mais qualidade e segurança para os consumidores

Note: Some news and announcements (most in Portuguese) about Brazilian public policies related to the energy transition.

Sources: Agência Gov (2024), BNDES (2023), BNDES (2024), Brasil (2023a), Brasil (2023b), Brasil (2024a), Brasil (2024b), Brasil (2024c), MDIC (2024), Ministério da Fazenda (2023), Ministério da Fazenda (2024) and Valor Econômico (2023).

3

Future drivers: trends and uncertainties

Future drivers: trends and uncertainties

The future is multiple, uncertain and changes constantly. Exploring it through the construction of **prospective scenarios** requires an important step: mapping factors that have a significant influence on the future evolution of the object being analyzed, known as **future drivers.**

Some of these factors are forces that exist today and will remain in the future, with a predictable and sufficiently consolidated direction, known as **trends**. Despite their magnitude and capacity for influence, trends are not constitutive elements of scenario logic but serve as a common backdrop for possible futures.

Uncertainties, on the other hand, are phenomena with low predictability and a high impact on the object of analysis. For this reason, hypotheses about their future states are important guiding elements for constructing the logic of scenarios and creating different possibilities for the future.

Climate change, transformations in the geopolitics of energy, and the growing need for a just and inclusive energy transition are examples of changes that not only require immediate responses from the country but also have clear effects on Brazil's energy transition. Much of these changes is characterized by a high level of uncertainty, but there are phenomena whose future developments can be glimpsed with a certain degree of predictability.

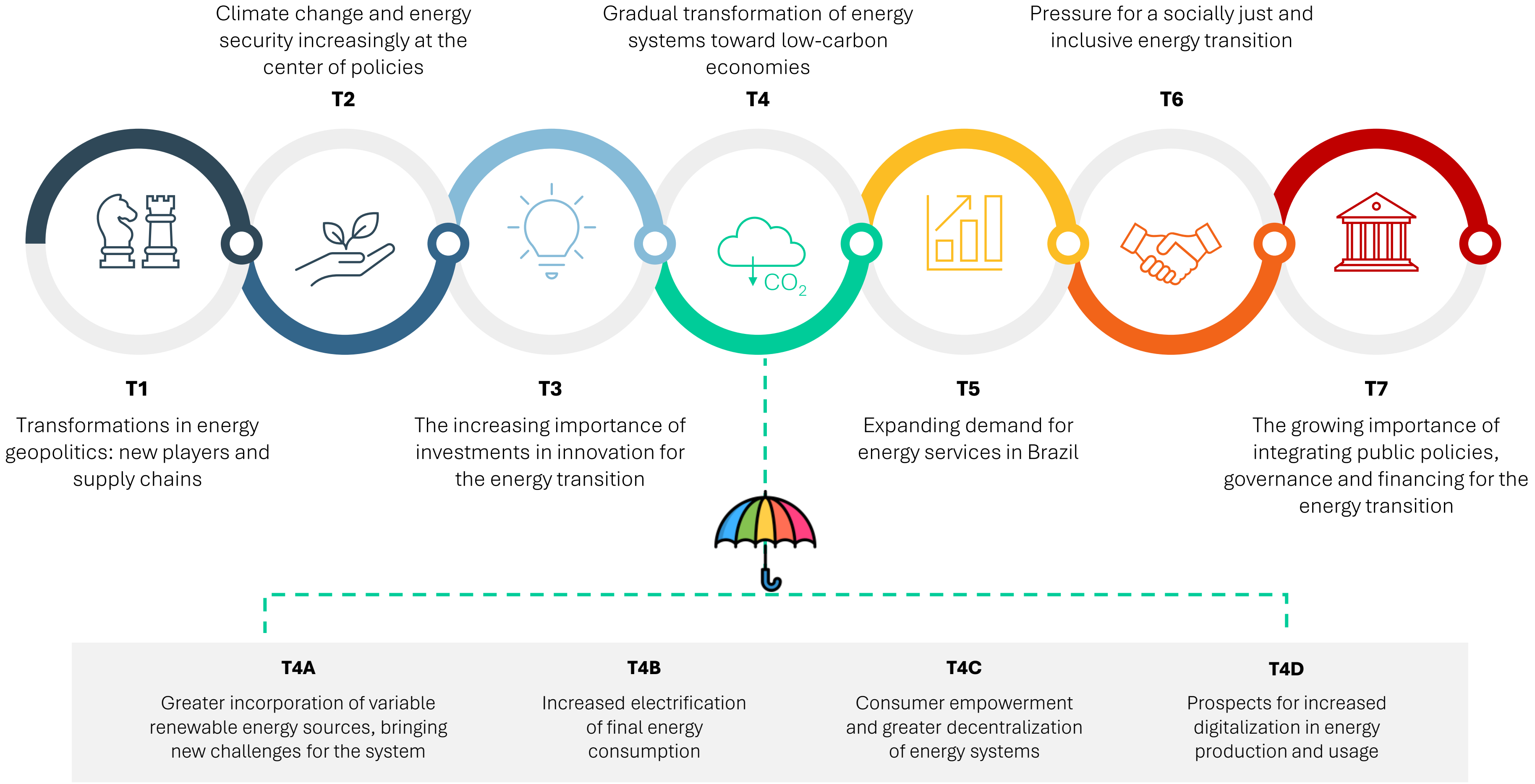
What is certain or almost certain: Trends

Phenomena whose direction is quite visible and sufficiently consolidated (movement with a predictable direction)

What changes: Uncertainties

Phenomena with low predictability and high impact in relation to the future of the object

Major trends for the national energy system until 2055



T1

Transformations in energy geopolitics: new players and supply chains

T2

Climate change and energy security increasingly at the center of policies

T3

The increasing importance of investments in innovation for the energy transition

T4

Gradual transformation of energy systems toward low-carbon economies

T5

Expanding demand for energy services in Brazil

T6

Pressure for a socially just and inclusive energy transition

T7

The growing importance of integrating public policies, governance and financing for the energy transition

T4A

Greater incorporation of variable renewable energy sources, bringing new challenges for the system

T4B

Increased electrification of final energy consumption

T4C

Consumer empowerment and greater decentralization of energy systems

T4D

Prospects for increased digitalization in energy production and usage

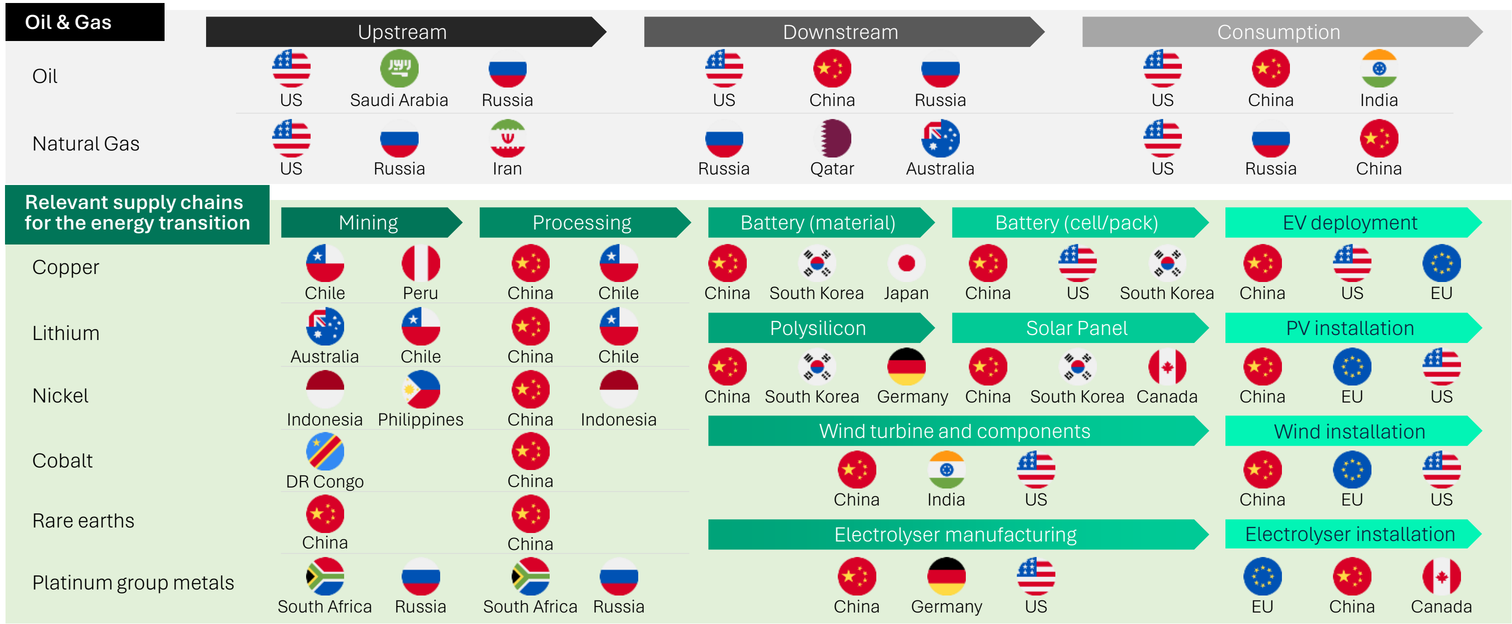
T1: Transformations in energy geopolitics: new players and supply chains

The global race toward low-carbon economies is transforming energy geopolitics. The value chains for fossil fuels and low-carbon solutions exhibit distinct geographic concentrations, leading to a shift in the axis of power in energy geopolitics, as illustrated in Figure 17. One example is the increasing demand for strategic minerals, whose supply chain is concentrated in countries that currently have low relevance in oil and gas production.

It is important to highlight that the diversity of conditions and priorities among countries and regions – technological, energy and mineral resources, energy security and socioeconomic development – creates a scenario of both competition and opportunities for international cooperation, which are becoming increasingly evident in the global energy transition process.

Technological competition and the race for critical minerals, essential for the expansion of renewable energies, along with the impacts of the war in Ukraine, demonstrate how geopolitics and the pursuit of more resilient energy systems have gained prominence. At the same time, economic and geopolitical interests continue to shape the climate agenda and the evolution of energy systems worldwide, as evidenced by policies such as the Inflation Reduction Act (IRA) and REPowerEU.

Figure 17: Supply chains for oil and gas and for relevant technologies to the energy transition



Oil & Gas	Upstream	Downstream	Consumption
Oil	US Saudi Arabia Russia	US China Russia	US China India
Natural Gas	US Russia Iran	Russia Qatar Australia	US Russia China

Relevant supply chains for the energy transition	Mining	Processing
Copper	Chile Peru	China Chile
Lithium	Australia Chile	China Chile
Nickel	Indonesia Philippines	China Indonesia
Cobalt	DR Congo	China
Rare earths	China	China
Platinum group metals	South Africa Russia	South Africa Russia

Battery (material): China South Korea Japan	Battery (cell/pack): China US South Korea	EV deployment: China US EU
Polysilicon: China South Korea Germany	Solar Panel: China South Korea Canada	PV installation: China EU US
Wind turbine and components: China India US		Wind installation: China EU US
Electrolyser manufacturing: China Germany US		Electrolyser installation: EU China Canada

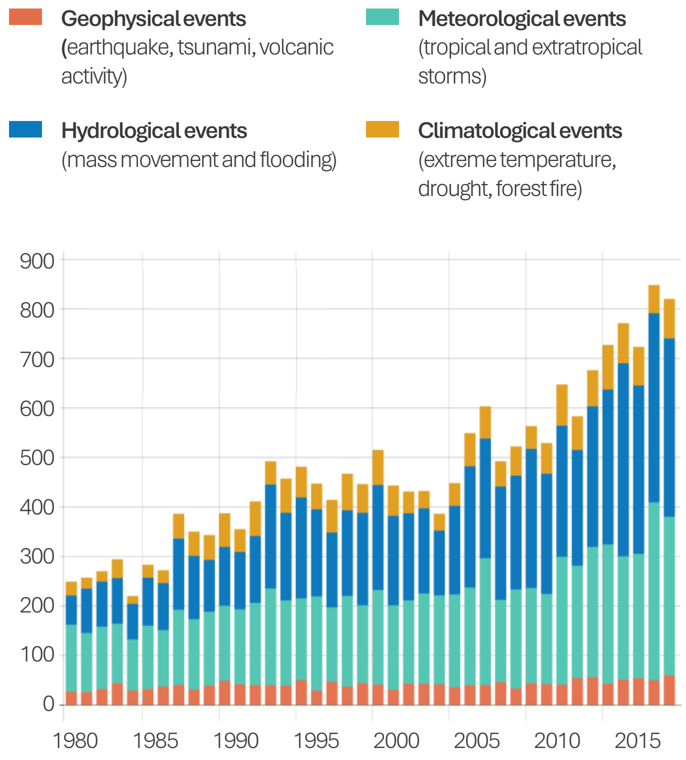
Source: Adapted from IEA (2022).

Implications for the Brazilian energy system

- The positioning of developed countries, China and other Asian countries in technological development and various key supply chains of the energy transition (such as transmission equipment, photovoltaic panels, batteries, etc.) creates challenges related to the productive and technological dependency of Brazil's energy system and national competitiveness.
- Concerns about energy security and opportunities for the development of supply chains (both new and existing) for the energy transition in the country.

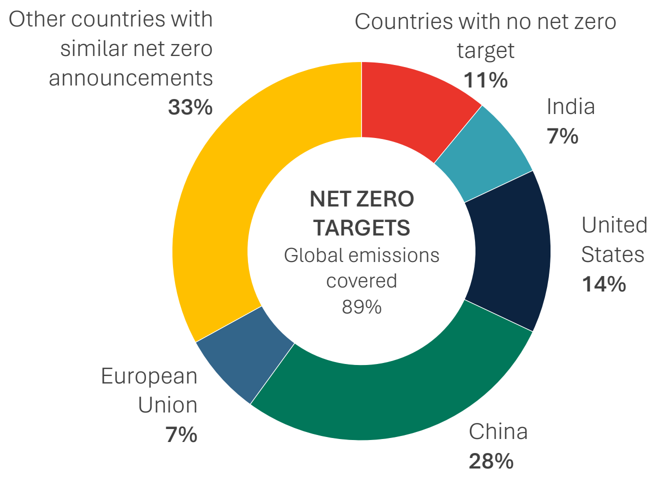
T2: Climate change and energy security increasingly at the center of policies

Figure 18: Number of extreme weather events worldwide (1980-2019)



Source: Adapted from Munich Re (2016) *apud* UK Met Office (2024).

Figure 19: Net zero emissions target announcements



Source: Adapted from Climate Action Tracker (2023).

The energy system is strongly influenced by climate issues due to its relevance in GHG emissions and its vulnerability to climate changes.

Periods of water scarcity, extreme heat waves and storms are examples of events that require measures to increase the resilience and security of the energy system.

In this context, global warming scenarios put pressure on mitigation measures for GHG emissions, such as the promotion of renewable sources and carbon pricing. In November 2023, around 145 countries had announced or were considering net zero emission targets, covering approximately 90% of global emissions (Climate Action Tracker, 2023).

Implications for the Brazilian energy system

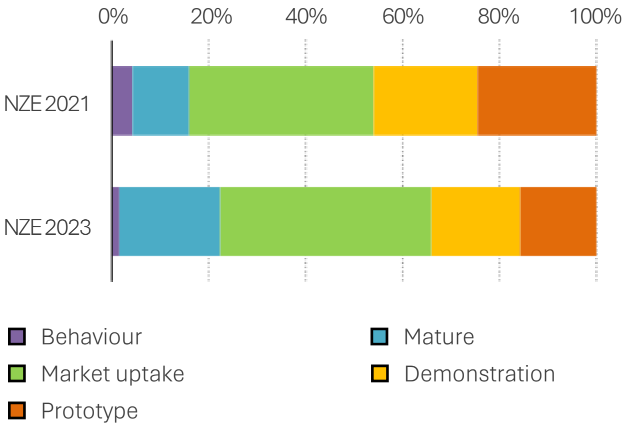
- Climate changes can impact the availability of natural and energy resources, energy demand, the efficiency and integrity of energy infrastructures.
- Thus, the need for resilience and security becomes essential in the planning of the national energy system, making it necessary to develop other business models/mechanisms to ensure supply security.

T3: The increasing importance of investments in innovation for the energy transition

In the context of the energy transition and responses to the challenges of climate change, **innovation is – and will continue to be – a fundamental driver for enabling and enhancing transformations in energy systems.** However, a large part of the technologies required to reduce GHG emissions to net zero are still in the early stages of the innovation chain: 35% in 2023. In 2021, this percentage was nearly 50%, demonstrating significant technological progress on a global scale (IEA, 2023).

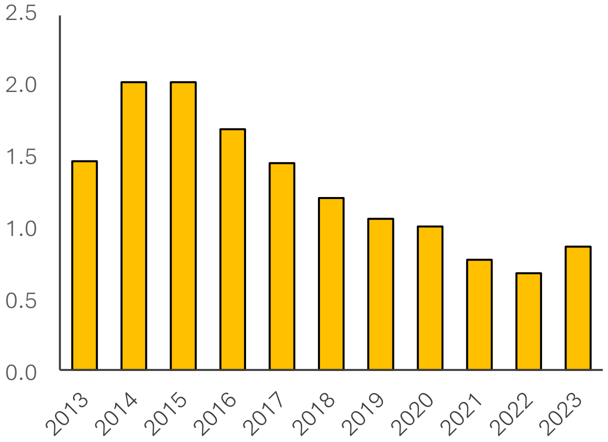
In Brazil, public and publicly-oriented investments in research, development, and demonstration (RD&D) in energy from 2013 to 2023 exceeded R$ 4.0 billion per year, with 74% of this amount being publicly-oriented investments, regulated by ANEEL and ANP. Meanwhile, public RD&D investments showed a significant decline in recent years, a trend that began to reverse in 2023 (Figure 21).

Figure 20: Comparison of cumulative CO_2 emission reductions in the energy sector relative to the baseline year, by technology maturity



Source: Adapted from IEA (2023).

Figure 21: Evolution of public investments in energy RD&D in Brazil (R$ billions)



Source: Own elaboration based on EPE (2024c).

Implications for the Brazilian energy system

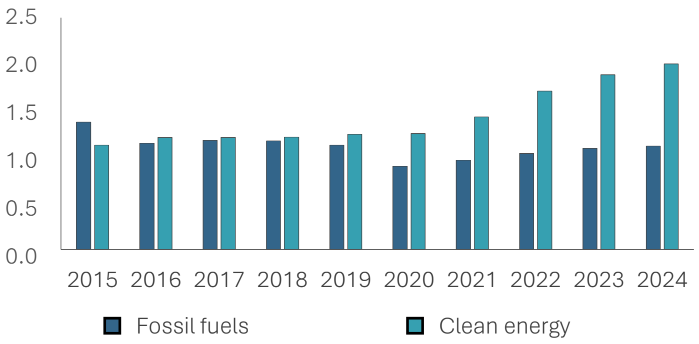
- It is necessary to accelerate and scale up investments in innovation, not only in energy efficiency and renewable energy but also in new technologies associated with hard-to-abate sectors (such as steelmaking, cement, freight transport, aviation, chemicals, etc.), as well as enabling technologies, such as those linked to digital transformation.
- Strengthening the innovative capacity of the national energy system and aligning it with the challenges of Brazil's energy transition will require strong interministerial coordination, as well as the integration of financial instruments. According to the IEA (2024a), energy innovation outcomes are more easily achieved when aligned with national visions of economic and social development. Innovation should be considered beyond the technological perspective – adopting a systemic approach that includes business models, financing arrangements and local conditions and challenges, leveraging Brazil's unique characteristics with the potential to generate employment and income.

T4: Gradual transformation of energy systems toward low-carbon economies

The climate emergency imposes pressure to reduce emissions across different economic sectors, including the energy sector. In Brazil's case, despite the greater contribution of land-use sectors to emissions, **the energy sector can serve as a key driver for the decarbonization of the transportation and industrial sectors** – which had renewability rates of 22.5% and 64.7%, respectively, in 2023, according to EPE (2024a).

The transformation toward low-carbon economies goes beyond the replacement of energy sources, involving movements such as decentralization and digitalization – the three Ds of the energy transition.

Figure 22: Global investments in fossil fuels and clean energy: 2015-2024 (US$ 2023 trillions)



Source: Own elaboration based on IEA (2024c).

Trends	Implications for the Brazilian energy system
T4A Greater incorporation of variable renewable energy sources, bringing new challenges for the system	▪ The expansion of variable renewable energy sources poses challenges for planning and operation, requiring investments in resources that enhance flexibility and controllability to effectively manage generation and load variations. ▪ In addition to a robust transmission system, the development/implementation of technologies such as energy storage, Flexible Alternating Current Transmission Systems (FACTs), variable reactive power compensation, demand response mechanisms, meteorological technologies, among others, can also contribute to the required increase in operational flexibility. ▪ It is important to consider the local socio-environmental impacts of variable renewables sources.
T4B Increased electrification of final energy consumption	▪ Although the electrification of the energy sector is considered a trend, the intensity and speed of this process remain uncertain, particularly in segments such as transportation and industry. ▪ Issues related to the cost of electricity may impact the electrification process. ▪ It is a driver for integrating new renewable generation projects, promoting the efficient and sustainable utilization of Brazil's energy potential and transmission system.
T4C Consumer empowerment and greater decentralization of energy systems	▪ Distributed Energy Resources (DERs) present challenges but can also bring benefits associated with their integration into the system, such as loss reduction, increased reliability, etc. ▪ There is a need for methodological improvements, modeling, and information-sharing policies that can ensure the proper identification of expansion requirements, enabling effective and efficient energy planning and a secure future operation.
T4D Prospects for increased digitalization in energy production and usage	▪ Across the entire energy sector, digitalization can help reduce costs, improve efficiency and resilience, and drive consumer behavior changes toward low-carbon options. ▪ Key challenges include building capacity to harness the potential of digitalization (infrastructure, technological services, and workforce), not just in specific niches but more broadly across the population, as well as concerns regarding cybersecurity.

T5: Expanding demand for energy services in Brazil

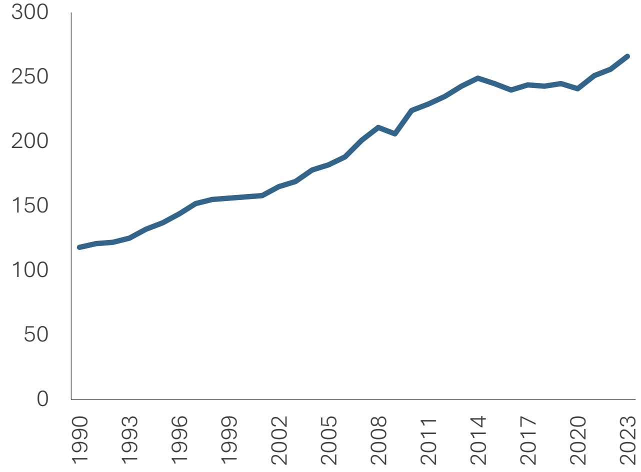
Emerging economies face growing energy demands due to their development process, population growth, improvement in living standards, among other factors, which increases the need for energy services.

According to EPE (2020), energy demand in Brazil is expected to double, and electricity demand to triple, by 2050. Behavioral changes and new business models (affecting how energy is used), energy efficiency and electrification may influence the trajectory of energy demand in end-use sectors, although the magnitude of these impacts remains uncertain.

The slowdown in population growth and income evolution, with an estimated increase in GDP per capita, will also impact the need for energy services. In 2023, per capita energy consumption in Brazil was still half that of the European Union.

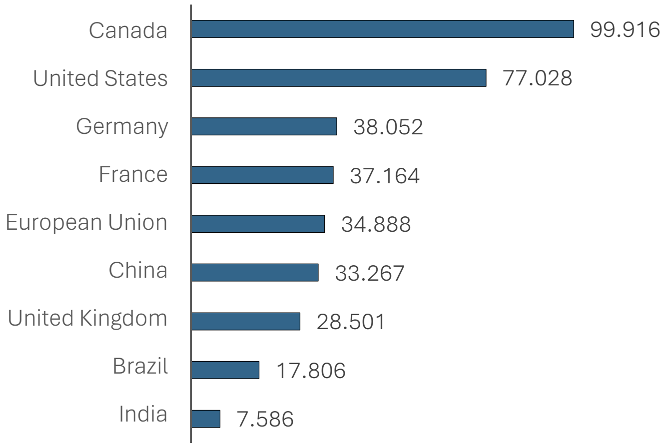
Cities account for a significant share of energy consumption, housing more than 50% of the population, generating 80% of GDP, consuming two-thirds of energy, and producing over 70% of carbon emissions. By 2050, it is projected that over 70% of the global population will live in cities, leading to massive growth in demand for urban energy infrastructure (IEA, 2021).

Figure 23: Final energy consumption in Brazil (million toe)



Source: Own elaboration based on EPE (2024a).

Figure 24: Energy consumption per capita in selected countries - 2023 (kWh)



Source: Own elaboration based on Our World in Data (2024).

Implications for the Brazilian energy system

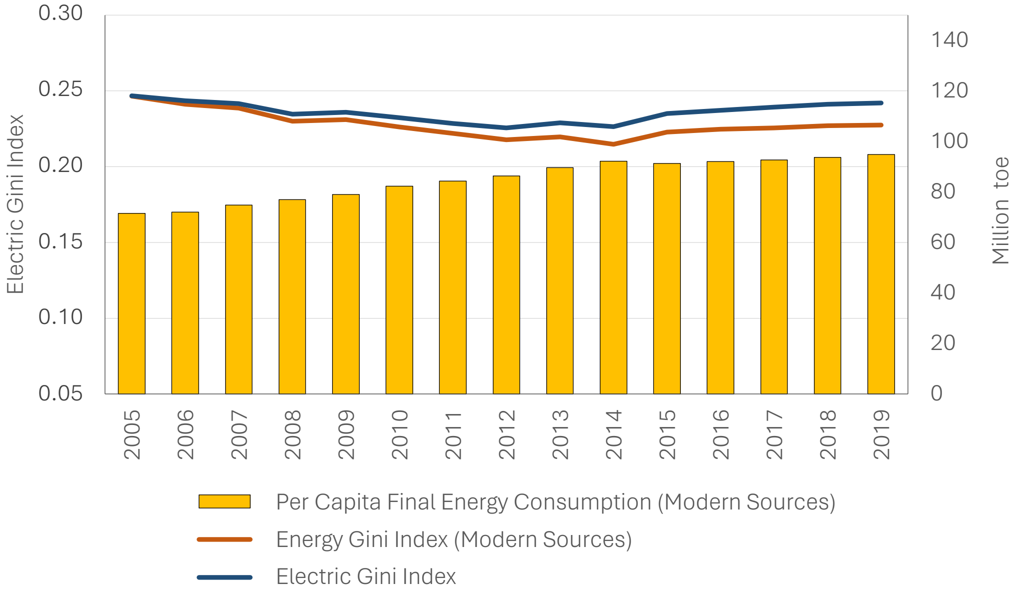
- Challenge of ensuring reliable, sustainable, modern and affordable access to energy for all (SDG 7).
- Expand and modernize infrastructure and technology to supply energy services.
- The pace and intensity of demand growth may be impacted by still-uncertain factors related to consumer behavior, energy efficiency, electrification in end-use sectors and income evolution in Brazil.

T6: Pressure for a socially just and inclusive energy transition

There is increasing **pressure for the transition to a low-carbon economy to be aligned with the Sustainable Development Goals (SDGs)** and the agenda for mitigating energy poverty, especially in developing countries, to ensure that all households have access to clean, modern and affordable energy sources.

In Brazil, firewood and charcoal account for 25% of all energy consumed in households, directly impacting health and quality of life, particularly for women and children, who spend most of their time on domestic tasks and family care.

Figure 25: Annual evolution of the Electric Gini Index in the residential sector and residential electricity consumption in Brazil



Source: EPE (2023).

Implications for the Brazilian energy system

- Potential for job and income generation based on Brazil's energy potential, social inclusion, combating energy poverty, reducing socioeconomic and regional inequalities, improving quality of life, economic growth, reindustrialization on more sustainable grounds, among other opportunities.
- The energy transition can be a driver for sustainable development in the country.

T7: The growing importance of integrating public policies, governance and financing for the energy transition

The energy transition is a cross-cutting issue throughout the Brazilian economy and, as such, has been the subject of actions in various ministries, such as MME, MDIC, Fazenda, MRE, MMA, MCTI, among others.

In this context**, the coordination and integration of these policies are crucial to the energy transition process.**

In this regard, the National Energy Transition Policy (PNTE), established by CNPE Resolution No. 5/2024, aims to integrate public policies to promote a just and inclusive energy transition.

Energy Policy	Economic Policy	Social Policy
Climate Policy	Industrial Policy	Environmental Policy
Technological Development Policy	Health Policy	Other policies

- Plano Plurianual (PPA)
- Novo PAC
- Plano Clima
- Nova Indústria Brasil
- Plano de Transformação Ecológica
- FNDCT
- Others

NOVO PAC
DESENVOLVIMENTO E SUSTENTABILIDADE

NOVO BRASIL
PLANO DE TRANSFORMAÇÃO ECOLÓGICA

PLANO CLIMA

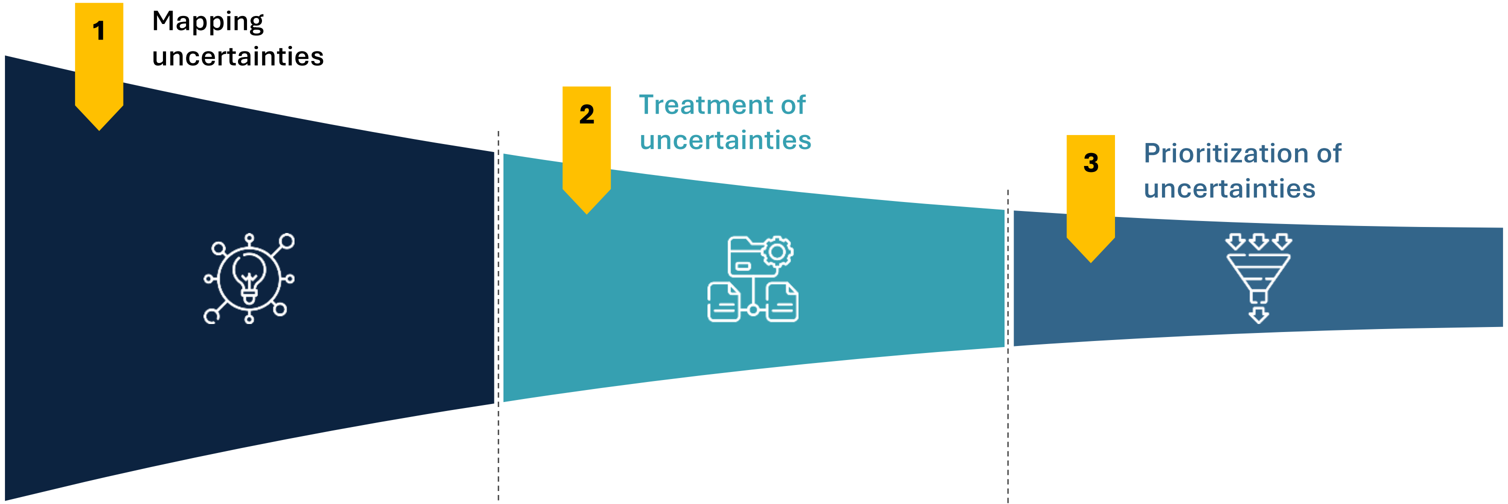
NOVA INDÚSTRIA BRASIL
FORTE, TRANSFORMADORA E SUSTENTÁVEL

Implications for the Brazilian energy system

- The level of policy coordination and integration is crucial for the success of the energy transition.
- Policies need to address the environmental impacts that may arise from the large-scale expansion of certain renewable energy sources.
- Manage and reconcile the interests of various sectors, often conflicting, to advance the energy transition process.
- Understand what our main objectives are, in the context of a developing country with numerous demands to be met.

After examining the major trends, we moved on to mapping the forces with a high level of uncertainty and significant impact on the national energy system until 2055 …

Uncertainties are fundamental for defining the logic of scenarios and are generally formulated as questions. So, what approach did PNE 2055 adopt for the process of mapping and prioritizing uncertainties?



1 Mapping uncertainties

2 Treatment of uncertainties

3 Prioritization of uncertainties

Broad process of mapping uncertainties:
- Dynamics with EPE's Advisory Council (Concepe).
- Interviews with EPE leadership.
- Workshops with external experts.
- Forms and questionnaires with EPE and MME collaborators.
- Other scenario studies.

Refinement and processing of the input list based on the discussions from workshops and interviews.

Step-by-step process for prioritizing uncertainties, applying the following techniques:
- Impact-Uncertainty Matrix.
- Motricity-Dependence Matrix or Structural Analysis.
- Morphological Matrix.

Internal workshops conducted by EPE to discuss uncertainties

1st Workshop – 03/11/2024
How will climate change impact the national energy system?

PNE 55
GT Cenários

Panelists
Representatives from EPE's technical areas

2nd Workshop – 3/15/2024
Poverty and energy justice: definitions, indicators, measures and governance

Convite Especial: Lançamento da Nota Técnica "Análise das Experiências Estatais Internacionais Relativas à Pobreza e Justiça Energética: Definições, Indicadores, Medidas e Governança"

O dia 15 de março foi escolhido por sua especial importância, pois marca o **vigésimo** aniversário da Lei que autorizou a criação da EPE. É a primeira ação para celebrarmos duas décadas de avanços e contribuições no setor energético e para refletirmos sobre os desafios presentes e futuros no caminho da justiça energética e da equidade social.

15.03.24 ÀS 9H30
AUDITORIO DA EPE E YOUTUBE

Panelists
Launch of the EPE Technical Note,with participation of panelists from EPE and MME

3rd Workshop – 3/25/2024
Net Zero: challenges and opportunities for Brazil

PNE 55
GT Cenários

Panelist
Túlio Andrade (Itamaraty)

4th Worshop – 4/3/2024
Transition of the oil & gas industry in Brazil

PNE 2055
GT Cenários

Panelists
Alexandre Szklo (COPPE/UFRJ)
Décio Oddone (Brava Energia)
Viviana Coelho (Petrobras)

5th Workshop – 4/11/2024
Pathways for Brazil in hard-to-abate sectors

PNE 2055
GT Cenários

Panelists
Darlan Santos (ANAC)
Fernando Costa (Brazilian Navy)
Fernando Salina (CSN)
Gonzalo Visedo (SNIC)

6th Workshop – 4/30/2024
Changes in the dynamics of the electric system in the context of the energy transition

PNE 2055
GT Cenários

Panelists
Bernardo Sicsú (Abraceel)
Christiano Vieira (ONS)
Jerson Kelman (UFRJ)
Joísa Dutra (FGV)
Paulo Pedrosa (Abrace)
Sinval Gama (Eletronuclear)

List of uncertainties for the National Energy System until 2055

	Uncertainties
01	What will be the **impacts of climate change** on the Brazilian energy system? Will the Brazilian energy system be flexible and resilient enough to handle **extreme weather events**?
02	How will Brazil **concile socio-economic development policies with the climate agenda?**
03	Will there be **sociopolitical consensus** to ensure governance and policy coherence in support of the energy transition?
04	Will there be the **capacity for coordination and integration among different public policies**, financing and governance mechanisms to support the energy transition?
05	How will **Brazil's development model** evolve? Will the country advance in global value chains and position itself as a sustainable industrial leader?
06	What will be the **impacts of innovation and technological advancements** on sustainable development?
07	How will **the relevant supply chains to Brazil's energy transition** evolve? How will the **production and technological dependency of these chains develop**?
08	How will **digital transformation** impact the national energy sector?
09	How will **financing for energy transition** expand in Brazil?
10	How will **regulation** for the development of low-carbon technologies and the **cost** of these technologies evolve?
11	What will be the strategy to address the planning and operation of a more decentralized power system with a high share of **variable renewable sources**?
12	Will it be possible to develop **flexible and resilient infrastructure and power grids** for the future electric system?
13	What will be the pace and intensity of **Distributed Energy Resources** (**DER**) **integration**, and what impacts will it have on the Brazilian energy system?
14	What will be the speed and intensity of **decarbonization in transportation and industry**?
15	How will **energy demand grow** in Brazil? How will **demographic and behavioral changes** affect it?
16	Will there be universal, reliable, modern, and affordable **access to energy**?
17	How will **energy poverty and inequality in energy consumption** evolve in Brazil?
18	Will **net zero** be effectively achieved in Brazil?
19	How will be the **exploration of new oil and gas frontiers** in Brazil?
20	How can Brazil's energy transition become a **driver for sustainable development** in the country?

4

Prioritization of uncertainties and development of the scenario logic

1. Impact-Uncertainty Matrix

What is it?

- A tool of prospective analysis that ranks key factors of the object to be analyzed in scenarios, based on two fundamental criteria: the degree of impact on the system-object, which in this case is the national energy system up to 2055 and the level of uncertainty.
- The higher the impact and uncertainty level of a given factor, the greater the need to consider it in scenario generation.

Starting point: A list of 43 uncertainties (questions) translated into **63 variables**.

These variables were analyzed based on the criteria of impact and uncertainty through a **form**.

GT Cenários PNE 2055 :
Priorização das incertezas

Dando continuidade ao nosso plano de trabalho, após o mapeamento preliminar de incertezas e o ciclo de Oficinas (que foi um sucesso!), chegou a hora de **priorizarmos as incertezas mais relevantes para o futuro do sistema energético nacional!**

Este formulário tem por objetivo hierarquizar as incertezas segundo dois critérios: **o grau de importância sobre o sistema-objeto** (que no nosso caso é o Sistema Energético Nacional até 2055) **e o nível de incerteza** em uma escala de 1 a 5, onde 1 representa "muito baixo" e 5 "muito alto".

Estimamos o tempo de resposta ao formulário em, aproximadamente, 30 a 45 minutos, sendo o deadline para o envio das respostas o final da reunião do GT, na próxima quinta-feira, 09/05 (15h30).

Antes de iniciar as respostas, sugerimos que você **revisite o escopo (quadro síntese) da cenarização e a planilha com a lista geral de incertezas e variáveis** que serão o foco deste questionário e que foram enviados por e-mail.

Agradecemos por seu tempo e apoio neste "filtro" coletivo! 😀

* Obrigatória

Página 1/2

1. Nome e diretoria *

Insira sua resposta

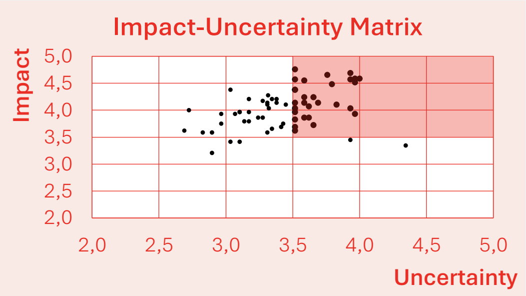
2. Impactos das mudanças climáticas sobre o sistema energético

	1 - Muito baixo	2 - Baixo	3 - Moderado	4 - Alto	5 - Muito alto
Grau de incerteza	○	○	○	○	○
Grau de importância	○	○	○	○	○

Compilation of **29 forms** answered by members of the Scenario Working Group, from both EPE and MME.

Plotting of factors on the Impact-Uncertainty Matrix.

Ranking and selection of a **reduced list of uncertainties**, which will be further analyzed in the subsequent prioritization stages.



2. Motricity-Dependence Matrix or Structural Analysis

What is it?

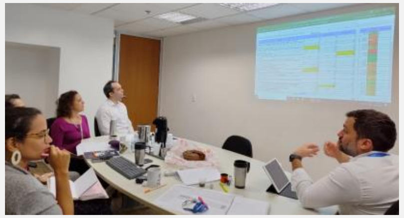
- It is a collective reflection tool that describes the "structure" of the relationships between the variables that characterize the studied system.
- Its objective is to highlight the main variables according to their degrees of motricity (influence) and dependence in relation to the system.
- Based on the Micmac Method developed by Michel Godet.

Step 1
Mapping of Variables
(derived from the Impact-Uncertainty Matrix)

Step 2
Explanation of the **direct relationships existing between the variables** using the Structural Analysis.

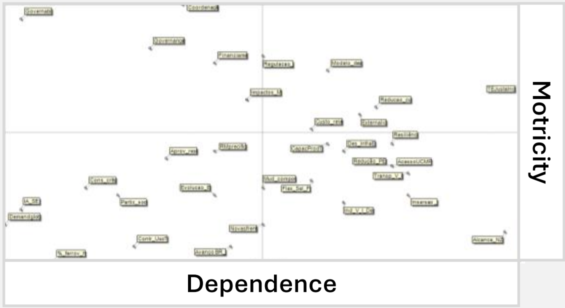
Influence on... / Influence of...	**Variables (Columns of the matrix)**	**Motricity**
Variables (rows of the matrix)	What is the level of influence of variable 'i' on variable 'j'?	
Dependence		

Step 3
Discussion and alignment dynamics



Step 4
Inputting results into the Micmac software

The Motricity-Dependence Matrix separates the variables into **4 groups**: the most driving, the linking, the resulting and the autonomous or independent ones.

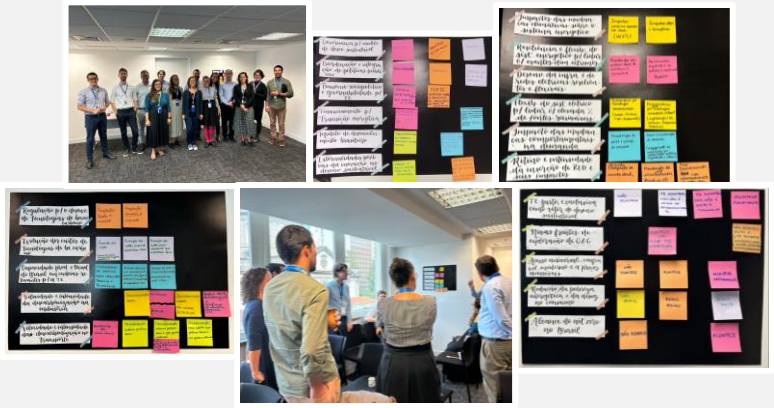


3. Morphological Matrix

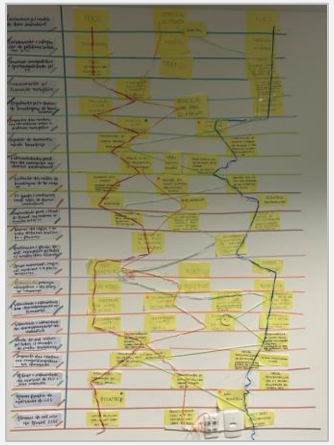
What is it?

- A technique that systematically configures possible scenarios for a given system, through the combination of different hypotheses about uncertainties, represented by variables related to this system.
- It highlights qualitatively distinct combinations.

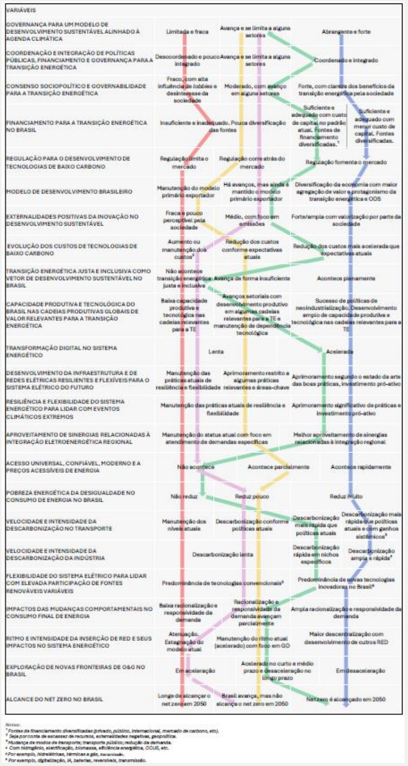
Group dynamics for constructing hypotheses (alternative future states) for a set of uncertainties defined in the previous stages.



Construction of the complete Morphological Matrix based on combinations of different hypotheses.



Digitization of the Morphological Matrix.



VARIÁVEIS				
GOVERNANÇA PARA UM MODELO DE DESENVOLVIMENTO SUSTENTÁVEL ALINHADO À AGENDA CLIMÁTICA	Limitada e fraca	Avança e se limita a alguns setores	Abrangente e forte	
COORDENAÇÃO E INTEGRAÇÃO DE POLÍTICAS PÚBLICAS, FINANCIAMENTO E GOVERNANÇA PARA A TRANSIÇÃO ENERGÉTICA	Descoordenado e pouco integrado	Avança e se limita a alguns setores	Coordenado e integrado	
CONSENSO SOCIOPOLÍTICO E GOVERNABILIDADE PARA A TRANSIÇÃO ENERGÉTICA	Fraco, com alta influência de lobbies e desinteresse da sociedade	Moderado, com avanço em alguns setores	Forte, com clareza dos benefícios da transição energética pela sociedade	
FINANCIAMENTO PARA A TRANSIÇÃO ENERGÉTICA NO BRASIL	Insuficiente e inadequado. Pouca diversificação das fontes		Suficiente e adequado com custo de capital no padrão atual. Fontes de financiamento diversificadas.[1]	Suficiente e adequado com menor custo de capital. Fontes diversificadas.
REGULAÇÃO PARA O DESENVOLVIMENTO DE TECNOLOGIAS DE BAIXO CARBONO	Regulação limita o mercado	Regulação corre atrás do mercado	Regulação fomenta o mercado	
MODELO DE DESENVOLVIMENTO BRASILEIRO	Manutenção do modelo primário exportador	Há avanços, mas ainda é mantido o modelo primário exportador	Diversificação da economia com maior agregação de valor e protagonismo da transição energética e ODS	
EXTERNALIDADES POSITIVAS DA INOVAÇÃO NO DESENVOLVIMENTO SUSTENTÁVEL	Fraca e pouco perceptível pela sociedade	Médio, com foco em emissões	Forte/ampla com valorização por parte da sociedade	
EVOLUÇÃO DOS CUSTOS DE TECNOLOGIAS DE BAIXO CARBONO	Aumento ou manutenção dos custos[2]	Redução dos custos conforme expectativas atuais	Redução dos custos mais acelerada que expectativas atuais	
TRANSIÇÃO ENERGÉTICA JUSTA E INCLUSIVA COMO VETOR DE DESENVOLVIMENTO SUSTENTÁVEL NO BRASIL	Não acontece transição energética justa e inclusiva	Avança de forma insuficiente	Acontece plenamente	
CAPACIDADE PRODUTIVA E TECNOLÓGICA DO BRASIL NAS CADEIAS PRODUTIVAS GLOBAIS DE VALOR RELEVANTES PARA A TRANSIÇÃO ENERGÉTICA	Baixa capacidade produtiva e tecnológica nas cadeias relevantes para a TE	Avanços setoriais com desenvolvimento produtivo em algumas cadeias relevantes para a TE e manutenção de dependência tecnológica	Sucesso de políticas de neoindustrialização. Desenvolvimento amplo de capacidade produtiva e tecnológica nas cadeias relevantes para a TE	
TRANSFORMAÇÃO DIGITAL NO SISTEMA ENERGÉTICO	Lenta		Acelerada	
DESENVOLVIMENTO DA INFRAESTRUTURA E DE REDES ELÉTRICAS RESILIENTES E FLEXÍVEIS PARA O SISTEMA ELÉTRICO DO FUTURO	Manutenção das práticas atuais de resiliência e flexibilidade	Aprimoramento restrito a algumas práticas relevantes e áreas-chave	Aprimoramento segundo o estado da arte das boas práticas, investimento pró-ativo	
RESILIÊNCIA E FLEXIBILIDADE DO SISTEMA ENERGÉTICO PARA LIDAR COM EVENTOS CLIMÁTICOS EXTREMOS	Manutenção das práticas atuais de resiliência e flexibilidade		Aprimoramento significativo de práticas e investimento pró-ativo	
APROVEITAMENTO DE SINERGIAS RELACIONADAS À INTEGRAÇÃO ELETROENERGÉTICA REGIONAL	Manutenção do status atual com foco em atendimento de demandas específicas		Melhor aproveitamento de sinergias relacionadas à integração regional	
ACESSO UNIVERSAL, CONFIÁVEL, MODERNO E A PREÇOS ACESSÍVEIS DE ENERGIA	Não acontece	Acontece parcialmente	Acontece rapidamente	
POBREZA ENERGÉTICA DA DESIGUALDADE NO CONSUMO DE ENERGIA NO BRASIL	Não reduz	Reduz pouco	Reduz muito	
VELOCIDADE E INTENSIDADE DA DESCARBONIZAÇÃO NO TRANSPORTE	Manutenção dos níveis atuais	Descarbonização conforme políticas atuais	Descarbonização mais rápida que políticas atuais	Descarbonização mais rápida que políticas atuais e com ganhos sistêmicos[3]
VELOCIDADE E INTENSIDADE DA DESCARBONIZAÇÃO DA INDÚSTRIA	Descarbonização lenta		Descarbonização rápida em nichos específicos	Descarbonização ampla e rápida[4]
FLEXIBILIDADE DO SISTEMA ELÉTRICO PARA LIDAR COM ELEVADA PARTICIPAÇÃO DE FONTES RENOVÁVEIS VARIÁVEIS	Predominância de tecnologias convencionais[5]		Predominância de novas tecnologias inovadoras no Brasil[6]	
IMPACTOS DAS MUDANÇAS COMPORTAMENTAIS NO CONSUMO FINAL DE ENERGIA	Baixa racionalização e responsividade da demanda	Racionalização e responsividade da demanda avançam parcialmente	Ampla racionalização e responsividade da demanda	
RITMO E INTENSIDADE DA INSERÇÃO DE RED E SEUS IMPACTOS NO SISTEMA ENERGÉTICO	Atenuação. Estagnação do modelo atual	Manutenção do ritmo atual (acelerado) com foco em GD	Maior descentralização com desenvolvimento de outros RED	
EXPLORAÇÃO DE NOVAS FRONTEIRAS DE O&G NO BRASIL	Em aceleração	Acelerado no curto e médio prazo e desaceleração no longo prazo	Em desaceleração	
ALCANCE DO NET ZERO NO BRASIL	Longe de alcançar o net zero em 2050	Brasil avança, mas não alcança o net zero em 2050	Net zero é alcançado em 2050	

Notas:

[1] Fontes de financiamento diversificadas (privado, público, internacional, mercado de carbono, etc).

[2] Seja por conta de escassez de recursos, externalidades negativas, geopolítica.

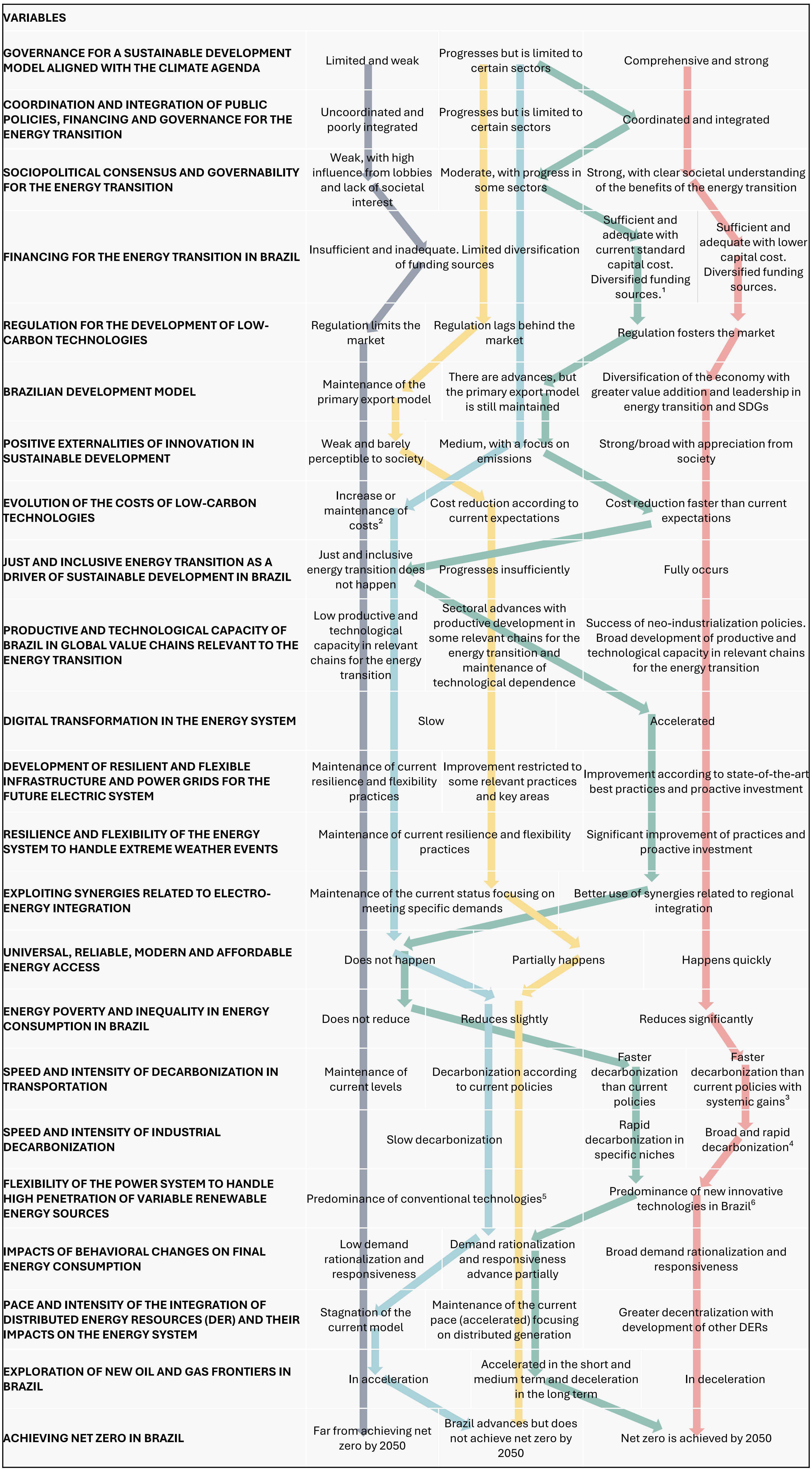
[3] Mudança de modos de transporte; transporte público; redução de demanda.

[4] Com hidrogênio, eletrificação, biomassa, eficiência energética, CCUS, etc.

[5] Por exemplo, hidrelétricas, térmicas a gás, [illegible]

[6] Por exemplo, digitalização, IA, baterias, reversíveis, transmissão.

3. Morphological Matrix



VARIABLES				
GOVERNANCE FOR A SUSTAINABLE DEVELOPMENT MODEL ALIGNED WITH THE CLIMATE AGENDA	Limited and weak	Progresses but is limited to certain sectors	Comprehensive and strong	
COORDINATION AND INTEGRATION OF PUBLIC POLICIES, FINANCING AND GOVERNANCE FOR THE ENERGY TRANSITION	Uncoordinated and poorly integrated	Progresses but is limited to certain sectors	Coordinated and integrated	
SOCIOPOLITICAL CONSENSUS AND GOVERNABILITY FOR THE ENERGY TRANSITION	Weak, with high influence from lobbies and lack of societal interest	Moderate, with progress in some sectors	Strong, with clear societal understanding of the benefits of the energy transition	
FINANCING FOR THE ENERGY TRANSITION IN BRAZIL	Insufficient and inadequate. Limited diversification of funding sources		Sufficient and adequate with current standard capital cost. Diversified funding sources.[1]	Sufficient and adequate with lower capital cost. Diversified funding sources.
REGULATION FOR THE DEVELOPMENT OF LOW-CARBON TECHNOLOGIES	Regulation limits the market	Regulation lags behind the market	Regulation fosters the market	
BRAZILIAN DEVELOPMENT MODEL	Maintenance of the primary export model	There are advances, but the primary export model is still maintained	Diversification of the economy with greater value addition and leadership in energy transition and SDGs	
POSITIVE EXTERNALITIES OF INNOVATION IN SUSTAINABLE DEVELOPMENT	Weak and barely perceptible to society	Medium, with a focus on emissions	Strong/broad with appreciation from society	
EVOLUTION OF THE COSTS OF LOW-CARBON TECHNOLOGIES	Increase or maintenance of costs[2]	Cost reduction according to current expectations	Cost reduction faster than current expectations	
JUST AND INCLUSIVE ENERGY TRANSITION AS A DRIVER OF SUSTAINABLE DEVELOPMENT IN BRAZIL	Just and inclusive energy transition does not happen	Progresses insufficiently	Fully occurs	
PRODUCTIVE AND TECHNOLOGICAL CAPACITY OF BRAZIL IN GLOBAL VALUE CHAINS RELEVANT TO THE ENERGY TRANSITION	Low productive and technological capacity in relevant chains for the energy transition	Sectoral advances with productive development in some relevant chains for the energy transition and maintenance of technological dependence	Success of neo-industrialization policies. Broad development of productive and technological capacity in relevant chains for the energy transition	
DIGITAL TRANSFORMATION IN THE ENERGY SYSTEM	Slow		Accelerated	
DEVELOPMENT OF RESILIENT AND FLEXIBLE INFRASTRUCTURE AND POWER GRIDS FOR THE FUTURE ELECTRIC SYSTEM	Maintenance of current resilience and flexibility practices	Improvement restricted to some relevant practices and key areas	Improvement according to state-of-the-art best practices and proactive investment	
RESILIENCE AND FLEXIBILITY OF THE ENERGY SYSTEM TO HANDLE EXTREME WEATHER EVENTS	Maintenance of current resilience and flexibility practices		Significant improvement of practices and proactive investment	
EXPLOITING SYNERGIES RELATED TO ELECTRO-ENERGY INTEGRATION	Maintenance of the current status focusing on meeting specific demands		Better use of synergies related to regional integration	
UNIVERSAL, RELIABLE, MODERN AND AFFORDABLE ENERGY ACCESS	Does not happen	Partially happens	Happens quickly	
ENERGY POVERTY AND INEQUALITY IN ENERGY CONSUMPTION IN BRAZIL	Does not reduce	Reduces slightly	Reduces significantly	
SPEED AND INTENSITY OF DECARBONIZATION IN TRANSPORTATION	Maintenance of current levels	Decarbonization according to current policies	Faster decarbonization than current policies	Faster decarbonization than current policies with systemic gains[3]
SPEED AND INTENSITY OF INDUSTRIAL DECARBONIZATION	Slow decarbonization		Rapid decarbonization in specific niches	Broad and rapid decarbonization[4]
FLEXIBILITY OF THE POWER SYSTEM TO HANDLE HIGH PENETRATION OF VARIABLE RENEWABLE ENERGY SOURCES	Predominance of conventional technologies[5]		Predominance of new innovative technologies in Brazil[6]	
IMPACTS OF BEHAVIORAL CHANGES ON FINAL ENERGY CONSUMPTION	Low demand rationalization and responsiveness	Demand rationalization and responsiveness advance partially	Broad demand rationalization and responsiveness	
PACE AND INTENSITY OF THE INTEGRATION OF DISTRIBUTED ENERGY RESOURCES (DER) AND THEIR IMPACTS ON THE ENERGY SYSTEM	Stagnation of the current model	Maintenance of the current pace (accelerated) focusing on distributed generation	Greater decentralization with development of other DERs	
EXPLORATION OF NEW OIL AND GAS FRONTIERS IN BRAZIL	In acceleration	Accelerated in the short and medium term and deceleration in the long term	In deceleration	
ACHIEVING NET ZERO IN BRAZIL	Far from achieving net zero by 2050	Brazil advances but does not achieve net zero by 2050	Net zero is achieved by 2050	

Notes:

[1] Diversified sources of financing (private, public, international, carbon market, etc).

[2] Due to resource scarcity, negative externalities, geopolitics.

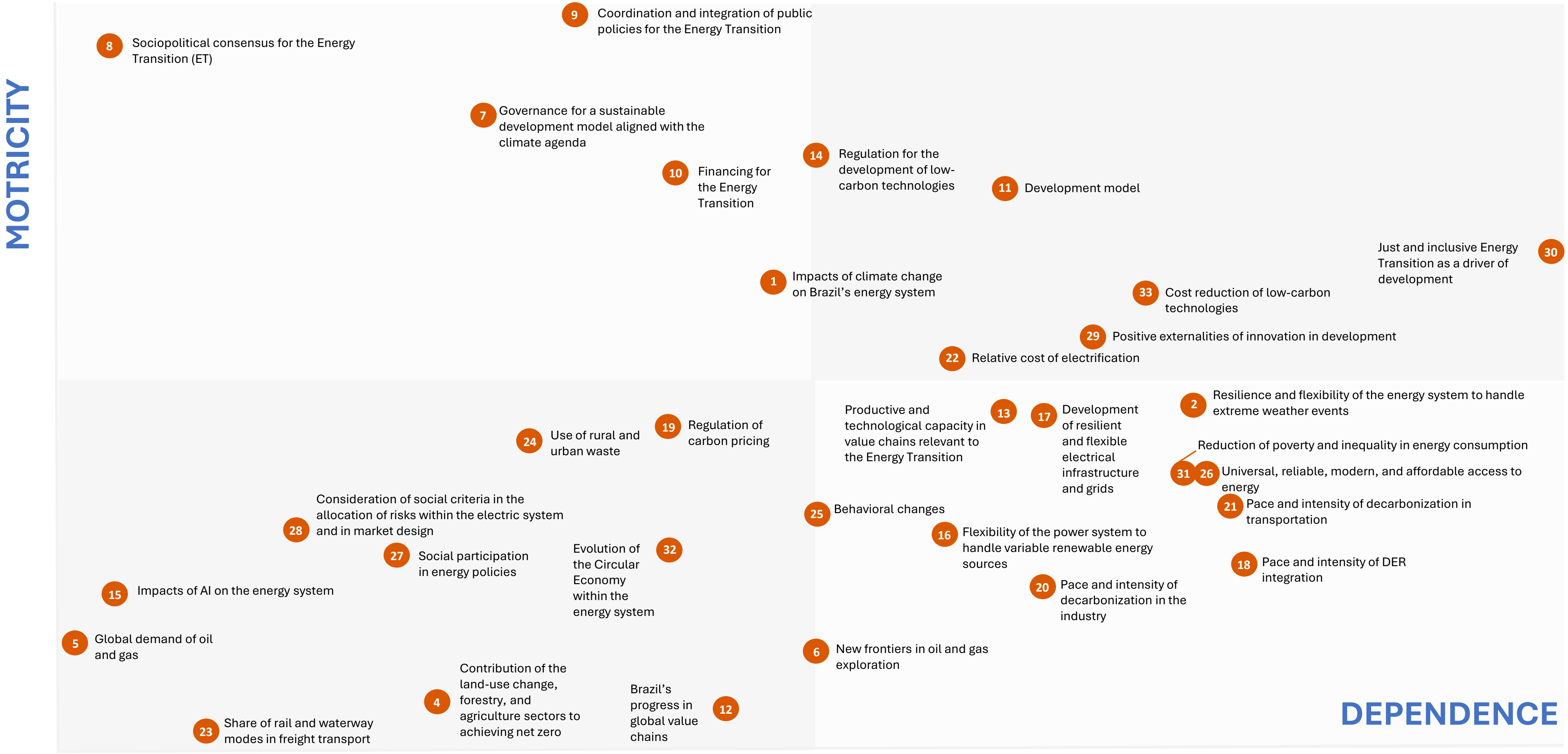
[3] Changes in modes of transport; public transportation; demand reduction.

[4] With hydrogen, electrification, biomass, energy efficiency, CCUS (Carbon Capture, Utilization, and Storage), etc.

[5] For example, hydropower plants, gas-fired thermal plants, transmission.

[6] For example, digitalization, AI, reversible batteries, transmission.

Results of the Structural Analysis



8 Sociopolitical consensus for the Energy Transition (ET)

9 Coordination and integration of public policies for the Energy Transition

7 Governance for a sustainable development model aligned with the climate agenda

10 Financing for the Energy Transition

14 Regulation for the development of low-carbon technologies

11 Development model

30 Just and inclusive Energy Transition as a driver of development

1 Impacts of climate change on Brazil's energy system

33 Cost reduction of low-carbon technologies

29 Positive externalities of innovation in development

22 Relative cost of electrification

24 Use of rural and urban waste

19 Regulation of carbon pricing

28 Consideration of social criteria in the allocation of risks within the electric system and in market design

27 Social participation in energy policies

32 Evolution of the Circular Economy within the energy system

15 Impacts of AI on the energy system

5 Global demand of oil and gas

4 Contribution of the land-use change, forestry, and agriculture sectors to achieving net zero

12 Brazil's progress in global value chains

23 Share of rail and waterway modes in freight transport

13 Productive and technological capacity in value chains relevant to the Energy Transition

17 Development of resilient and flexible electrical infrastructure and grids

2 Resilience and flexibility of the energy system to handle extreme weather events

31 Reduction of poverty and inequality in energy consumption

26 Universal, reliable, modern, and affordable access to energy

21 Pace and intensity of decarbonization in transportation

25 Behavioral changes

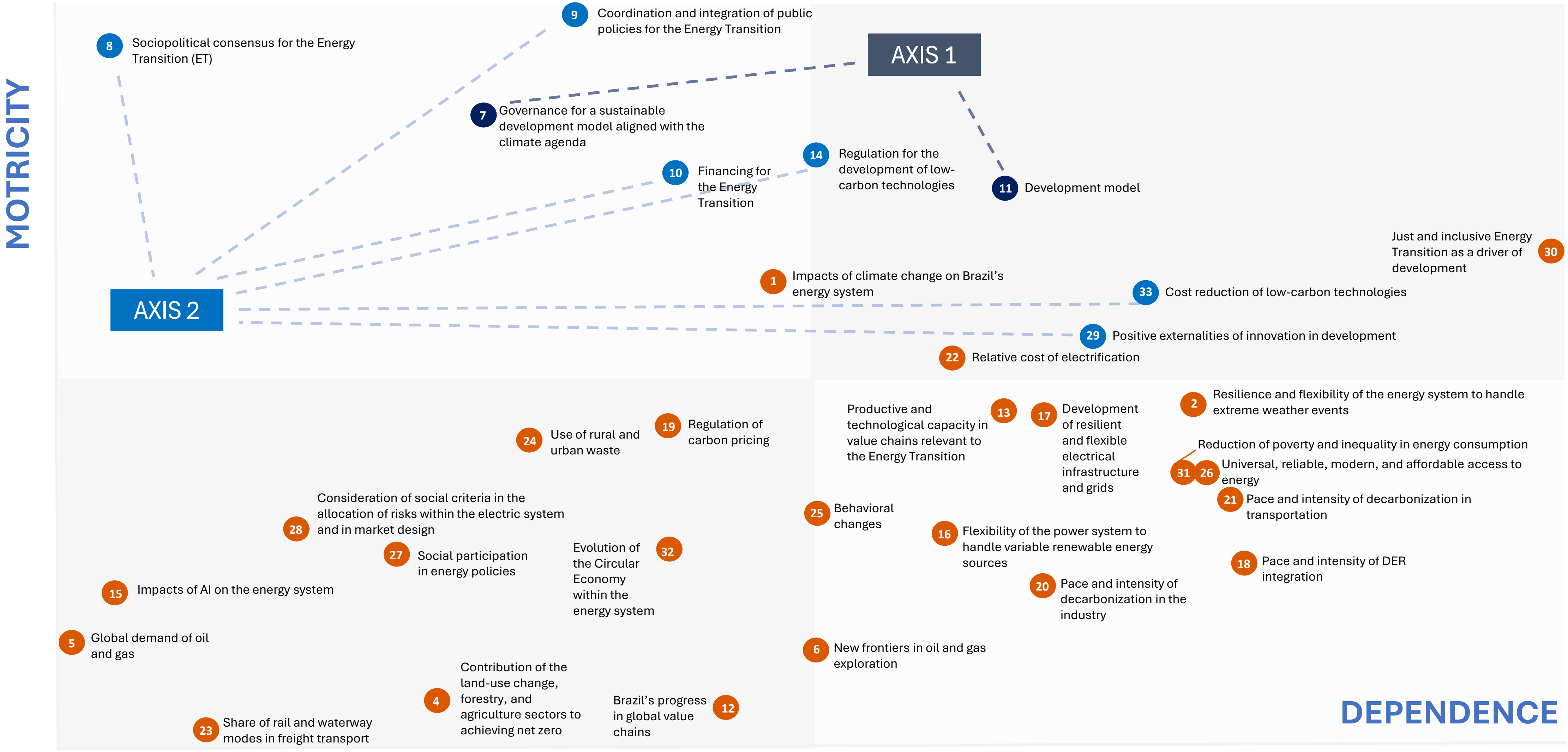
16 Flexibility of the power system to handle variable renewable energy sources

18 Pace and intensity of DER integration

20 Pace and intensity of decarbonization in the industry

6 New frontiers in oil and gas exploration

Results of the Structural Analysis



MOTRICITY

AXIS 1

AXIS 2

8 Sociopolitical consensus for the Energy Transition (ET)

9 Coordination and integration of public policies for the Energy Transition

7 Governance for a sustainable development model aligned with the climate agenda

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6 New frontiers in oil and gas exploration

DEPENDENCE

The variables represented in the structural matrix reflect the uncertainties considered in the process.

Results of the Structural Analysis: definition of axes

Based on the results obtained from the Structural Analysis, as represented on the previous page, variables with a high level of influence were selected to construct the scenario axes for the PNE 2055 energy outlook. These axes are of critical importance as they facilitate the understanding of the scenario logic by simplifying the **visualization of key differences among the scenarios.**

Axis 1 represents **Governance for a sustainable development model aligned with the climate agenda**, which can take two states: "limited and weak" or "comprehensive and strong."

Axis 2 represents **Enabling factors for the energy transition**, encompassing variables such as the costs and regulation of low-carbon technologies, the coordination and integration of policies for the energy transition, among others. These factors can also take two states: "insufficient and fragmented" or "effective and integrated."

Figure 26: Energy Scenario Axes for PNE 2055

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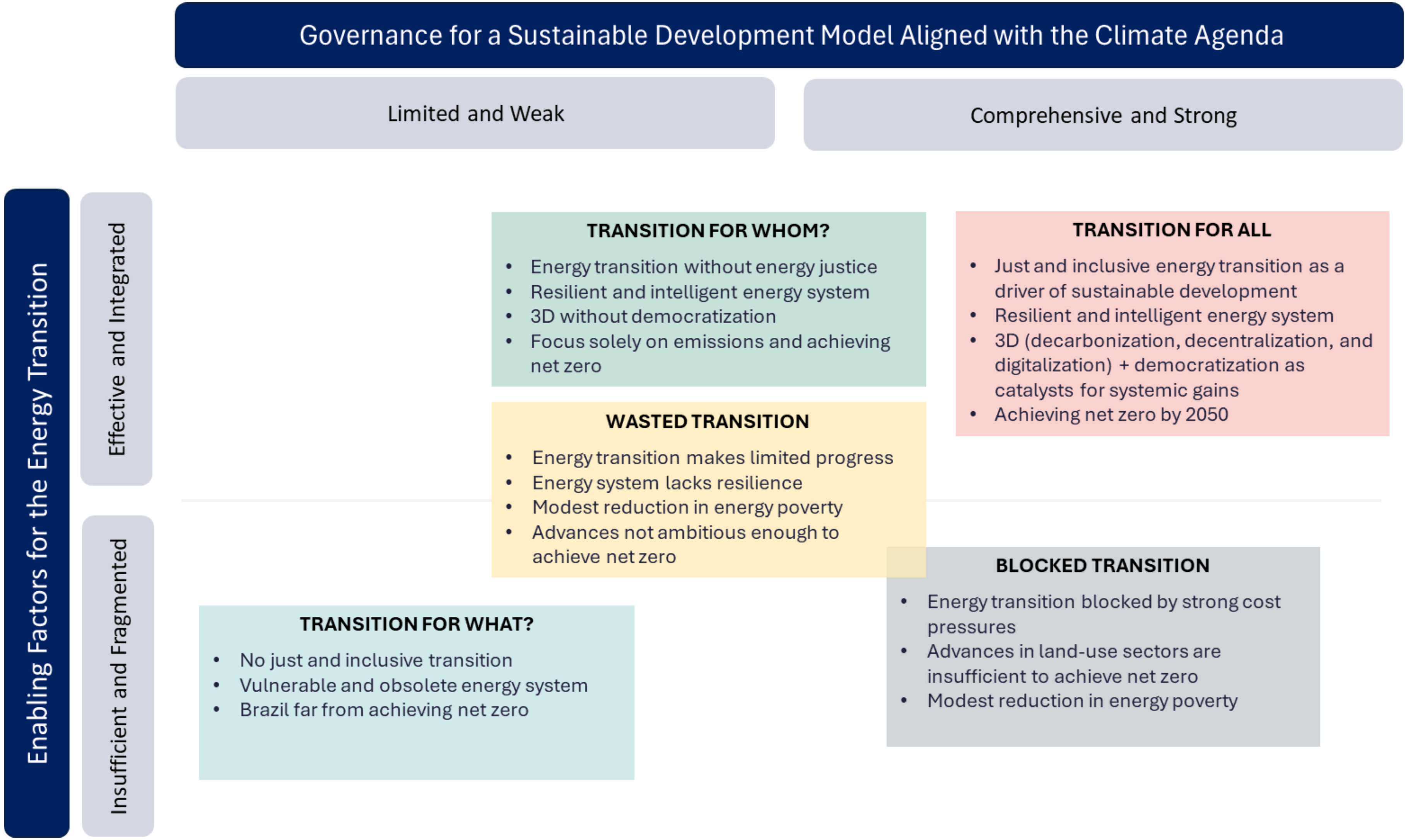
[3] The variables represented in the Structural Matrix reflect the uncertainties considered in the process.

The logic of energy scenarios



Governance for a Sustainable Development Model Aligned with the Climate Agenda

Limited and Weak

Comprehensive and Strong

Enabling Factors for the Energy Transition

Effective and Integrated

Insufficient and Fragmented

TRANSITION FOR WHOM?

- Energy transition without energy justice
- Resilient and intelligent energy system
- 3D without democratization
- Focus solely on emissions and achieving net zero

TRANSITION FOR ALL

- Just and inclusive energy transition as a driver of sustainable development
- Resilient and intelligent energy system
- 3D (decarbonization, decentralization, and digitalization) + democratization as catalysts for systemic gains
- Achieving net zero by 2050

WASTED TRANSITION

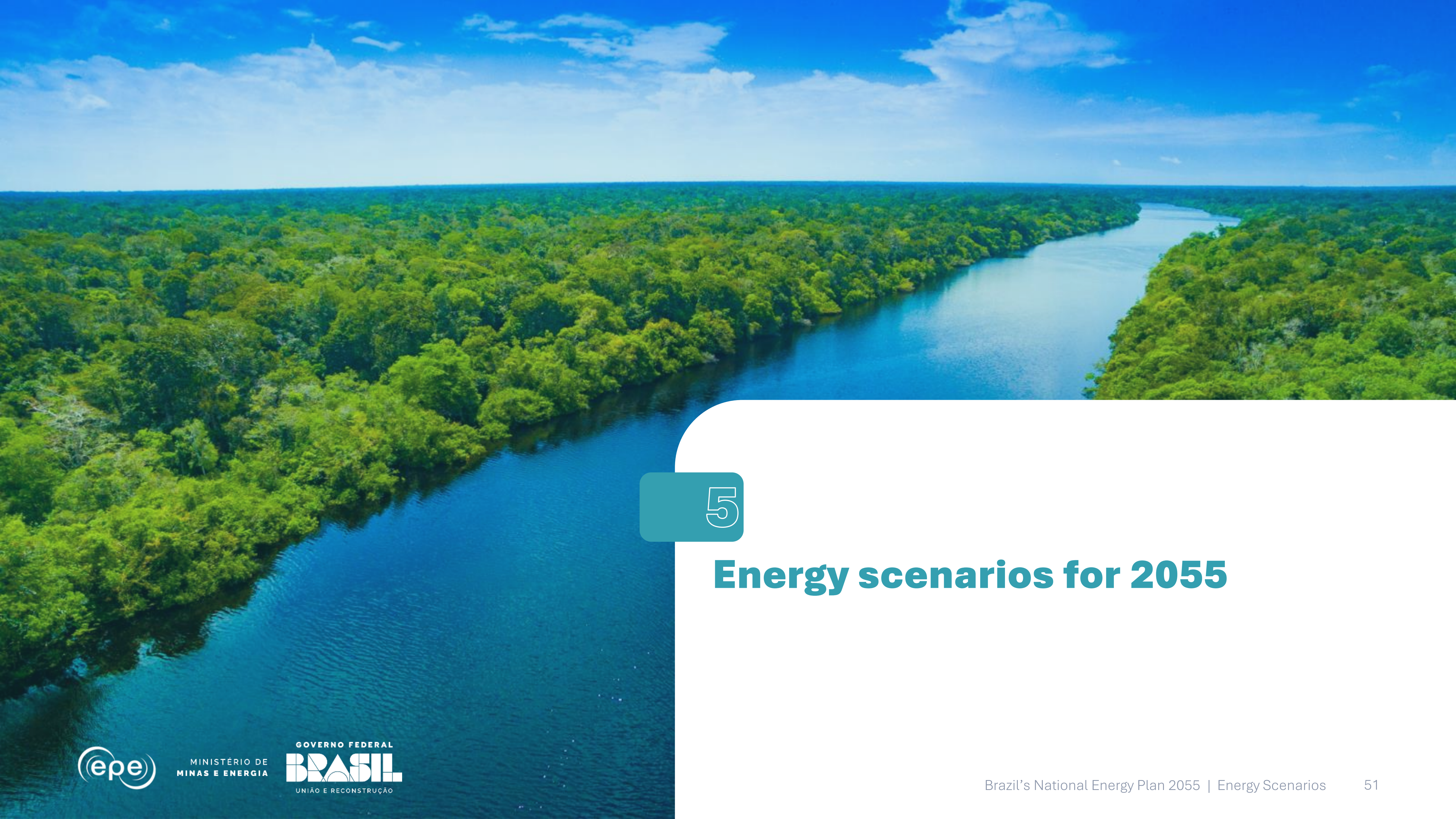
- Energy transition makes limited progress
- Energy system lacks resilience
- Modest reduction in energy poverty
- Advances not ambitious enough to achieve net zero

TRANSITION FOR WHAT?

- No just and inclusive transition
- Vulnerable and obsolete energy system
- Brazil far from achieving net zero

BLOCKED TRANSITION

- Energy transition blocked by strong cost pressures
- Advances in land-use sectors are insufficient to achieve net zero
- Modest reduction in energy poverty



5

Energy scenarios for 2055

C1 – Transition for all

Imagine a future where ...

Brazil's climate ambition aligns with the commitments under the Paris Agreement and climate neutrality goals – net zero greenhouse gas emissions by 2050 – to limit global warming.

Strong and comprehensive governance was reinforced during and after international events hosted by the country (G20, COP, BRICS) in the 2020s. The increasing frequency and severity of extreme climate events also spurred extensive interministerial mobilization in this direction.

Anchored in a shared vision of the future and the integration of planning instruments, this mobilization was also supported by a **more aware, critical and participatory society**, stemming from advancements in Brazilian education. This context significantly contributed to the **alignment between Brazil’s climate agenda and a clear sustainable development strategy for the country**. As a result, **Brazil's energy transition progressed synergistically with this strategy, fostering diversification and structural change in the country's development.**

The supply chains relevant to the energy transition – including renewable energy, hydrogen, bioeconomy, strategic minerals, carbon capture and storage technologies, among others – **were strengthened in their productive and technological capacities**, reducing external dependency and internalizing the benefits to foster the country’s development. **Quality jobs, income generation, wealth distribution and improvements in the export portfolio, with a greater share of higher value-added goods and services**, are some examples of these benefits, driven by various programs and instruments focused on innovation, industrialization and capacity building.

The pursuit of greater value-added production would not have been possible without other enabling factors, such as **coordination among various policies for the energy transition, financing and strong regulation that promotes low-carbon technologies.**

The diversification of financing instruments, such as funds and international concessional loans, public and private investments in energy innovation, carbon pricing, and the effective implementation of a sustainable taxonomy (aligned with Brazil’s energy potential), coupled with the coordination of political actions around the energy transition, contributed to lowering the cost of capital in the country.

C1 – Transition for all

This spurred and directed **investments toward a low-carbon economy, respecting and developing the country's national energy potential while reducing socioeconomic inequality.** Additionally, there was a significant increase in the focus on measuring the costs and benefits of the energy transition across the three pillars of sustainability – economic, social, and environmental – as well as a greater societal awareness and understanding of these impacts.

In a consensual and coordinated manner, **the energy transition initiated a process of changes across multiple fronts.** Proactive investments in **smart infrastructure and innovative technologies**, aimed at addressing both the growth of variable renewable energy sources and the increasing frequency of extreme climate events, enhanced the resilience and flexibility of Brazil's energy system. Key developments included the **acceleration of decarbonization processes in both transportation and industry, the scaling up of distributed energy resources** (beyond solar distributed generation, encompassing other types of distributed generation, self-generation of energy, energy efficiency, and demand response), **greater consumer protagonism and responsiveness**, and, fundamentally, the **eradication of energy poverty and the reduction of inequality in energy consumption in Brazil** (a state-level commitment made by Brazil in the 2020s).

The extensive utilization of Brazil's diverse energy resources (with an emphasis on low-carbon options), combined with a circular economy perspective within the energy system, enabled **improved management of rural and urban waste, generating positive externalities at regional and local levels.**

In a context of reduced global oil demand and significantly lower costs for low-carbon technologies, **the oil and gas sector underwent a profound transformation, redirecting its expertise toward a low-carbon economy.** In this scenario, domestic supply peaked in the 2030s, with a slowdown in the exploration of new frontiers during this period. With greater rationalization and effectiveness in its use, **oil revenues were more effectively allocated to fostering low-carbon technologies and enhancing their impacts on sustainable development for the benefit of society as a whole.**

At the regional level, **electro-energy integration was able to effectively leverage synergies and opportunities**, going beyond specific and emergency situations. The successful energy integration in South America delivered a wide range of benefits.

Energy security was significantly strengthened through the diversification of supply sources and increased system reliability. System efficiency was enhanced, enabling energy resources from one country to meet demand in another in a mutually beneficial relationship. Moreover, the integration contributed to reducing energy prices, thanks to economies of scale, market access, and efficiency gains, making energy more affordable. Finally, the creation of synergies with strategic projects stimulated infrastructure development and cross-sector partnerships, fostering sustainable growth and comprehensive regional integration. In this way, **Brazil also contributed to strengthening cooperation and achieving a higher level of market integration in the region, further highlighting its regional leadership.**

Finally, **Brazil met its climate commitments with gradual and increasingly ambitious emission reduction targets, achieving climate neutrality even before 2050.** As a result, the country presented at COP 2055 the outcomes of a just and inclusive energy transition, centered on wealth distribution, which successfully transformed comparative advantages into tangible benefits for society while reinforcing its leadership on the international climate agenda.

C2 – Transition for whom?

Imagine a future where ...

Over the past 30 years, **progress has been made in governance aimed at a development model focused on reducing emissions.** However, these advancements have been concentrated in specific sectors, without resulting in a sustainable development trajectory encompassing the economic, environmental and social pillars. As such, **Brazil is now a low-carbon economy**, achieved through the integration and coordination of policies for the energy transition and advancements in building a sociopolitical consensus for such a shift. **However, the country still faces the social challenges of the past.**

In this context, **the energy transition occurred with some gains for society but without social justice.** This is evident in the **persistence of energy poverty** and the significant number of households without access to reliable, modern, and affordable energy.

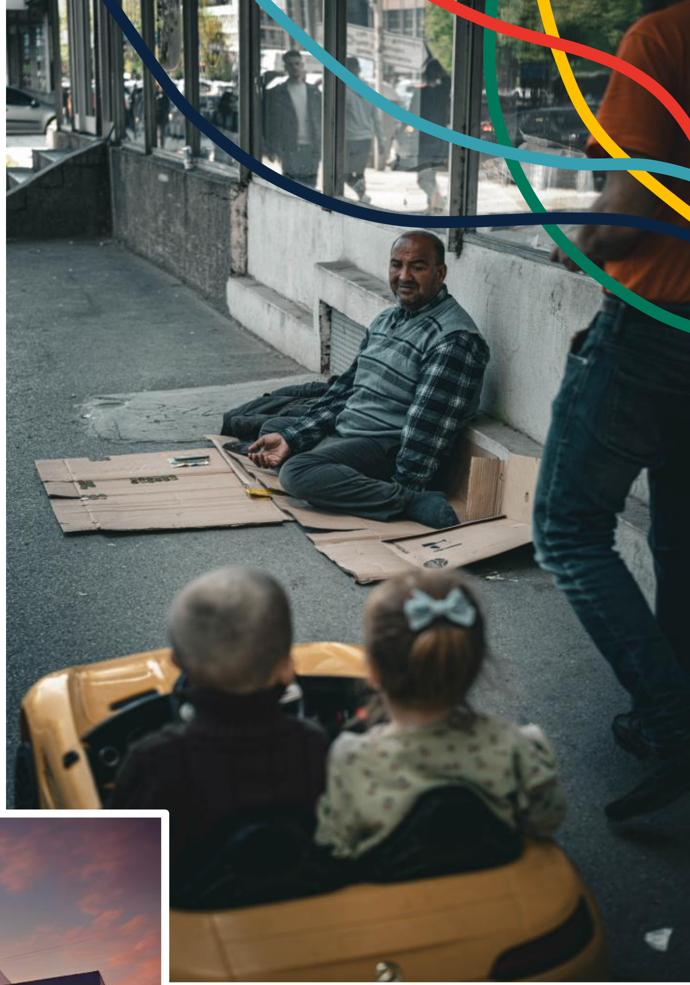
The intensification of subsidy policies for technologies that were already mature led to distortions and negatively impacted the final consumer prices. Thus, inequality in electricity consumption among different income classes and regions of the country exemplifies the persistence of social vulnerabilities within a **dual energy system – on one hand, lagging in its social dimension, and on the other, cost-efficient in its trajectory toward climate neutrality.**

C2 – Transition for whom?

The race for decarbonization in transportation and industry, along with significant improvements in infrastructure, resilience, and flexibility of the national energy system, was largely driven by a **substantial reduction in the costs of low-carbon technologies.** However, external pressures led to the adoption of certain technological options that were not necessarily the most suitable for the Brazilian context, requiring greater investment in new infrastructures and resulting in **some technological lock-ins, making the transition more costly for the country.** These factors created a more **favorable environment for the development and diffusion of new technologies, supported by subsidies**, which utilized local energy resources only partially and compromised the achievement of climate neutrality. For instance, biomass with carbon capture and storage (BECCS) as a strategy for achieving negative emissions in the energy sector developed only partially.

These advancements, combined with the **eradication of illegal deforestation in Brazil before 2030** and the **reduced costs of carbon capture and storage (CCS) technologies**, gave momentum to the path toward climate neutrality and provided room for accelerating the exploration of new oil and gas frontiers until the late 2030s, followed by a deceleration.

At COP 2055, Brazil faced criticism for, despite efficiently achieving climate neutrality by 2050, failing to drive more structural changes in its economy – which remained reliant on a primary export model and somewhat dependent on external technologies – through an energy transition that moved away from fossil fuels and away from its people.



C3 – Wasted transition

Imagine a future where ...

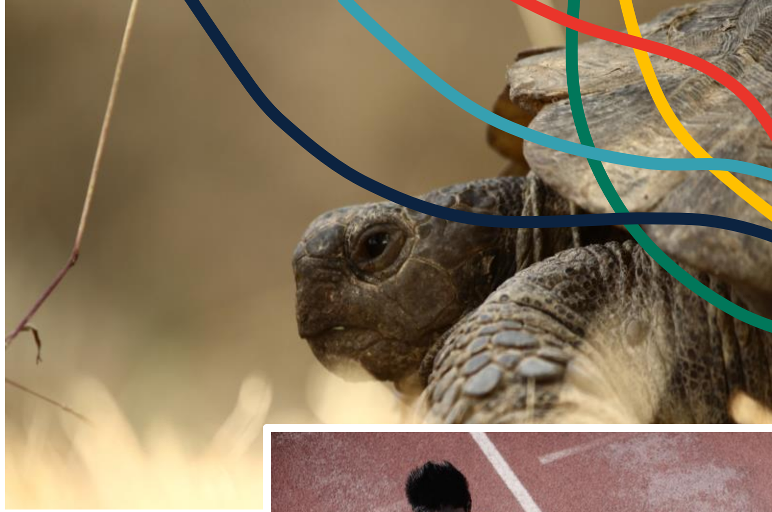
Brazil progressed slowly in building a set of public policies aimed at a sustainable development model aligned with the climate agenda. These policies achieved positive sectoral results in supply chains where the country was already established, particularly those with clear comparative advantages, such as biofuels. Advancements in these sectors were supported by a certain level of sociopolitical consensus and **moderate policy coordination and integration**, which resulted in a modest increase in the productive capacity of these supply chains.

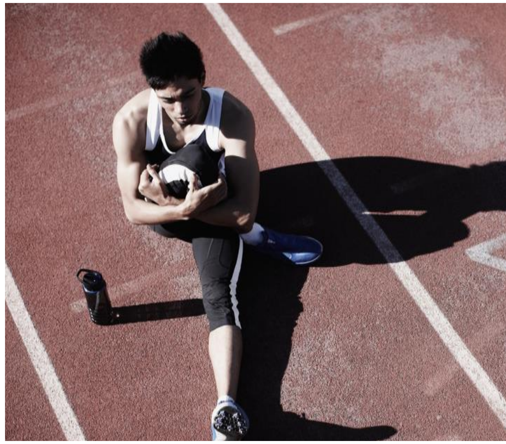
However, the outcomes of this governance were not comprehensive, with limited success in developing national productive and technological capacity in innovative chains relevant to the energy transition. Despite the gradual reduction in the costs of low-carbon technologies, financing was insufficient and inadequate, and regulation was reactive. As a result, **decarbonization in hard-to-abate sectors progressed slowly**, and the country failed to meet its commitment to achieve net zero greenhouse gas emissions by 2050.

Thus, **Brazil's economic development remained heavily reliant on a primary export model.** In the energy sector, this pattern was evident in the development of large hydrogen production projects aimed at the international market, with limited progress in value-added segments of the chain and a high dependency on imported technology.

In this context, Brazil made limited progress toward its Sustainable Development Goals (SDGs). Specifically, regarding SDG 7, **there was minimal reduction in energy poverty, and universal, reliable, modern, and affordable energy access was not fully achieved.** Consequently, the just and inclusive energy transition as a driver of sustainable development advanced only partially.

Despite the increasing frequency and intensity of extreme climate events, **measures to enhance the resilience of the national energy system were not significantly strengthened.** As a result, there was no substantial adoption of modern technologies to provide flexibility and resilience in grid operations or to increase storage capacity, leaving conventional technologies predominant. This characteristic led to higher operational costs, preventing a more efficient utilization of the system. Nonetheless, there were some **isolated improvements in the development of specific areas.**





C3 – Wasted transition

Fossil fuels remained the dominant sources in the global primary energy supply. However, their share in the global energy mix has been gradually decreasing since the 2020s, driven by the increasing competitiveness of renewable sources. In this context, **Brazil continues to be a major producer and exporter of oil and has experienced a significant increase in natural gas production, reducing its external dependency on this resource.** The national oil industry was primarily driven by the exploration of new frontiers during the 2020s and 2030s.However, starting in the 2040s, the decline in global oil demand limited the development of new large-scale oil and gas projects in the country.

C4 – Transition for what?

Imagine a future where ...

A weak and limited governance for a development model aligned with the climate agenda has hindered a more structural transformation of the Brazilian economy. This has **prevented the country from leveraging the climate agenda and the energy transition as a differential in its development strategy.**

As a result, the Brazilian economy has not advanced in key sectors relevant to the energy transition, remaining reliant on foreign technology and preserving its primary export model, with a significant share of commodities in its export portfolio, including oil.

Despite a global context of heightened concern over climate change, **Brazil has made limited progress in the energy transition and failed to meet its global climate commitments, such as achieving climate neutrality by 2050**. This shortfall is largely due to a lack of clear sociopolitical consensus and the strong influence of lobbying, particularly from the agribusiness and fossil fuel sectors. This absence of consensus has translated into **inadequate coordination and integration of public policies for the energy transition, undermining the country's progression toward a low-carbon economy.**

The energy transition process was further constrained by regulatory issues and the high costs associated with low-carbon technologies. The regulatory framework did not evolve to foster the widespread adoption of these technologies, and their costs remained elevated, inhibiting their development within the country. Additionally, the high cost of capital persisted, resulting in insufficient and inadequate financing for the energy transition.

Despite the challenging environment for low-carbon technologies, the energy mix did not undergo substantial changes compared to its state in the early 2020s. With increased cost pressures and a slow pace of digital transformation in the sector, **the electric system failed to adopt innovative solutions – such as digitalization, battery storage, and pumped storage hydropower – that could enhance its flexibility. Instead, it continued to rely on conventional technologies**, such as hydroelectric and natural gas thermal power plants.

The unfavorable conditions surrounding key enablers of the energy transition – such as the high costs and inadequate regulation of new technologies, along with the lack of consensus and coordination in energy transition policies – have negatively affected **the pace and scale of decarbonization in hard-to-abate sectors.**

C4 – Transition for what?

This sluggish progress has been particularly evident in the transportation and industrial sectors, adversely impacting exports and weakening the national economy.

Despite the increased frequency of extreme weather events and heightened concerns about energy security, over the past 30 years, the electric system has continued to rely on the same resilience practices, with fossil fuels still playing a significant role in its operations. This reliance has left the system somewhat vulnerable, leading to additional costs that further burdened consumers.

In terms of electro-energy integration in Latin America, there has been no significant progress. Brazil has, has focused primarily on addressing specific demands, not taking advantage of potential synergies of regional integration.

Over the years, the demand for energy services has expanded, but it has remained with low responsiveness. No significant rationalization of energy consumption **has been observed, largely due to modest advancements in energy efficiency.**

While there has been an increased emphasis on consumer engagement and greater decentralization of energy systems, the expansion of distributed energy resources (DERs) has been subdued, with a **certain stagnation in the distributed generation-based DER model.**

With significant demand for oil and oil products both internationally and domestically, coupled with the high costs of low-carbon technologies, the oil and gas sector holds a prominent position in Brazil in 2055. Over the past 30 years, **the country accelerated the exploration of new frontiers, increasing its production and influence in the international market.**

On the social front, there have been few advancements, as the limited energy transition failed to achieve inclusivity and fairness. Sectoral inefficiencies intensified, further burdening consumers, resulting in a lack of reduction in energy poverty. By 2055, Brazil has still not achieved universal, reliable, and modern energy access with affordable tariffs. Additionally, innovations had a minimal impact on sustainable development, with these effects largely unnoticed by society. Consequently, **innovation was not leveraged as a catalyst for the country's development.**

C5 – Blocked transition

Imagine a future where ...

The climate events hosted in Brazil during the 2020s created momentum for partial progress in the country’s climate governance. **Despite increased mobilization and coordination in certain sectors**, particularly those related to land-use change, **Brazil failed to meet its commitment to climate neutrality by 2050. Furthermore, the energy system was unable to drive more structural changes toward a low-carbon economy.**

The uncoordinated and competitive actions among countries hindered the expansion of supply chains, resulting in a prolonged period of inflation driven by rising prices of products and services related to the energy transition. This inflationary pressure delayed the development of low-carbon economies. In this context, **Brazil's energy transition was constrained by significant cost pressures on low-carbon technologies.** These challenges were partly attributed to the **country's limited productive and technological capacity in these supply chains, which perpetuated its dependence on other economies** and its vulnerability to international market dynamics. Furthermore, the **lack of progress in establishing a regulated carbon market and in creating**

C5 – Blocked transition

innovative and more integrated financing mechanisms for energy innovation further hindered Brazil's transition to a low-carbon economy.

Additionally, on the international stage, escalating tensions in low-carbon supply chains (including CCS) and their associated high costs elevated the prominence of **oil and gas in meeting both national and global energy needs.** This shift drove growth in the international supply and demand for O&G (without CCS), creating significant challenges for the decarbonization of Brazil’s energy system.

Domestically, the regulatory **reactivity to low-carbon technologies, the slow adoption of digital technologies, and the lack of coordinated policies for the energy transition** resulted in a patchwork approach (“puxadinhos” in Portuguese) that **hindered progress in the three Ds – decentralization, digitalization and decarbonization – and limited improvements in energy access across the country.**

Despite the increasing frequency and intensity of extreme climate events, **the national energy system failed to expand its use of modern technologies that provide greater flexibility and resilience in operations**, maintaining reliance on conventional technologies. This reliance led to rising operational costs and prevented the system from achieving more efficient utilization.

Even so, there were some **targeted improvements in the development of infrastructure for the electric system.**

Despite the accelerated exploration of new oil and gas frontiers, the country was unable to effectively channel oil revenues into building local productive and innovative capacity or maximize their impact on sustainable development for society as a whole.

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