CARBON CAPTURE, UTILIZATION AND STORAGE IN BRAZIL

Contributions to Area Selection: 2025 Cycle

Superintendence of Oil and Natural Gas

2026

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Public Value

EPE conducts studies and research to support the formulation, implementation, and evaluation of Brazilian energy policy and planning.

Within the decarbonization agenda, EPE contributes to informing debate and supporting decision-making on routes for carbon capture, transport, utilization, and geological storage in Brazil, through the organization and systematization of relevant technical information.

This document, in its second edition, expands and updates the database, with methodological improvements aimed at better reflecting the geological, productive, and logistical diversity of different regions of the country. Acknowledging the inherent limitations of the exercise, the document is presented as a technical reference to support planning and the prioritization of opportunities in carbon capture and storage routes, also helping to reduce information asymmetries among institutions, sectoral agents, and society

Contents

The Global Context of Carbon Capture and Storage Routes

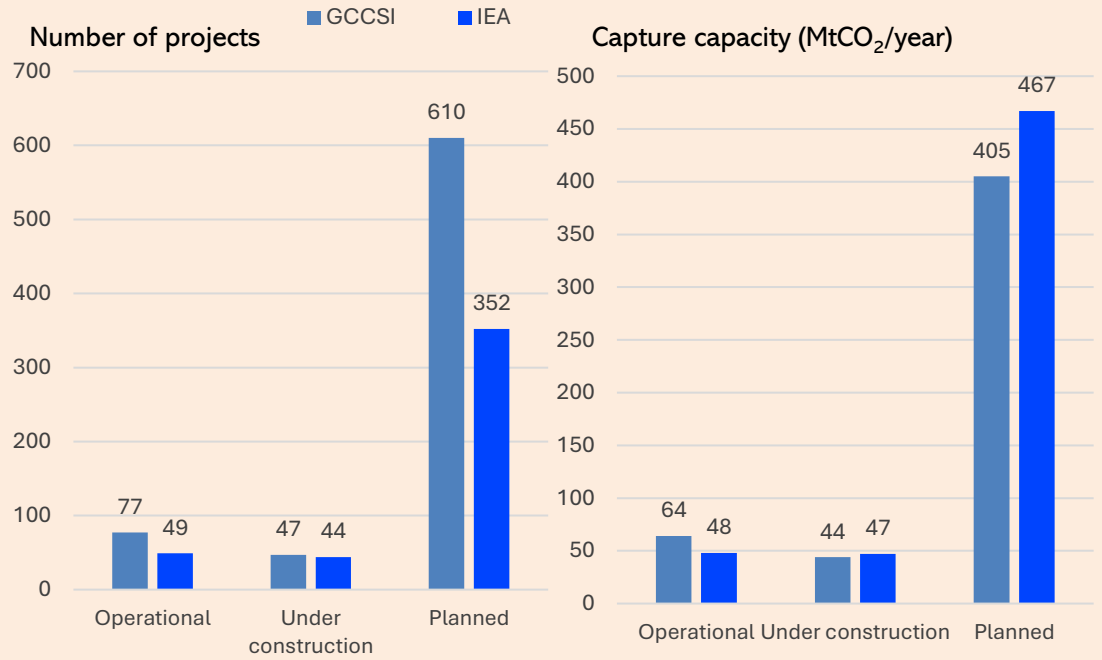
Successive records of increases in the global average temperature show that the carbon budget is being rapidly depleted (WORLD METEOROLOGICAL ORGANIZATION, 2026). As we fail to reduce the pace of emissions, it becomes increasingly **urgent to adopt measures that simultaneously reduce emissions** at the source and **remove CO_2 from the atmosphere**. Carbon capture and storage routes[1] stand out as **the only set of technologies capable of playing both roles**, reducing emissions in key sectors and removing the residual carbon that cannot be avoided (IEA, 2020).

CCS is entering a phase of accelerated expansion, **driven** by more **robust policies**, **greater private-sector engagement**, and **expansion of global infrastructure**. More than 27 countries have already included CCS in their national carbon management strategies. According to the Global CCS Institute (GCCSI), the number of commercial facilities (sum of operational, under-construction, and planned projects) rose from 628 in 2024 to 734 in 2025, with **operational units increasing from 50 to 77**, which **raised global capture capacity by 23% in just one year**, reaching about 64 $MtCO_2$/year of installed capacity. Although the International Energy Agency (IEA) - another key reference institution - records slightly lower numbers (445 projects), due to different methodologies and inclusion criteria, the global surge in interest is unquestionable.

The year 2025 marked an **inflection point with the start-up of Northern Lights**, the **first cross-border hub for CO_2 transport and storage**. By 2030, **operational CCS capacity** is expected to **grow significantly** and **diversify beyond traditional sectors**, with **low-carbon hydrogen and ammonia** leading capacity additions before being overtaken by projects in **power generation and industrial heat**.

By the end of the decade, **North America is expected to remain the main global CCS hub**, followed by Europe, which is accelerating the deployment of regional hubs. In the U.S. context, combining CCS with natural-gas plants offers firm, cost-competitive, and low-carbon electricity - a feature increasingly relevant to **support the growth of AI data centers**, whose energy demand is rising rapidly (GCCSI, 2025).

NUMBER OF PROJECTS AND CAPTURE CAPACITY BY STATUS, 2025



Differences between GCCSI and IEA project numbers/capacities reflect **distinct methodologies, inclusion criteria**, and **objectives**.
The **GCCSI database** typically includes **all projects** for CO_2 capture, transport, storage, and utilization, **regardless of development stage**, **purpose** (e.g., includes EOR), and **climate impact.** It is closely **linked with industry members and partners**. The **IEA applies a more conservative approach**, collaborating with **governments**, **companies**, and **regulators**.

Sources: GCCSI (2025) e IEA (abr/2025)

[1] In this document, the acronym CCS (carbon capture and storage) is used as an umbrella term to encompass the different routes that involve capturing CO_2 - either from point sources or directly from the atmosphere - its transport, and its permanent or non-permanent storage (therefore including utilization routes).

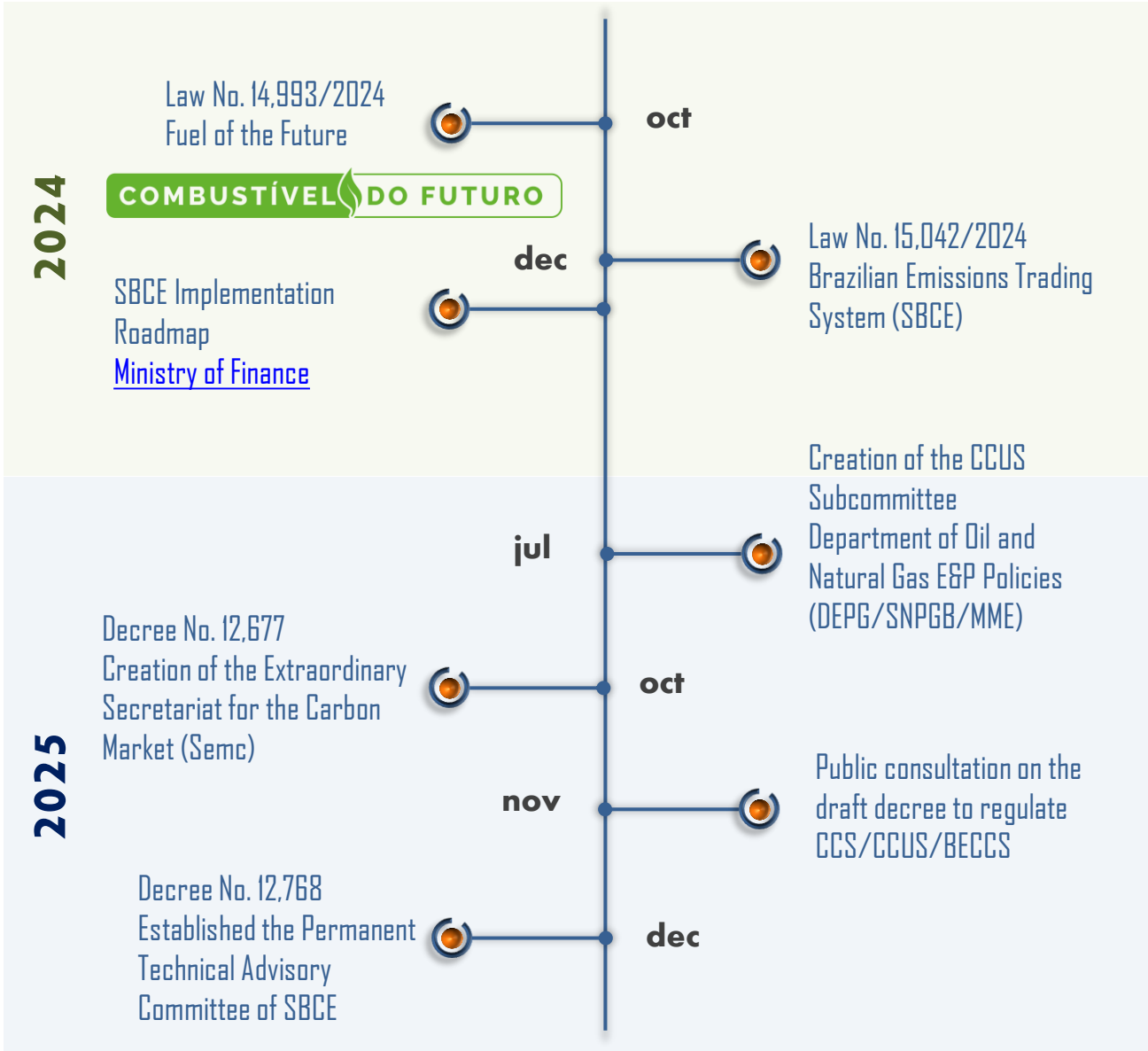
The National Scenario: Institutional milestones and regulatory agenda (2024-2025)

Over the last two years, Brazil has taken **relevant steps to structure the enabling environment** for carbon capture, transport, utilization, and geological storage routes, amid greater international visibility associated with COP30 in Belém, held at the end of 2025.

In 2024, the enactment of **Law No. 14,993/2024 (Fuel of the Future)** provided the long-sought legal framework, establishing - even if in a basic form - the pillar for the regulation and oversight of geological CO_2 capture and storage activities, recognizing **central definitions for project classification and assigning a regulatory role to the National Agency of Petroleum, Natural Gas and Biofuels (ANP)**.

In the same period, **Law No. 15,042/2024** established the **Brazilian Emissions Trading System (SBCE)**, creating prospects for economic instruments to support the viability of CCS/CCUS routes - especially in sectors with unavoidable emissions (so-called hard-to-abate sectors).

As a follow-up, the Ministry of Mines and Energy (MME), within the Permanent Technical Committee of Fuel of the Future, created a **subcommittee** specifically dedicated to **CCUS**, which consolidated the **draft decree to regulate CCS/CCUS/BECCS**. The proposal underwent public consultation (Nov 17–Dec 16, 2025), reinforcing a gradual, learning-by-doing approach with pilot projects and setting general guidelines for authorization and technical requirements across the chain.



The National Scenario: Signs of maturation (projects, hubs, and innovation)

CLIMATE PLAN AND THE ROLE OF CCS ROUTES IN BRAZIL

The Climate Plan (2024-2035) organizes the federal mitigation and adaptation strategy and makes explicit the need to broaden the set of decarbonization solutions. In this context, BECCS and CCS/CCUS are treated as **relevant routes to help meet climate targets**, by enabling both **emissions mitigation** in **intensive sectors** and the **compensation of residual emissions over the long term (MMA, 2025)**.

Structuring actions mentioned include:

CCS/CCUS[1]

ENR.E.08 - Developing Carbon Capture, Transport, Use and Storage

BECCS

ENR.E.09 - Develop bioenergy production with carbon capture and storage (BECCS)

ENR.E.10 - Strengthen biomass production for energy use;

ENR.E.13 - Promote infrastructure for carbon dioxide transport and storage

[1] The CCS and CCUS solutions are linked to a specific long-term structuring action (ENR.E.08), directly impacted by other actions, such as ENR.E.13.

Alongside institutional advances, the recent period shows signs of maturation of the national market. Petrobras progressed with initiatives associated with a CCUS/CCS hub and pilot project linked to the CO_2 stream from the UTG Cabiúnas (RJ) and approved the São Tomé CCS Pilot Project (Macaé/RJ), integrating capture, transport, and storage in a saline reservoir, with monitoring by regulatory and environmental authorities (AGÊNCIA PETROBRAS, 2025b).

Instruments were also signed to expand opportunities: a memorandum of understanding for CCUS hub studies in Espírito Santo and an agreement to deepen studies on carbon capture and storage in Bahia, with potential to structure shared networks and reservoir mapping (AGÊNCIA PETROBRAS, 2024; 2025b).

In removal and bioenergy routes, noteworthy initiatives include DAC.SI (Repsol Sinopec Brasil/PUCRS), focused on direct air capture with storage via mineralization, and FS's BECCS project in Lucas do Rio Verde (MT), which advanced to subsequent implementation phases targeting capture and storage of fermentation CO_2 (MARCELINO, 2025a; 2025b; PUCRS, 2024).

As a sign of a strengthening innovation ecosystem, the EPE's Inova-e platform records that R&D&I investments in the energy sector reached BRL 7.6 billion in 2024 (a 33% increase vs. 2023), a context likely to favor technological maturation of low-carbon solutions, including CCUS.

EPE's Support in Route Planning

In this **second edition**, EPE **deepens this agenda** and **consolidates methodological and analytical improvements** to reflect the **country's regional diversity** - with objectives and axes of action presented next.

Since 2023, EPE has been structuring a **study agenda** on **routes for carbon capture, transport, utilization and geological storage** (CCS/CCUS/BECCS/DACCS) in Brazil. In **2024**, the company published the first edition of its thematic notebook, advancing its contribution to the topic (EPE, 2024).

By making data and assumptions more transparent, these **studies help reduce information asymmetries** among government, sector agents, industry, and academia, strengthening **predictability** and **coordination** of **efforts** in carbon capture and storage chains.

Since then, EPE has **broadened dialogue** with industry, the energy sector, and academia through new materials - bulletins, fact sheets, chapters, participation in forums, among others - reinforcing its **mission** to make **evidence accessible** and **connect multiple stakeholders** impacted by national energy planning.

As an institution supporting energy planning, EPE works on the **organization and integration of technical and economic evidence** that **help the debate** and **support decisions** associated with decarbonization routes.

Objective

MAPPING

Update the relevance map for carbon capture, transport, and geological storage, integrating available technical and economic evidence in the country.

Axis 1

METHODOLOGY

Improve the methodology developed since the first cycle (published in 2024), expanding capacity to extract, qualify, and interpret data.

Axis 2

HOTSPOTS & ROUTES

Identify and differentiate hotspots suitable for different routes (CCS, BECCS, DACCS, CCUS), considering geological and logistical conditions.

Axis 3

INDUSTRIAL SECTORS

Map sectoral opportunities and challenges, supporting evaluation of carbon capture and storage routes as an industry decarbonization strategy

Axis 4

PLANNING

Deepen EPE's contribution to planning CCS/BECCS/DACCS/CCUS, strengthening coherence between public guidelines and regional realities.

Axis 5

INTEGRATION

Consolidate EPE as a national reference, connecting CCUS to other decarbonization options in the energy and industrial sectors.

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Geological Perspective

Storage Sites

This map qualitatively identifies where there are geological formations with potential to store CO_2 underground. It brings together three main classes of storage sites: (i) depleted or depleting oil and gas fields, (ii) saline reservoirs, and (iii) mafic/ultramafic rocks with mineralization potential (storage via chemical reaction).

To increase technical consistency, the mapping applies minimum viability criteria: presence of a caprock (to reduce leakage risk), typical depth ≥ 800 m for depleted fields and saline reservoirs (a condition in which CO_2 tends to remain in a supercritical state), and a differentiated criterion ≥ 400 m for mafic/ultramafic rocks, given the nature of the mineralization trapping mechanism.

[1] In this edition, the term "storage sites" was adopted to replace the designation previously used ("reservoirs of interest"), as it more accurately reflects the technical concept applied internationally (EPE, 2024). Furthermore, the use of the term "storage site" allows for a clearer understanding that the applied methodology encompasses not only the reservoir unit itself, but the integrated geological system, including the storage formation, the sealing rock(s), and the geological conditions that ensure CO_2 confinement in the subsurface. This approach avoids restrictive interpretations and reinforces that the mapping considers the feasibility of the complete geological system required for the safe and permanent storage of CO_2.

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Storage Sites: Main methodological advances

BASALT MINERALIZATION

In this edition, the analysis of potential sites explicitly differentiates mafic and ultramafic rocks and, for the first time, has incorporated a site whose main storage mechanism is mineralization: the tholeiitic basalts of the Serra Geral Formation, in the Paraná Basin. In this case, the assessment prioritized flows with higher ferromagnesian silicate content - such as Urubici, Pitanga, Paranapanema, Ribeira, Esmeralda, and Gramado - which typically show porosities between 0.3% and 28.3%. This update increases the representativeness of mineralization within the portfolio of options for geological storage and improves the reading of potential in Brazilian igneous terrains. As a result, in addition to outlining additional opportunities in the Campos, Santos, and Pelotas basins, new areas of interest emerge in the Paraná Basin, especially in stretches previously underestimated due to the historical focus on conventional porous reservoirs (FREITAS, 2023).

DISTANCE FROM THE COAST

The new mapping incorporates a progressive penalty for reservoirs located farther from the coast, especially those beyond the continental shelf. This adjustment accounts for greater logistical complexity, additional CO_2 transport costs, and technical requirements of facilities in deep and ultra-deep waters. The update makes the result more consistent with real operational constraints in offshore projects, allowing differentiation of opportunities with a better balance between reservoir quality and logistical feasibility. Thus, more distal regions are naturally deprioritized, while proximal regions with higher relative potential gain prominence.

DEPLETED FIELDS

The methodology now includes oil and gas fields that are likely to reach depleted conditions over approximately a ten-year horizon, based on the latest versions of ANP's Annual Production Program (PAP), EPE's Decennial Energy Plan (PDE 2035), and ANP's Permanent Offer listing of relinquished fields (reference: May/2025). In total, 111 onshore and offshore fields were characterized, considering porosity, permeability, and effective thickness using data provided by S&P Global. Including these assets makes the map more adherent to the actual maturation flow of Brazilian fields and strengthens the identification of opportunities with existing infrastructure and data. The result is a prioritizable portfolio of sites with a more robust technical basis for initial studies and pre-feasibility analyses.

SEISMICITY

The analysis now penalizes regions where the Brazilian Seismographic Network (RSBR) recorded shallow earthquakes (hypocenter $\leq$ 10 km) and higher magnitudes ($\geq$ 4, Richter scale). The decision reflects the importance of tectonic stability for long-term storage, recognizing that faults and fractures associated with intraplate seismicity may compromise CO_2 containment over hundreds or thousands of years. Including the seismic criterion enhances the geological safety filter and reduces the probability of false positives in areas prone to instabilities - thus focusing efforts on regions with lower geomechanical risk and more reliable reservoir and seal performance.

Storage Sites

Although the first records of earthquakes in Brazil date back only to the beginning of the 20th century, the Brazilian Seismographic Network now has around 100 stations distributed throughout the national territory. Even so, there is **great heterogeneity in coverage**, especially **in regions with low equipment density**, such as the northern portion and areas under the Amazon rainforest. Although the **country** is in a **tectonically very stable situation**, **expanding the network** is essential to identify and monitor seismic events relevant to the **planning of geological carbon storage projects**, as well **as other strategic infrastructure** works..

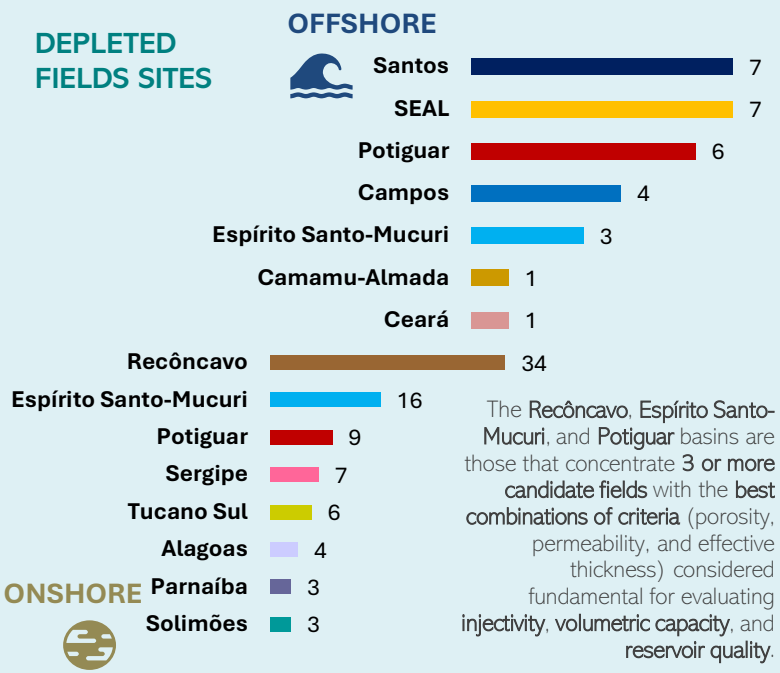
TOTAL
175
Effective Reservoirs

The methodological advances employed contributed to **greater heterogeneity** in expectations regarding areas within Brazilian sedimentary basins and **increase the ability to plan coherent strategies** capable of identifying the best opportunities **onshore** and **offshore**.

A clear example of the effect of the changes adopted was distinguishing reservoirs in mafic and ultramafic igneous rocks which, especially in the Paraná Basin, increased the granularity of the qualitative storage potential expectations across the entire basin and made the central portion stand out more.

It is worth noting, however, that all expectations respond to the context in which the analysis and its assumptions were defined. Therefore, as **field testing and real-world projects advance**, it is expected that future cycles will **change the indicated relevances**.

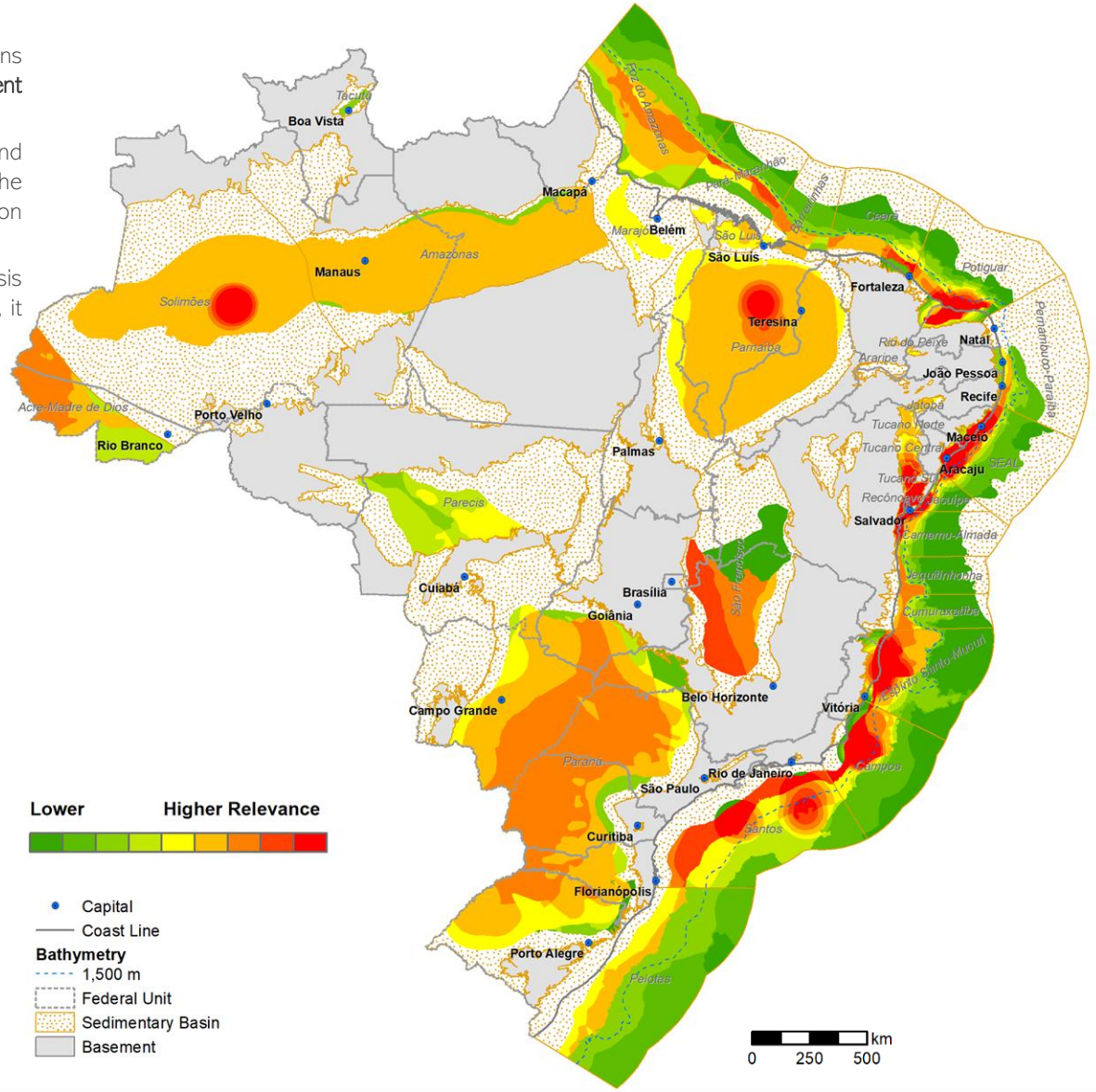
DEPLETED FIELDS SITES



The **Recôncavo**, **Espírito Santo-Mucuri**, and **Potiguar** basins are those that concentrate **3 or more candidate fields** with the **best combinations of criteria** (porosity, permeability, and effective thickness) considered fundamental for evaluating **injectivity**, **volumetric capacity**, and **reservoir quality**.

The **areas of greatest relevance** continue to fall on the **proximal portions** of the **high-potential offshore basins** (Santos, Campos, Espírito Santo-Mucuri) and the **new frontier with well-established E&P activities** (SEAL, Potiguar and Ceará) and **saline reservoirs with high prospects**. The recognition of **good reservoirs** and the presence of **fields that could serve as storage sites** are favorable points for estimating **high relevance** on **land in all mature basins** (Alagoas, Espírito Santo-Mucuri, Potiguar, Recôncavo and Sergipe).

In the **new frontier basins with prominent O&G sector activity**, such as Parnaíba and Solimões, there is also **high relevance**, especially in the portions with candidates for sites in depleted fields. The São Francisco Basin maintained its increasing relevance westward, where saline and carbonate reservoirs with high prospects occur.



Geological Perspective

Knowledge Framework

This map shows where there are geological and geophysical data capable of supporting technical decisions with greater confidence on geological CO_2 storage. It serves as an indicator of subsurface knowledge maturity, combining the presence of exploratory wells and 2D/3D seismic surveys.

In practice, it helps distinguish areas with greater uncertainty (few data) from those better characterized (many data), supporting the prioritization of investments in additional studies, exploratory campaigns, and risk reduction prior to demonstrative or commercial projects.

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Knowledge Framework

EXPLORATORY WELLS

The analysis retained the restriction to exploratory wells available in the National Agency of Petroleum, Natural Gas and Biofuels (ANP) (https://geomaps.anp.gov.br/geoanp/) database but considered only those that the agency's well table indicates as having conventional and/or digital logs. This selection seeks to ensure that the final well set used provides a minimum suite of information needed for basin characterization and geological support to select potential storage sites.

2D AND 3D SEISMIC SURVEYS

All types of processing are now considered, since essential information for identifying suitable structures may be present in both pre-stack and post-stack products - an approach consistent with EPE's experience in the "Basin Analysis Improvement" project (part of EPE's Annual Business Plan). The restriction on using non-reprocessed lines was maintained, ensuring a minimum level of quality in the interpreted data.

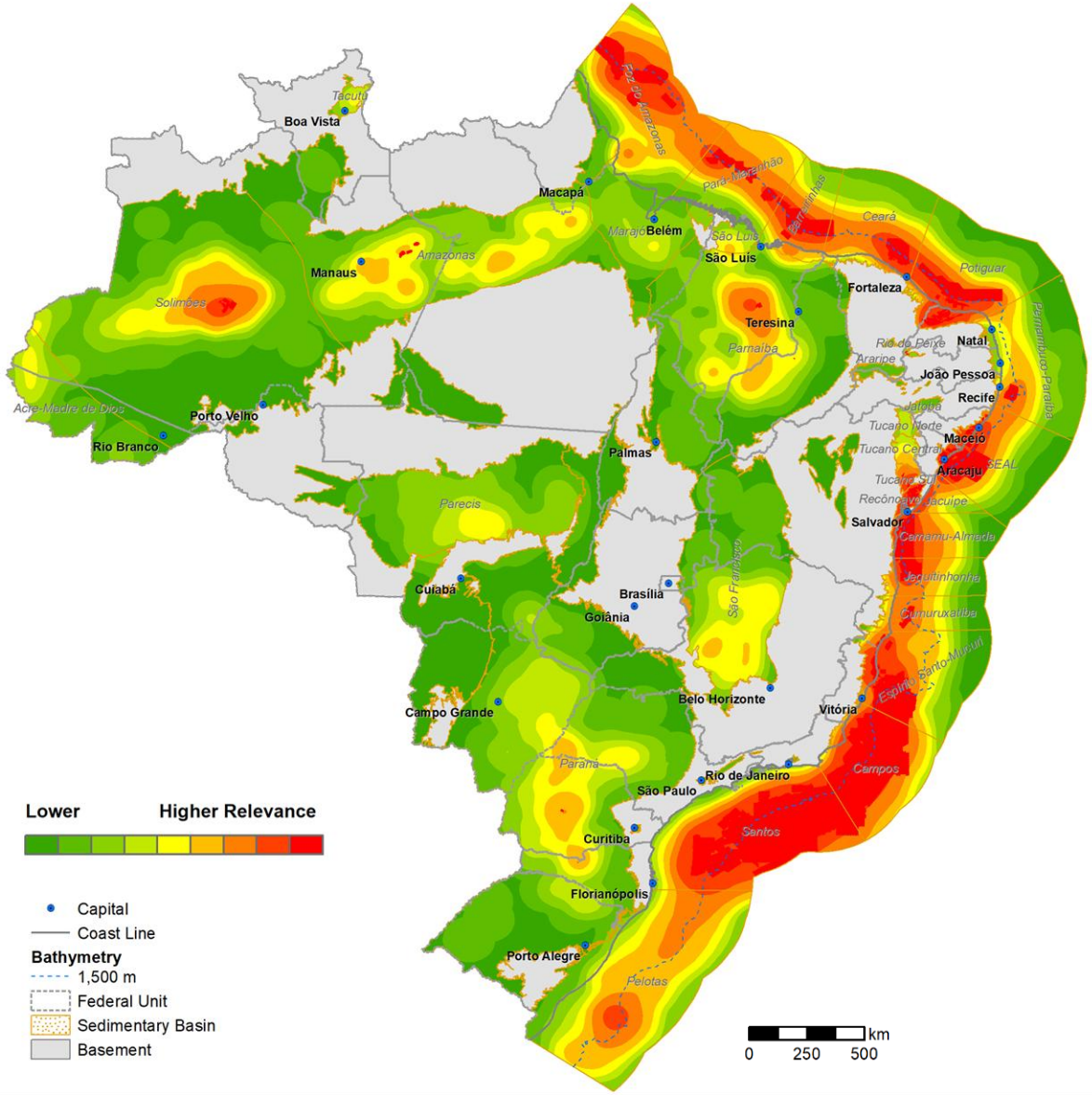
Once again, the **positive effect of O&G exploration activity** in identifying deep reservoir and seal layers is emphasized.

Given that only about half of the Brazilian sedimentary area has geological and geophysical data coverage, the **clear need to acquire data in interior portions remains**, especially in the Center-West and South regions.

Considering all types of processing led to an **increase in importance across the entire continental margin** and in the **Paraná Basin**. On the other hand, **restricting to wells with digital logs** increased **heterogeneity** of results in **onshore** basins.

FUTURE ADVANCES

In the future, the intention is to incorporate new types of data - such as hydrogeological information, structural models, and regional geophysical data - that can complement the analyses of the well framework and seismic data. These inputs will help refine reservoir boundaries and seals and identify critical elements for the safety and effectiveness of permanent storage.



Economic Perspective

Transport Infrastructure

This map indicates where there is infrastructure that can enable CO_2 movement from capture points to geological storage and/or utilization sites. The focus is on modes with a track record or applicability in international projects: pipelines, port facilities, highways, and railways.

Assumptions aim to reflect operational feasibility; for instance, port facilities with incompatible uses (e.g., tourism) and unpaved roads that would prevent sustainable CO_2 transport by trucks were excluded. This map is key to understanding cost, scale, and connectivity of potential hubs.

Transport Infrastructure

De-risking for CO_2 infrastructure

De-risking consists of **reallocating**, **sharing**, or **reducing risks** that currently block investments in low-carbon projects such as CO_2 transport and storage. It involves **policy actions** (regulatory clarity, standardized licensing, governance risk mitigation) and **financial instruments** (public guarantees, risk coverage, support for geological studies). These **reduce investor uncertainty**, **unlock upfront CAPEX**, and **accelerate essential infrastructure formation** for decarbonization chains (CHOI; ZHOU; LAXTON, 2022)[4].

The database update was essentially responsible for the changes observed between cycles.

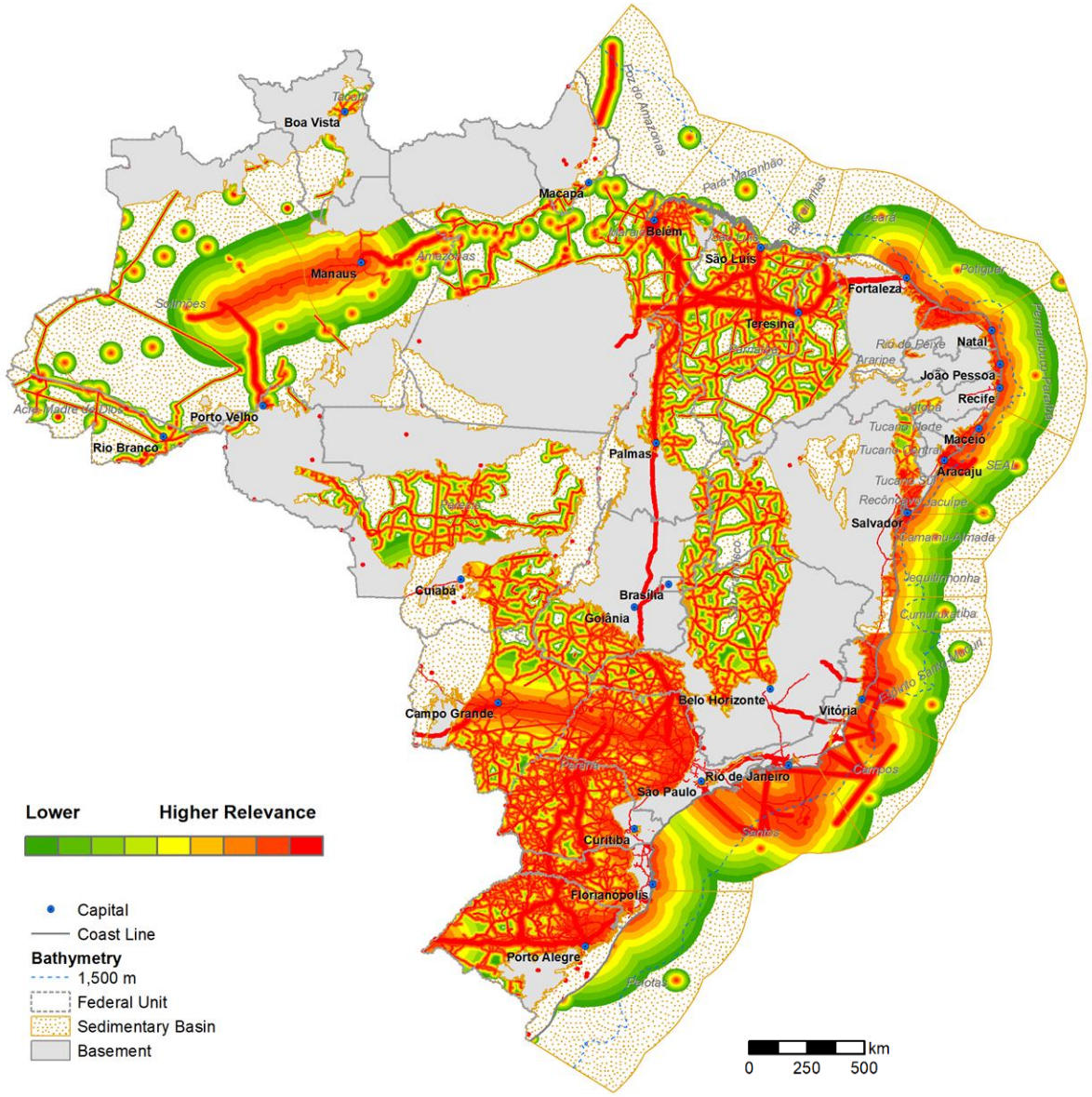
In addition to the adoption of the pipeline database used in the latest version of the National Zoning of O&G Resources (ZNMT 2023-2025)[1], the most recent versions of the following free and federal government databases had an impact:

- Federal Highways: DNIT
- State Highways: INDE
- Railways: Ministério dos Transportes
- Port Facilities: ANTAQ

In particular, the representation of platforms, which can serve as logistical support bases, helps to understand the **new points added in the offshore basins.**

The concentration of infrastructure in the Center-South region and along coastal portions of the South, Southeast, and Northeast significantly increases the relevance of these areas. This **concentration favors movement of CO_2 in large volumes**, especially **by pipelines** and **ships**. However, **expansion into the interior** of the country **requires robust technical and economic solutions**, in addition to a **clear regulatory framework**.

European experience shows that transport and storage are often bottlenecks due to regulatory complexity, **high upfront CAPEX**, and **lack of de-risking mechanisms** (GUIDEHOUSE, 2023)[2].



PIPELINES

The **most globally established and efficient mode** for **transporting large volumes of CO_2**, especially in **onshore operations**, offering **relatively lower operating costs** and economic viability over **long distances**. However, it requires a **high initial investment**. There are technical differences depending on the transport phase: gaseous in onshore pipelines and gaseous or liquid/dense in offshore pipelines (requiring higher pressures and diameters when transporting gas).

SHIPS

Highly flexible in routes and volumes, with **lower implementation costs** and **higher operating costs**. It is still mainly used for small volumes destined for the food and beverage industries. Recent studies show that ships **become more competitive than pipelines over distances greater than 300-1,000 km**. Operation in the liquid phase under strict temperature and pressure control.

HIGHWAYS

Suitable for **short distances** or **initial deployment phases**, operating with **liquid-phase CO_2** under moderate pressures. However, its **costs become significant in large-scale projects**, in addition to being a **more polluting mode of transport** and **sensitive to weather and traffic conditions**. Its **sustainability depends on ensuring that transport emissions do not exceed captured CO_2.**

RAILWAYS

They can be advantageous over **medium and long distances**, combining energy efficiency and greater capacity than road transport. However, **large-scale CO_2 systems are not yet implemented**, and their **adoption depends on the proximity between capture and use/storage points** and **available rail infrastructure**. Transport occurs in the **liquid phase**, under relatively low pressures, but requires **strong logistical coordination**.

Fonte: PILLER (2023)[3]

[1] The ZNMT is a biennial study published by EPE. Its latest version was in press at the time of the release of this booklet.
[2] GUIDEHOUSE. 2023. Best practices of CCUS infrastructure in Europe. Gas for Climate, setembro de 2023.
[3] PILLER, S. et al; 2023. Best practices of CCUS infrastructure in Europe. Gas for Climate, setembro de 2023. Disponível em GfC_Best-Practices-of-CCUS-Infrastructure_Whitepaper.pdf
[4] CHOI, E.; ZHOU, L; LAXTON, V. 2022. How to De-risk Low-carbon Investments. Disponível em https://www.wri.org/insights/de-risking-low-carbon-investments

Pipelines: retrofit or new dedicated infrastructure?

The choice between repurposing existing pipelines (retrofit) or building new dedicated infrastructure **involves multiple technical, regulatory, and economic factors**. The **absence of a fully consolidated international standard** for CO_2 quality specifications is a **material obstacle** to **interoperability**, reinforcing that **each case must be assessed individually**, according to **route, impurities, phase and operating conditions**.

International experience suggests that **retrofit can be economically attractive**, with **53%-88% CAPEX reductions** in some cases and savings of up to ~US$ 3 million/km, **especially in offshore segments**. However, these gains **may be accompanied by up to 50% higher OPEX**, due to the **need for intensive corrosion monitoring** and **greater maintenance of aging assets**.

From a technical standpoint, **conversion requires a detailed analysis of pressure and temperature**, especially when operating with supercritical CO_2 (pressures > 7.38 MPa and T > 31.1°C). These **requirements can exceed the design envelopes of existing pipelines**, demanding **adaptations, reinforcements**, and **re-evaluation** - particularly in marine environments.

CO_2 corrosivity is one of the most critical points, **intensified in the presence of water and impurities** (e.g., **H_2S and SO_2**). Wet CO_2 can corrode carbon steel at high rates, making dehydration and impurity control central requirements. In addition, **fracture propagation in CO_2 pipelines can be more severe than in natural-gas pipelines**, requiring specific studies, experimental validation, and robust integrity management.

The **decision matrix** should include **structural integrity** and **remaining life, fracture/leak risk**, **dehydration needs**, and the **adequacy of auxiliary equipment** (pumps, valves, sensors, and monitoring systems). International evidence indicates **relevant potential for repurposing** (often more viable offshore than onshore, case-dependent), **and hybrid solutions** - **combining new and repurposed pipelines**, or even parallel CO_2 and H_2 networks - can reduce system costs and accelerate deployment.

Decision Matrix: Retrofit vs. New Infrastructure[1]

PARAMETER	REUSE	NEW PIPELINE
Initial CAPEX	Lower (between 53% and 88% savings)	Higher
OPEX	Larger (monitoring and maintenance)	Lower
Total Cost	Potential for a reduction of approximately 25% in 20 years.	Higher
Flexibility	Larger for pilot projects or scaling up	Requires a constant volume.
Easement	Already existing, it reduces time and cost.	Requires purchase

[1] Consolidated data based on Ziyang et al. (2025); Kim, Yoon e Lee (2024) and Carbon Limits e DNV (2021).

The **lack of dedicated infrastructure for CO_2 transportation** is **one of** the **main bottlenecks for the development of CCS routes in Brazil**. The **economic viability** of the projects is **directly related** to the **proximity between emission sources and storage sites**. In this sense, European experience shows that the **creation of industrial hubs** with **shared infrastructure** is **an effective strategy** to **reduce costs** and **attract investment**.

Hybrid solutions, combining different modes of transport, can be **strategic** to overcome regional bottlenecks and **connect emitters to storage sites** in remote areas.

Economic Perspective

BECCS - Immediate Availability of Biogenic CO_2

This map depicts available sources of biogenic CO_2 (based on actual 2024 production) that generate relatively pure and concentrated streams - particularly ethanol fermentation (from sugarcane and corn) and biomethane routes. Because capture is less complex in these cases, they tend to require smaller investments (e.g., compression, logistics, and storage).

This layer serves as a short-term priority indicator for BECCS: it points to where projects can likely be enabled more quickly, thereby accelerating learning, market formation, and the potential achievement of negative emissions at scale.

Notes on the analysis of biogenic CO_2 availability (immediate and potential)

SUGARCANE VS. CORN

Sugarcane and corn routes were distinguished to properly reflect **operational differences between the feedstocks**. Each crop yields **distinct production profiles over the year** - and thus **different operating windows for BECCS** - which **directly affects logistics sizing**, **costs**, and **planning** for the infrastructure required for geological storage.

This distinction avoids data over-aggregation and enables more realistic estimates of available CO_2 and supply stability.

BIOMETHANE

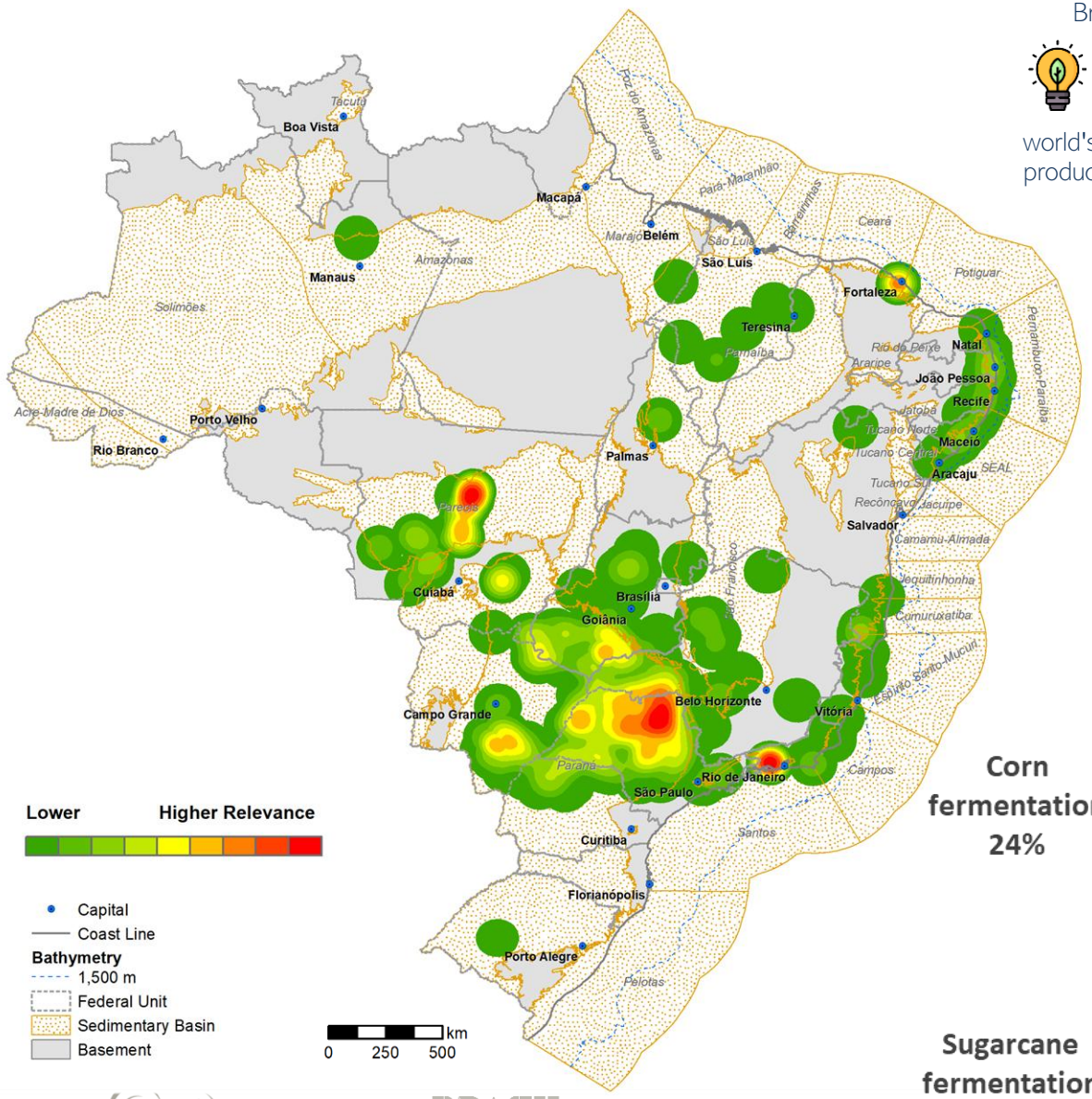
For biomethane plants, **only the fraction destined for the market**, **excluding** volumes for **on-site self-consumption**, was considered. Therefore, **available CO_2 -** immediate or potential - **may be underestimated**, as the underlying dataset reflects lower productivities than observed in practice.

Immediate availability corresponds to CO_2 generated in current biogas upgrading; potential availability includes both production expected from new plants attached to ethanol mills and the CO_2 associated with vinasse and filter cake processing and with biomethane from units under construction.

STREAM PURITY

CO_2 from **fermentation** and **biomethane purification** is **high-purity**, **reducing technical complexity and capture costs**. By contrast, capturing CO_2 from boilers (**cogeneration** using **sugarcane bagasse or woodchips**) requires operations such as solvent absorption and/or adsorption, which demand **higher investment** in dedicated equipment and **increase operational complexity**, since these units often primarily serve to supply heat to the main facilities.

BECCS (Immediate Availability)



Brasil is

2º

world's largest ethanol producer (OECD/FAO, 2025)

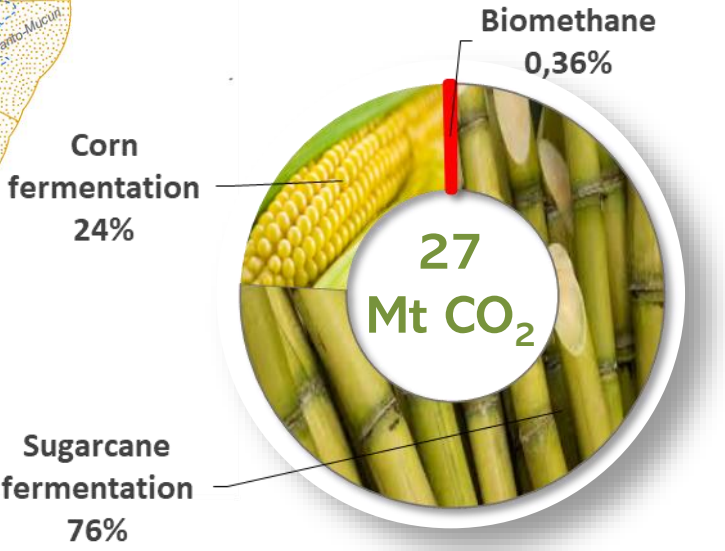
The ability to fit into **multiple business models** makes **Brazil's bioenergy sector strategic** for developing **low-carbon routes**. The **abundance of sustainable biomass** (notably the sugar-energy sector), its **established role in the national energy matrix**, the sector's **technological maturity**, and its **historic integration with climate policies** - especially **carbon pricing** - position it as a cornerstone of the global energy transition, with strong potential to lead BECCS scale-up.

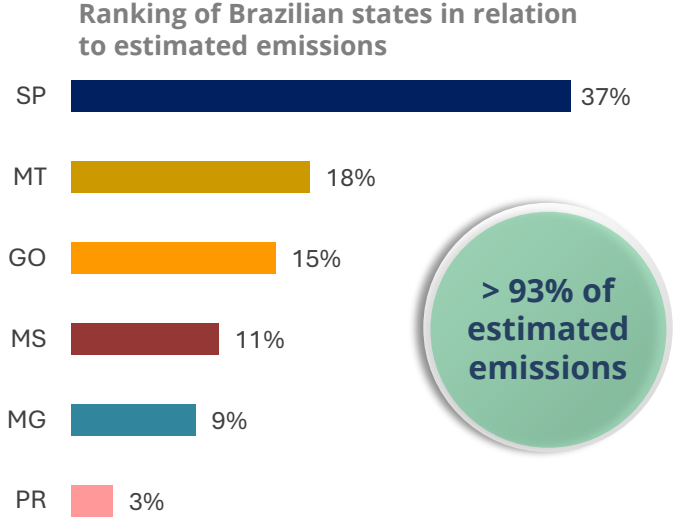
Alcoholic fermentation at sugarcane and corn mills is the main source of biogenic CO_2 already available for direct capture in Brazil. As a high-purity gas (>95% vol/vol), these streams are an **immediately exploitable opportunity, requiring minimal investment in compression and transport**, without complex separation processes.

Corn ethanol mills, concentrated in **Mato Grosso**, **Goiás**, and **Mato Grosso do Sul**, **operate year-round**, **ensuring stable CO_2 supply** and **favoring standalone capture projects**. **Sugarcane mills**, concentrated in **São Paulo, Goiás, Minas Gerais, Mato Grosso do Sul**, **Paraná**, and **Mato Grosso**, provide **strong potential for regional hubs**, though harvest seasonality challenges CO_2 availability (EPE, 2025).

Biomethane is becoming more relevant as a **renewable fuel in Brazil's transition**, being interchangeable with natural gas. During its production, biogas is upgraded to concentrate methane, and the separated CO_2 emerges as a **high-purity stream**, **ready for capture** (EPE, 2025).

In this cycle, the three states with the largest installed capacities stand out; **landfill emissions in Rio de Janeiro** were **the largest estimated** (52%), followed by **Ceará** (30%) and **sugar-energy sector emissions in São Paulo** (18%). This concentration indicates strategic **opportunities for BECCS projects and for utilizing residual CO_2**.





Economic Perspective

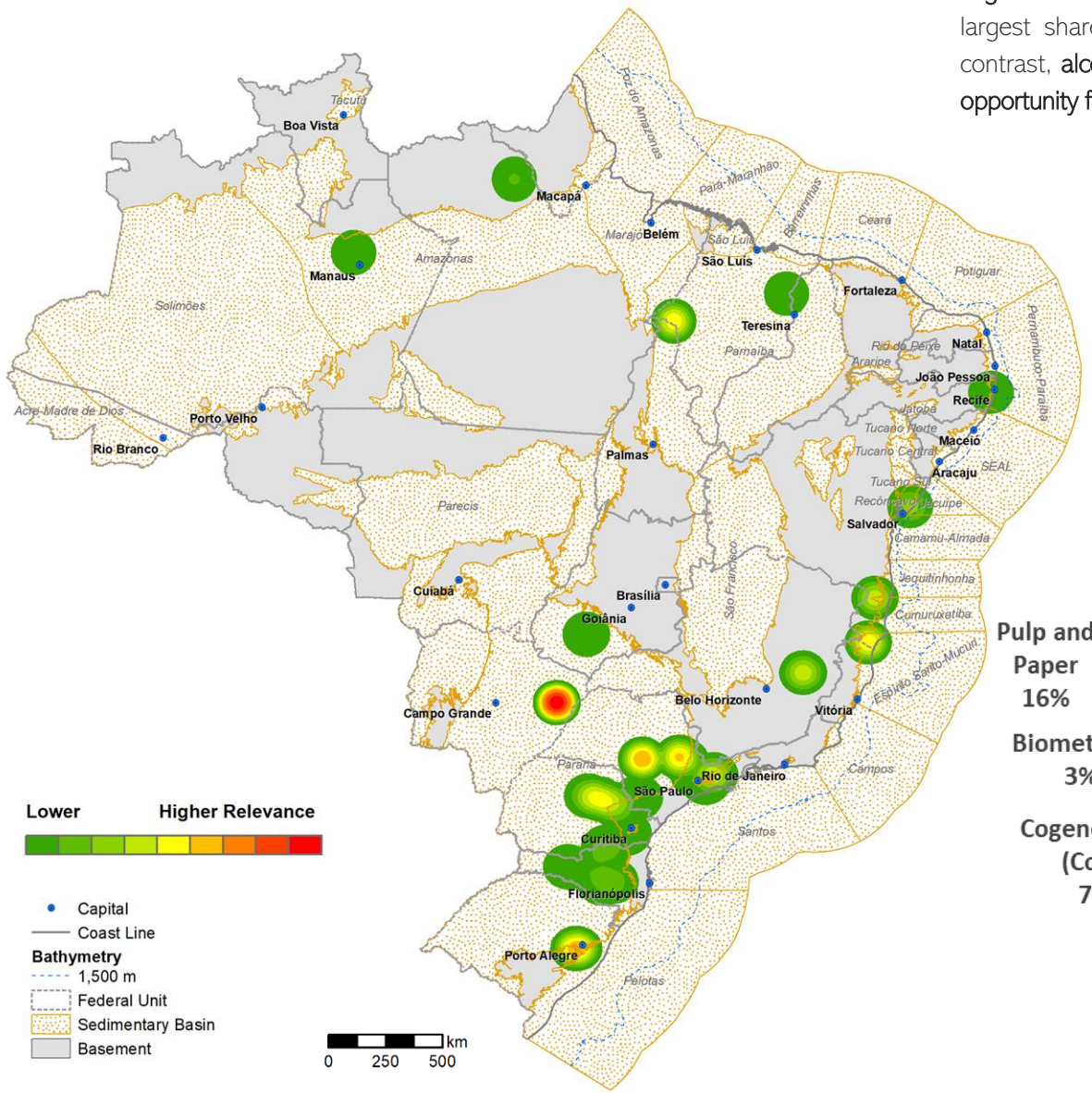
BECCS - Potential Availability of Biogenic CO_2

This map widens the scope to less immediate opportunities, linked to future expansion (new sugarcane or corn ethanol plants, increased biomethane output) and to sources that require additional capture infrastructure (e.g., cogeneration flue gases or processes with more diluted CO_2, such as pulp and paper).

It therefore guides medium-term planning, indicating where BECCS can grow with more robust investments and industrial integration, helping anticipate needs for infrastructure (transport/storage) and policies to unlock scale.

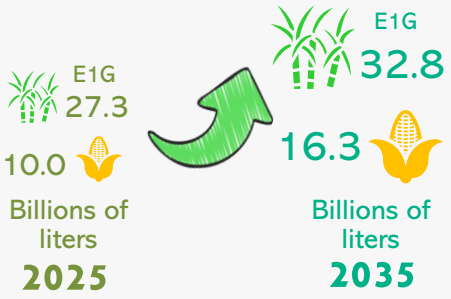
BECCS (Potential Availability)

The **Southeast** and **Center-West regions** account for over **77% of emissions** from **alcoholic fermentation and 85% from cogeneration** (**sugarcane and corn biomass**) that could be captured in BECCS projects. Although **cogeneration** represents the largest share of biogenic CO_2 potential, its **low concentration** (<15%) **implies higher capture costs and complexity**. By contrast, **alcoholic fermentation**, with only **8% of the total estimated** potential, offers **>95% purity CO_2**, making it a **strategic opportunity for initial BECCS projects**.

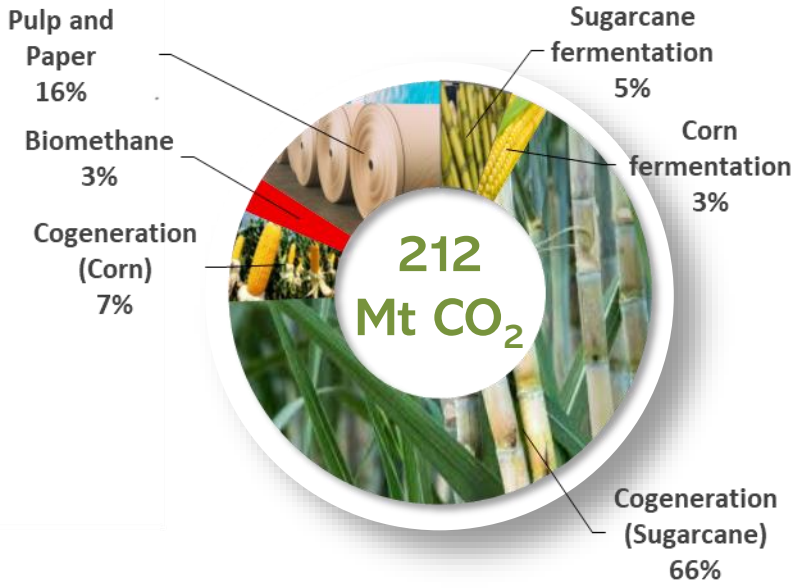


By 2035, **expanding sugarcane and corn ethanol supply**, together with **progress in second-generation ethanol and SAF production**, significantly increases the volume of available biogenic CO_2. This growth creates favorable conditions for BECCS development, enabling direct coupling between fermentation processes and capture/storage routes, with potential to produce **fuels with a negative carbon footprint**.

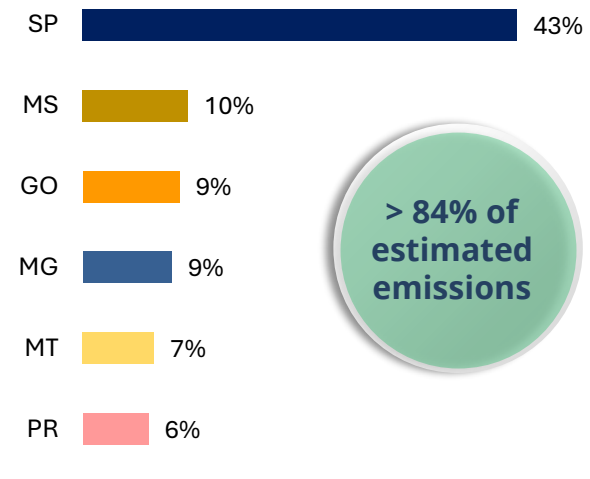
Ethanol supply (EPE, 2025)



The **National Energy Plan 2055 (PNE 2055)**, released for public consultation by EPE in 2026, reinforces the strategic potential of BECCS by indicating that its application in **liquid biofuel production** can enable removals of more than **100 $MtCO_2eq$**, while its adoption in **biomethane production** can reach up to **43 $MtCO_2eq$**.



Ranking of Brazilian states in relation to estimated emissions

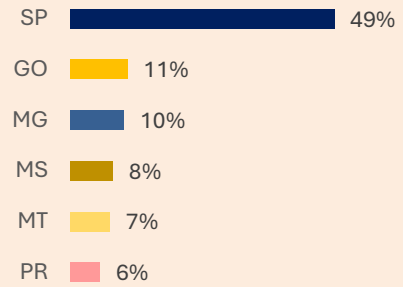


> 84% of estimated emissions

BECCS (Potential Availability)

COGENERATION

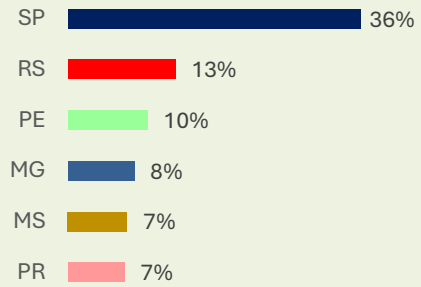
Ranking of Brazilian states in relation to estimated emissions



Potential availability associated with sugarcane and corn cogeneration is heavily concentrated in the Southeast (~59% of the total), with SP and MG standing out. Next comes the Center-West (~26%, with GO slightly ahead of MS and MT). The Northeast (~8%, strongest in AL) and South (~6%, led by PR) show intermediate participation, while the North remains residual (~1%, spread among TO, PA, and AM). These patterns reflect the geography of ethanol and biomass production and installed cogeneration capacity.

BIOMETHANE

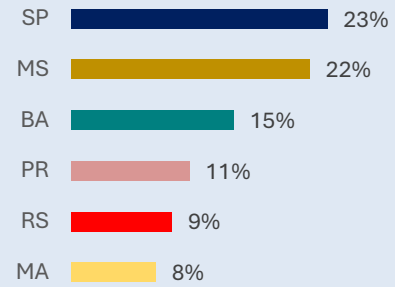
Ranking of Brazilian states in relation to estimated emissions



Potential CO_2 from biomethane is led by the Southeast (~57%), followed by the Center-West (~27%), Northeast (~8%), South (~7%), and North (~1%). Most potential emissions come from the sugar-energy sector (cane ethanol), with SP and MG leading in the Southeast and PE in the Northeast. Corn-based biomethane is more relevant in the Center-West, especially GO and MT. According to Abiogás, daily biomethane production capacity is expected to increase from 1.77 million m³/day in 2025 to about 8 million m³/day in 2032, significantly expanding the future CO_2 potential for BECCS (ABIOGAS, 2025).

PULP AND PAPER

Ranking of Brazilian states in relation to estimated emissions



This industry is another important source of biogenic CO_2 in Brazil, with emissions concentrated in a few states. São Paulo, Mato Grosso do Sul, and Bahia account for more than half of the total; Paraná, Rio Grande do Sul, and Maranhão complete the group representing ~87% of estimated sector emissions. This geographic concentration creates ideal conditions for regional BECCS hubs, leveraging continuous, large-scale flows with significant decarbonization potential and the generation of negative credits (i.e., removals)..

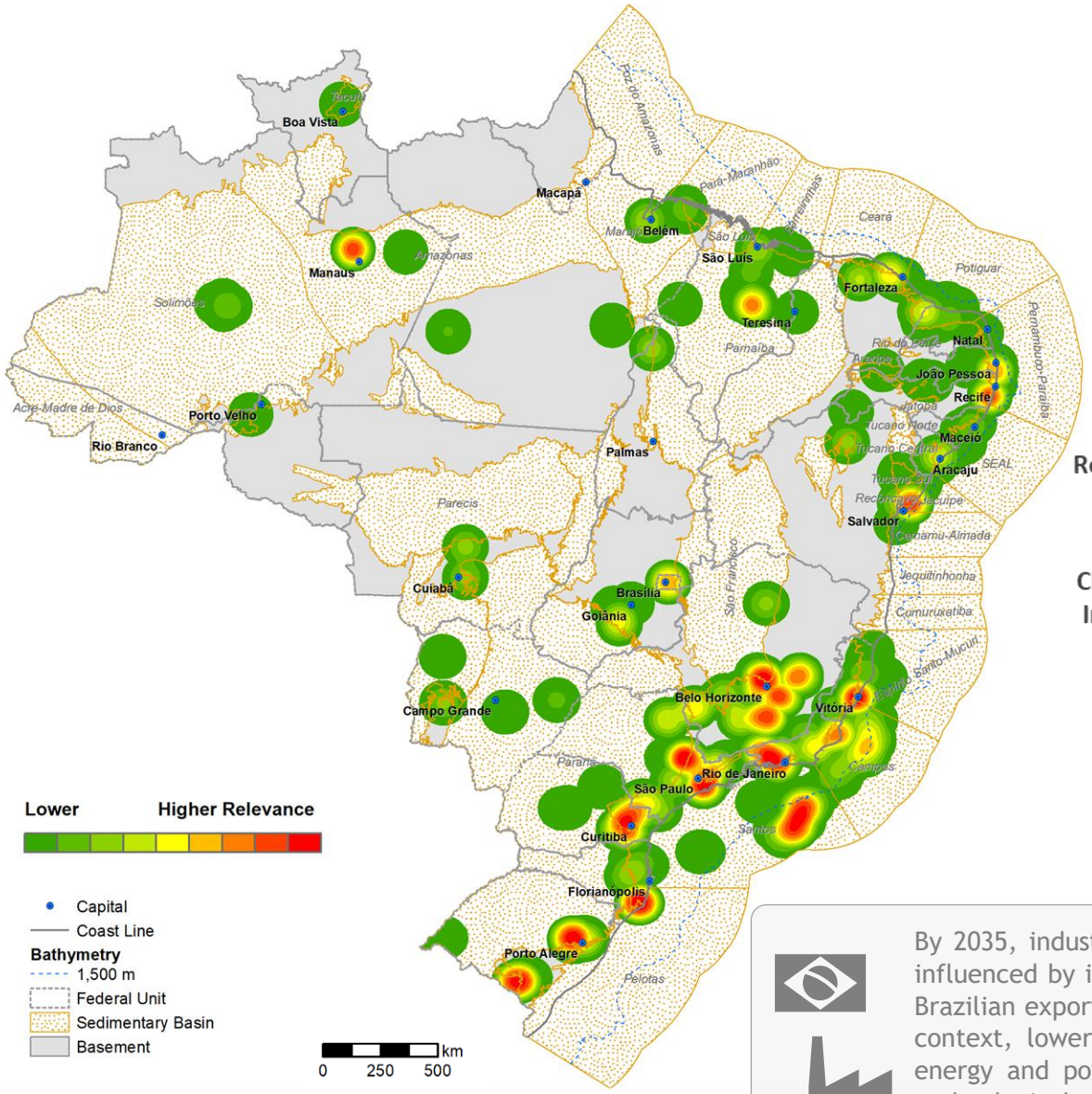
Economic Perspective

Potential (hard to abate) industries interested in CCS/CCUS

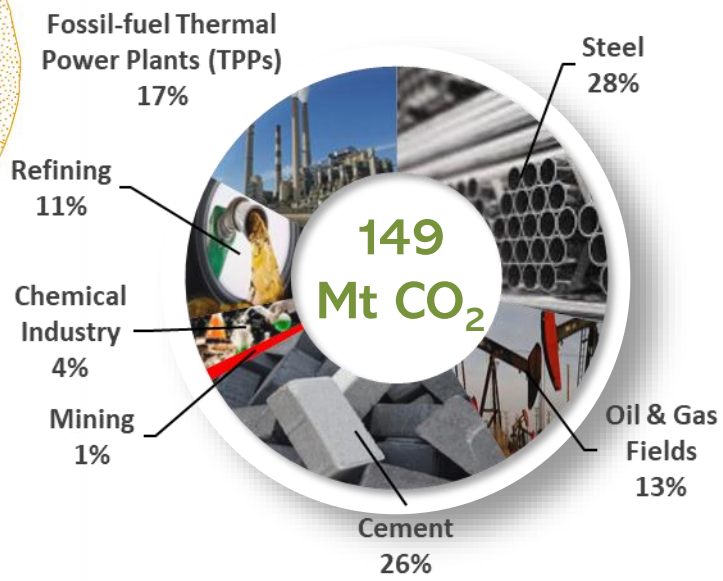
This map identifies industrial units with greater decarbonization challenges, and hence a higher likelihood of considering CCS/CCUS as a mitigation route. The analysis highlights the spatial distribution of major emitting sources, allowing the identification of industrial clusters with potential to enable hubs, share infrastructure, and reduce system costs - and also indicating where demand for carbon credits may be stronger.

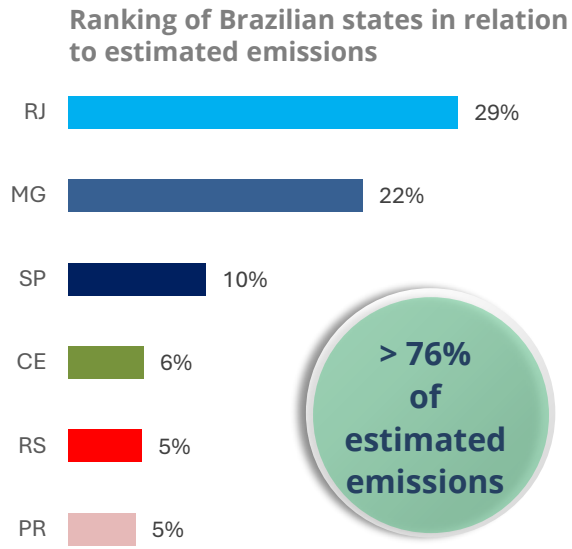
Seven sectors were considered: steel, cement, oil & gas production, refining, chemicals, mining, and fossil-fuel thermal power plants (TPPs). For steel, cement, chemicals, and mining, emissions estimated for 2024 were used; for O&G production and refining, 2023 data was used. For fossil-fuel TPPs, only units operational between 2021 and 2025 were included, using the average for the period to reduce the effect of hydrological variability on thermal dispatch. This approach provides a more representative spatial picture of existing emitters and aligns with the polluter-pays principle.

Potential (hard to abate) industries interested in CCS/CCUS



Emissions from **hard-to-abate sectors** amount to **significant volumes**, led by steel (42.5 $MtCO_2$), cement (38.2 $MtCO_2$), and thermal power plants (25.5 $MtCO_2$), followed by oil and gas fields (19.2 $MtCO_2$), refining (16.4 $MtCO_2$), the chemical industry (6.0 $MtCO_2$), and mining (1.4 $MtCO_2$). Geographically, these emissions are **heavily concentrated in the Southeast region**, which accounts for **62% of the total**, while the **Northeast (16%) and South (14%)** appear as **secondary hubs**, and **the Center-West and North contribute only 4% each.** This regional concentration reinforces **the feasibility of establishing capture hubs close to the main industrial clusters**.





By 2035, industrial energy demand in Brazil is expected to grow, while export competitiveness becomes strongly influenced by international carbon-pricing policies, such as the EU's CBAM, which may impact billions of dollars in Brazilian exports, especially aluminum, iron/steel, and cement (EPE, 2025; MDIC; GPI, 2024; TOSCAN, 2024). In this context, lower-carbon industries will likely expand access to global markets. The high renewability of Brazil's energy and power matrices is a key comparative advantage, but turning it fully into competitiveness requires technological options for further emissions reduction - among which CCUS stands out as a strategic tool for hard-to-abate sectors.

Results from key sectors potentially interested in CCS/CCUS

STEEL

The **Southeast region concentrates 87%** of the estimated emissions for the period, far ahead of the **Northeast (12%)**. This concentration stems from the **density of the industrial base** and the **major load centers** in the Southeast, where the **country's main steelmaking and industrial transformation hubs are located** (CSN/Volta Redonda-RJ; Ternium/Rio de Janeiro-RJ; Usiminas/Ipatinga-MG; Gerdau Açominas/Ouro Branco-MG).

In addition to **production scale**, the **predominant technological profile plays a significant role** - **integrated coke/blast-furnace** (BF-BOF) plants with **high carbon intensity** - as well as the **presence of energy and logistics infrastructure** that supports **large continuous volumes of production**.

From a macroeconomic perspective, the **Southeast accounts for more than half of Brazil's industrial GDP** (IBGE), which reinforces the concentration of energy-intensive activities and, consequently, of emissions.

CEMENT

The **Southeast region** accounts for **nearly half of the cement sector's emissions**, but the **largest individual source is located in Rio Branco do Sul (Paraná)**, responsible for **8% of the total f**or the cycle. Although the **South region** hosts this standout facility, its regional total represents only **16%** of national emissions - slightly less than the **Northeast (18%)**, with the **Center-West** and **North** contributing the remaining **14%** and **3%**, respectively.

The **Southeast contains 40 units**, and the municipal breakdown reinforces the significance of the calculated volumes: three cities in Minas Gerais - Barroso, Itaú de Minas, and Carandaí - rank among the five largest emitters, together accounting for 13% of total sector emissions. Thus, even without hosting the country's highest-emitting plant, the Southeast remains at the top because it **combines production scale, the predominant technology** (rotary kilns with high clinker content), and **high industrial density** - factors that sustain elevated CO_2 levels and highlight major opportunities for applying CCS/CCUS in this regional cluster.

The strong presence of the cement industry in the **Northeast** (with 34 units) and the **South** (12 units considered) results from **recent investments in units** in these regions, aimed at improving **logistical competitiveness and meeting local demand**.

FOSSIL-FUEL TPPS

There is a **concentration in the state of Rio de Janeiro**, which accounts for **22% of the sector's emissions** and includes **13 units considered** in the analysis, followed by **Santa Catarina (15%)** and **Rio Grande do Sul (14%)**. **Maranhão and Amazonas** each account for 11%, highlighting the **importance of thermal power plants in the electricity mix of the North and Northeast**. These **regional differences reflect the composition of the thermal generation fleets** - **mostly powered by natural gas and fuel oil** - and their **proximity to major load centers**.

The unit with the highest average emissions is located in the city of **São João da Barra**, in the state of Rio de Janeiro (**Porto do Açu**), followed closely by those in **Candiota (Rio Grande do Sul)**, **Capivari de Baixo (Santa Catarina)**, **Duque de Caxias (also in Rio de Janeiro)**, and **Manaus (Amazonas)**. In the states of **Ceará and Maranhão**, the plants in **São Gonçalo do Amarante** and **Santo Antônio dos Lopes**, respectively, **stand out**. The **concentration of large-scale units reinforces the importance of targeted strategies for carbon capture and storage (CCS) projects in these locations**.

O&G FIELDS (E&P)

The concentration of emissions in the **Southeast reflects the productive dominance of the Campos and Santos basins**, which in 2023 accounted for nearly **94% of national output**. Although this region concentrates the highest absolute emissions, its **carbon intensity is below the national average**, due to the high production levels of pre-salt fields, which rely on modern technologies capable of ensuring greater energy efficiency in extracting the large volumes produced.

Emissions in the North and Northeast regions represented around **3% of the total**. It is worth noting that in these regions, **natural gas production from onshore units stands out**, particularly in the **Espírito Santo–Mucuri, Solimões, Recôncavo, and Parnaíba basins**, which lie across the states of Espírito Santo, Amazonas, Bahia, and Maranhão. It is especially in the mature assets of these basins that the highest carbon intensities recorded in the sector nationwide occur.

The continuous effort to reduce both carbon intensity and absolute emissions in the E&P sector is recognized as a driving force behind investment in CCUS routes. Already successfully applied in the Santos Basin - demonstrating the feasibility of permanent storage in pre-salt sedimentary basins - this approach is expected to expand over the next decade, with higher volumes of CO_2 captured and broader application of the technology in other basins, particularly in declining fields.

Results from key sectors potentially interested in CCS/CCUS

REFINING

With six refining units equipped with **Hydrogen Generation Units (HGUs)**, the **Southeast region** accounted for **59% of the sector's emissions** in 2023. This result reflects not only the **larger number of refineries with HGUs, but above all the region's historical centrality in Brazil's refining network**, where **large-scale and higher-complexity refineries are located** - facilities designed to process substantial volumes of both domestic and imported crude oil. The presence of **major consumer centers, proximity to maritime terminals, and integrated logistics infrastructure** also contribute to the higher operating intensity of the region's refineries.

The **South region**, despite having only **two units equipped with HGUs**, accounted for **22% of the estimated emissions** - a larger share than the **Northeast**, which, even with three plants, represented **19% of the total**. This difference stems from variations in processing profiles, installed capacity, crude slate, and refining configuration, all of which directly influence CO_2 emissions at each facility.

It is important to note that **GHG emissions profiles** can **vary significantly among refineries**, mainly due to the **type of crude processed, the facility's level of complexity, the degree of conversion, and hydrogen consumption**. For this reason, the **emissions estimated** in this exercise **should be interpreted as approximate values**, which do not necessarily reflect the operational reality of each individual refinery.

CHEMICAL INDUSTRY

The **South region concentrates 42% of the estimated emissions** from the **petrochemical segment**, followed by the **Northeast (38%)** and the **Southeast (20%)**. The **industrial hubs of Triunfo (Rio Grande do Sul) and Camaçari (Bahia) stand out**, each accounting for more than **30% of the total.** In the **Southeast**, the **Duque de Caxias hub** (**Rio de Janeiro**) accounts for **16% of emissions estimated for 2024**. This geographical distribution reflects the fact that **Triunfo and Camaçari are large-scale, integrated petrochemical complexes** - with **multiple ethylene/olefin, aromatics, and polymer plants - operated by groups such as Braskem and partners**, and marked by **successive investments in capacity expansion** and **energy efficiency**. Examples include the decarbonization projects in Triunfo (a Braskem-Veolia partnership, with a potential reduction of 500 thousand tCO_2e/year) (BRASKEN, 2024) and the expansion projects at the Camaçari complex (BRASKEM, 2025).

In the Southeast, **Duque de Caxias (RJ)** has consolidated itself as a **relevant hub due to its proximity to Reduc and to the natural gas sector**, in addition to the R$ 33-billion investment package announced to integrate refining, gas processing, and petrochemicals—further strengthening the cluster's activity (COELHO, 2025).

In the **basic chemicals segment** (chlor-alkali), the **Northeast leads with 57% of estimated emissions**, while the **Southeast** accounts for **43%**. In the Northeast, **Alagoas represents 38%** and **Bahia 19%,** reflecting the historical presence of chlor-alkali plants integrated with PVC production (in Maceió/Marechal Deodoro and Camaçari) - even though Alagoas is undergoing a transition following the definitive shutdown of rock salt mining and the later resumption with imported salt in 2021, followed by the announced plan to close chlor-alkali operations in 2026 (BERNARDINO, 2025; BRASKEM, 2021).

In the **Southeast**, **São Paulo** dominates the chlor-alkali segment (**40%**), housing **large-scale plants undergoing continuous technological modernization** - such as the **Cubatão and Santo André units**, which have been adopting membrane-electrolysis technologies, achieving substantial energy-efficiency gains, as well as specific measures to reduce scope 1 and 2 emissions (UNIPAR, 2024). **Espírito Santo and Rio de Janeiro jointly account for 3% of emissions**, reflecting the more limited presence of chlor-alkali plants in the region.

MINING

In the period analyzed, only the **Northeast and Southeast** regions had units considered (**restricted to pelletizing**). The **Southeast** accounted for **90%** of estimated emissions - **47%** in **Espírito Santo** and **43%** in **Minas Gerais** - while **Maranhão**, in the Northeast, accounted for the **remaining 10%**, concentrated in the São Luís facility.

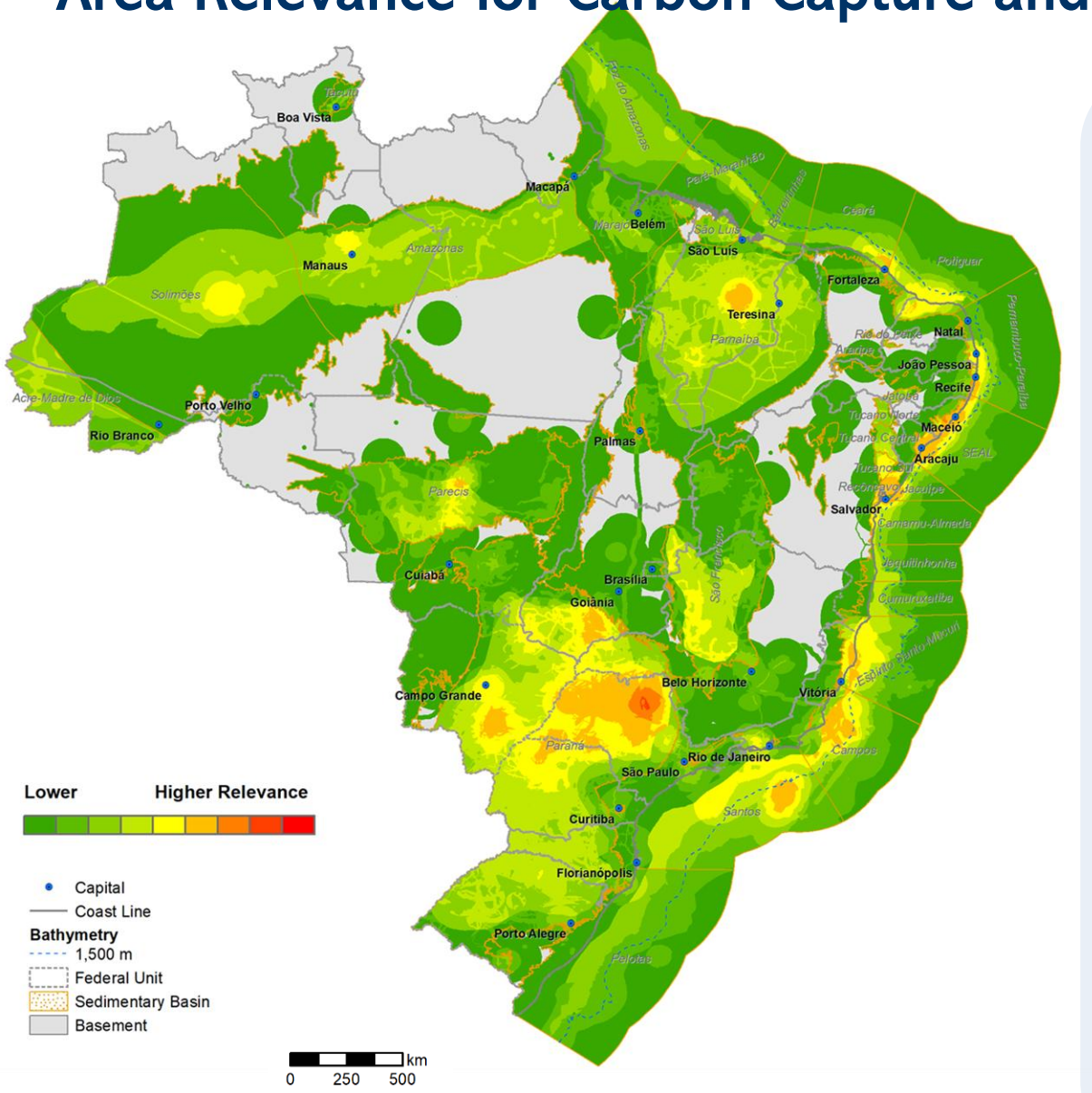
In **Espírito Santo**, the **Tubarão Complex** hosts **one of the most traditional pelletizing clusters in the country**, composed of plants and joint ventures associated with Vale (such as Nibrasco, Itabrasco, Kobrasco, and Hispanobras), which operate (or have operated) **multiple production lines**, in addition to recent initiatives related to iron-ore briquettes (VALEa). The combination of a dedicated port, integrated logistics, and industrial scale helps explain the state's high production volume and, consequently, its total emissions.

In **Minas Gerais**, the **strong mineral base and the integrated operations of companies** such as Samarco sustain significant production volumes. The reactivation of units, with capacity expected to grow through 2028, further reinforces the importance of the MG-ES axis in the sector's aggregate emissions (SAMARCO, 2024).

In **Maranhão**, the **São Luís facility plays a strategic role in Vale's portfolio**. For this reason, **initiatives aimed at innovation and lower-carbon mining are part of the company's agenda**. Since 2022, Vale has had an agreement with Eneva to convert the plant from fuel oil to natural gas—a transition that, once fully implemented, could reduce the facility's GHG emissions by up to 28% (VALEb; VALEc).

Synthesis Map of Area Relevance

Area Relevance for Carbon Capture and Storage Projects



The synthesis map was designed as a decision-support tool, seeking to balance the **two structuring perspectives of this study**: (i) the technical–geological characterization of potential storage sites, and (ii) the economic constraints associated with the viability of CCS routes in Brazil. Although the representation of reservoirs has predominant weight in the spatial analysis, it is recognized that, in the current context, **economic factors tend to exert slightly greater influence on the definition of investment priorities**.

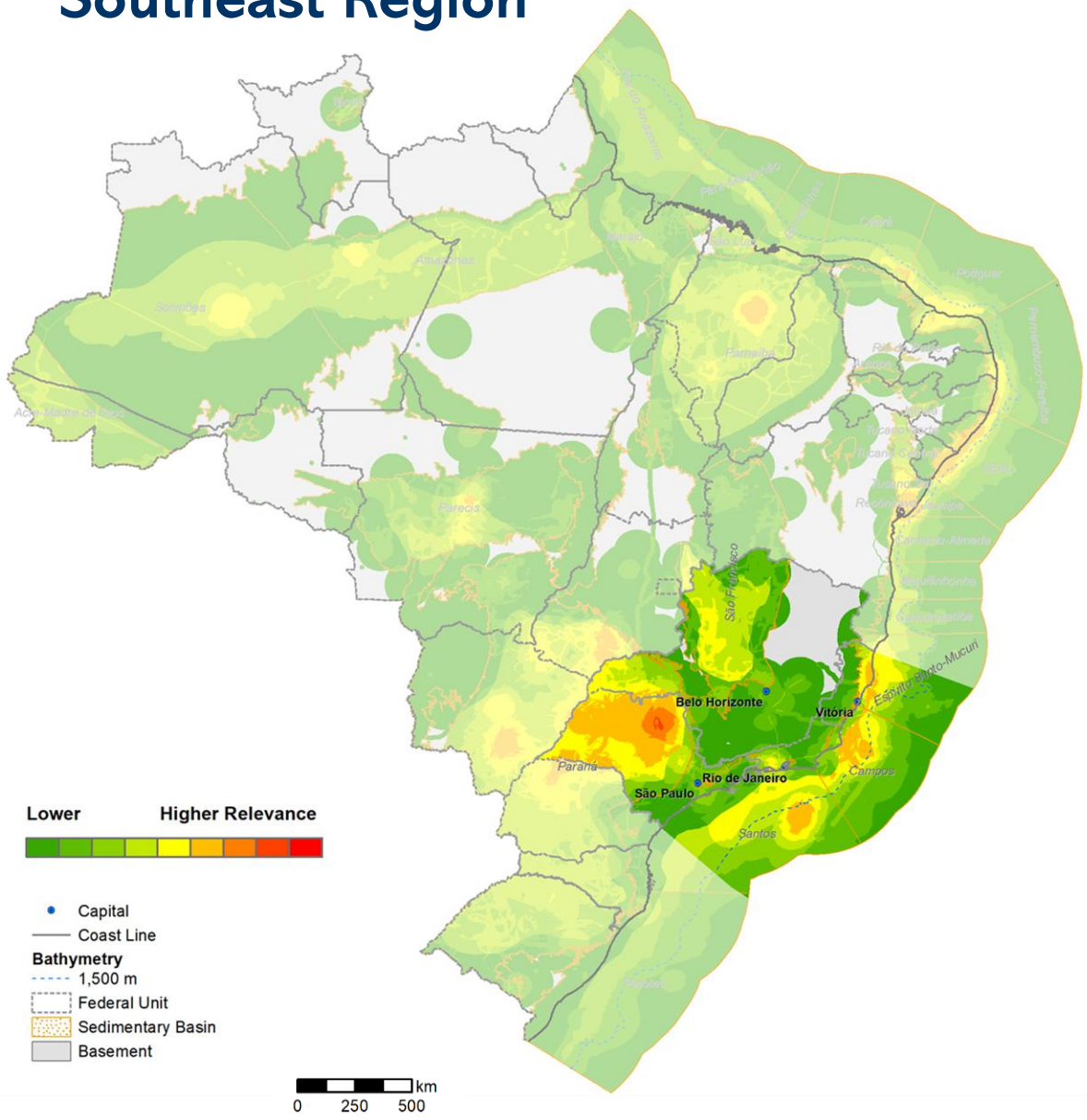
Integrating the six information layers allows the **identification of areas across the national territory where presumed favorable technical conditions** - based on current geological knowledge - **converge with relatively more mature economic environments** for the implementation of carbon capture and geological storage projects. These areas therefore **represent zones with higher potential for the formation of CCS hubs**.

It should be emphasized that **the synthesis map does not incorporate socio-environmental constraints**, such as conservation units, Indigenous lands, and other legally protected areas. This omission reflects the **exploratory and qualitative nature of the product**, **designed** to **identify territorial trends** based on the technical-economic convergence of the six layers. The **spatial potential indicated** here **should not be interpreted as a direct estimate of areas effectively available**; **specific project design** - public or private - **must assess compatibility with environmental and territorial constraints**.

Because the synthesis weighs six layers, variations in the assigned weights—depending on business model, investor profile, or public policy—may materially change the final map, elevating some areas and lowering others. For this reason, the product should be viewed as a **scenario-building tool, not as a single fixed ranking**.

It is also worth noting that, although **the use of captured CO_2 is not explicitly represented** in the spatial model, **it tends to correlate with major emitting clusters and with value chains capable of absorbing this input**. Nevertheless, **CO_2 utilization is not expected to constitute the central axis of initial investments in CCS routes in Brazil**; rather, it will function as **an additional benefit** within **hub configurations** that bring together multiple industrial segments.

Southeast Region

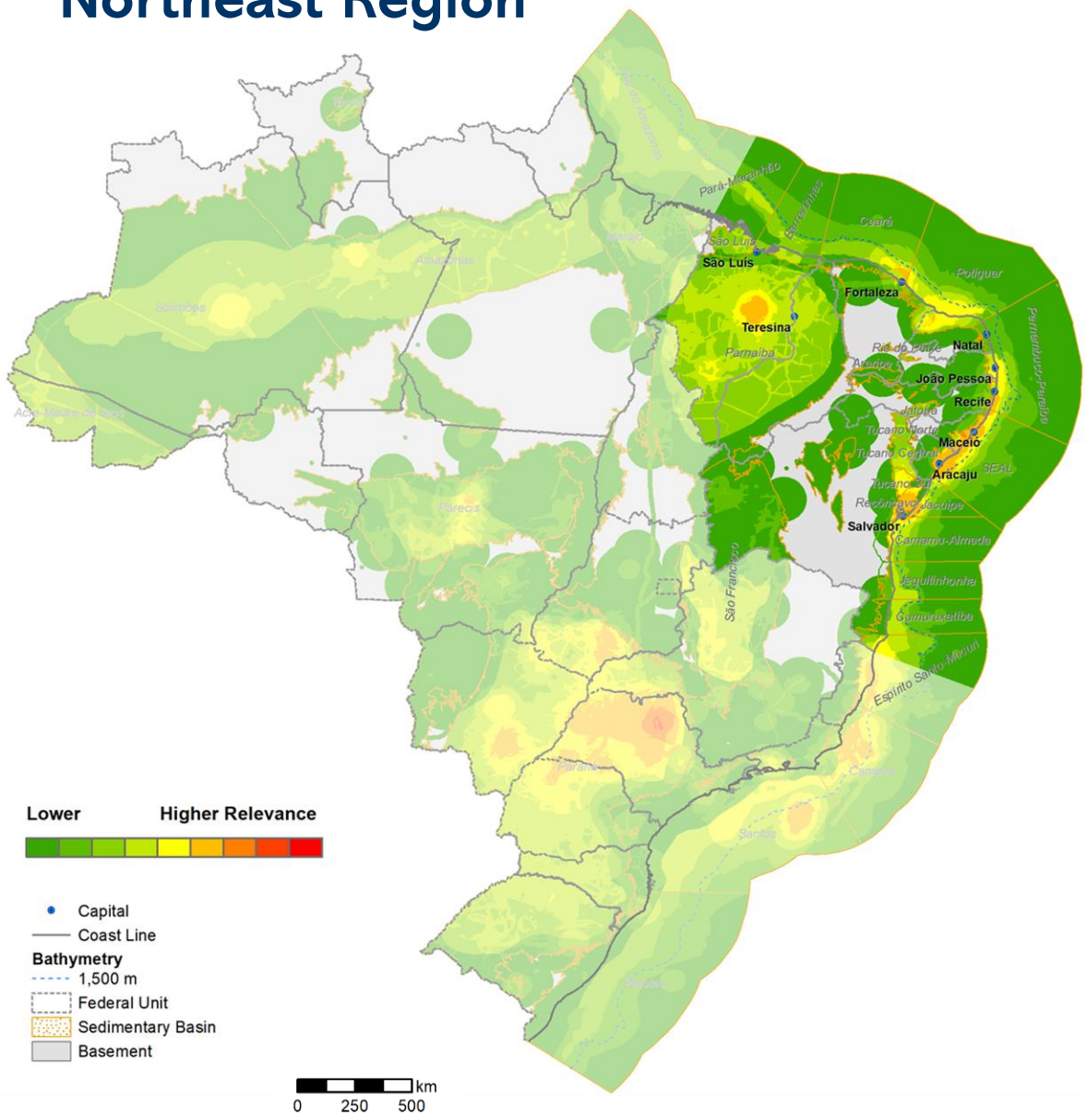


The **Southeast region** remains the portion of the national territory with the **highest relevance** for the development of carbon capture and geological storage projects. This is driven by the **concentration of potential storage sites** of **presumably high quality**, by the **broader availability of geological and geophysical data** (derived from the oil and gas sector), by the presence of the **densest transport-infrastructure network** (pipelines, highways, railways, and port terminals), and by the **diversity of productive sectors with potential demand for CCS solutions** - with particular **emphasis** on the **sugar-energy industry**. In this context, the **state of São Paulo shows the highest assessed relevance**, especially in its central-eastern portion.

In **offshore areas**, although the distance from shore and ultra-deepwater conditions impose logistical and cost challenges, **scaling up projects** that bring together different partners and industrial segments **can help overcome** these **barriers**. The region **hosts proven high-quality reservoirs**, and injection and storage activities associated with enhanced oil recovery (EOR) have been conducted continually for more than a decade.

Since the publication of the first version of this study, **new projects, announcements, and memorandum of understanding have reinforced the growing interest of major Brazilian industrial players** in various carbon-capture and storage routes **across all Southeast states** - initially onshore, but with expectations of expansion offshore (AGÊNCIA PETROBRAS, 2024; 2025b; CHIAPPINI, 2025; MANACÁ CCS, 2024). These initiatives include both deep geological storage (in saline reservoirs, basalts, and other site types) and CO_2 utilization as an industrial input, notably in synthetic fuels and low-carbon construction materials (CNI, 2024; EQUINOR, 2025; PETROBRAS,2025; REPSOL SINOPEC BRASIL, 2025). This movement indicates an increasingly favorable economic and institutional environment for CCS initiatives in the Southeast.

Northeast Region



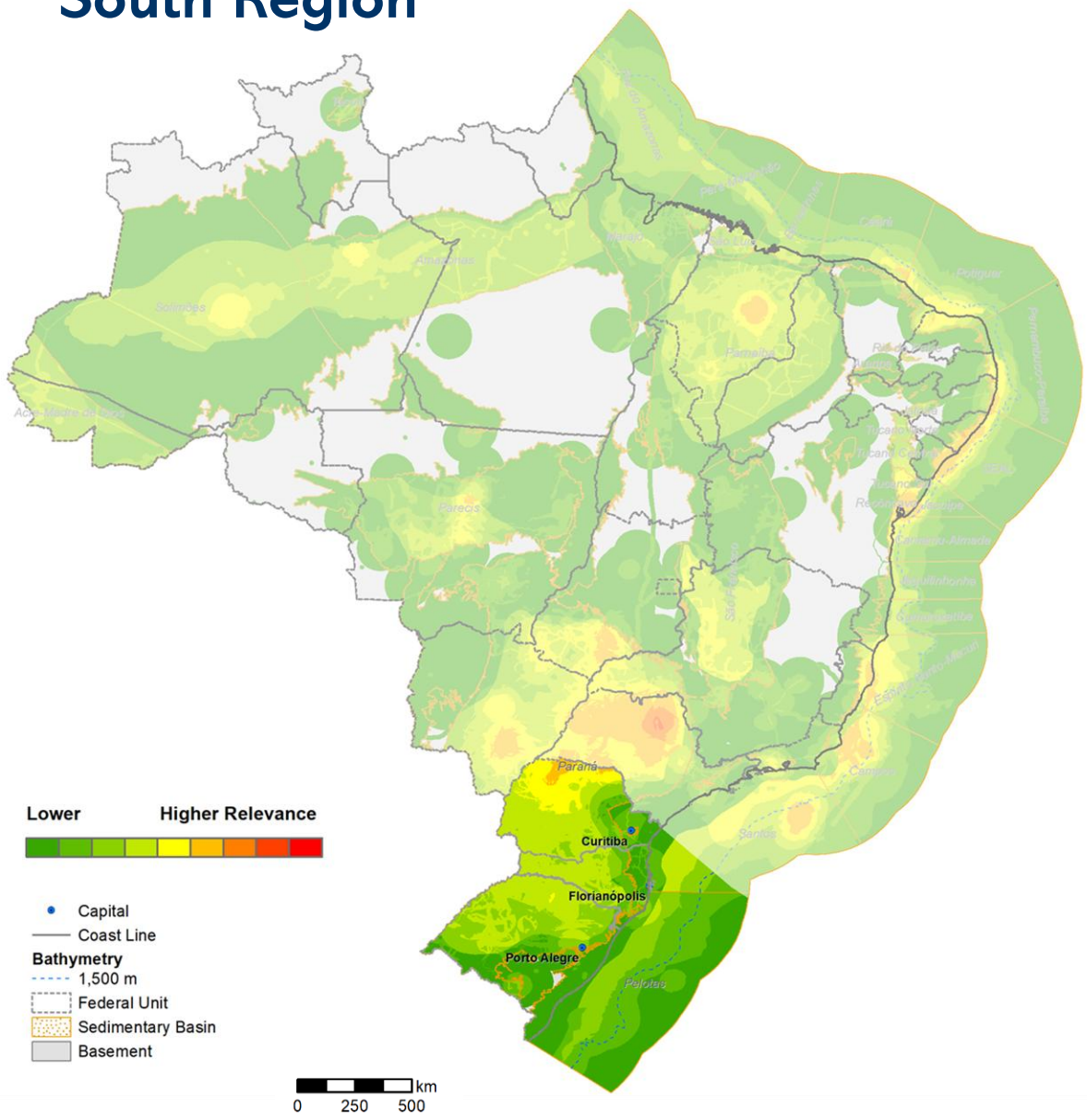
In the **Northeast region**, the highest-relevance areas concentrate **along the coastal belt**, particularly in **Bahia**, **Sergipe**, and **Rio Grande do Norte**, where **hydrocarbon-production activity** has contributed to regional development for decades. These areas combine known, **good-quality reservoirs**, **infrastructure associated with oil and gas**, and an **institutional environment capable of supporting carbon capture and geological storage initiatives**.

The **central-northern portion** of the **Parnaíba Basin** also shows **intermediate relevance**. In this region, **reservoirs** are **well characterized due to natural-gas exploration and production** and are **located near existing or planned infrastructure** that **may serve** potential **cement, chemical, refining, and thermal-power segments**.

Although current relevance levels are lower than those of the Southeast - consistent with methodological assumptions and available data - **the region has increasingly stood out due to research initiatives, cooperation agreements**, and **exploratory studies focused on assessing its storage potential** (AGÊNCIA PETROBRAS, 2025b; CHIAPPINI, 2025).

It is therefore essential that **new investments** be **gradually directed** to the Northeast, **expanding the knowledge base**, **reducing long-standing asymmetries in geological-assessment capacity**, and **creating more balanced conditions for the national development of CCS** routes. The expansion of such investments also represents a **strategic opportunity** for the region, **generating qualified jobs** and **local income and fostering new technical capabilities**. Strengthening professional competencies related to the carbon capture, transport, and storage chain **may position the Northeast as an emerging hub for this agenda**, **contributing to regional economic development and a more inclusive energy transition**.

South Region



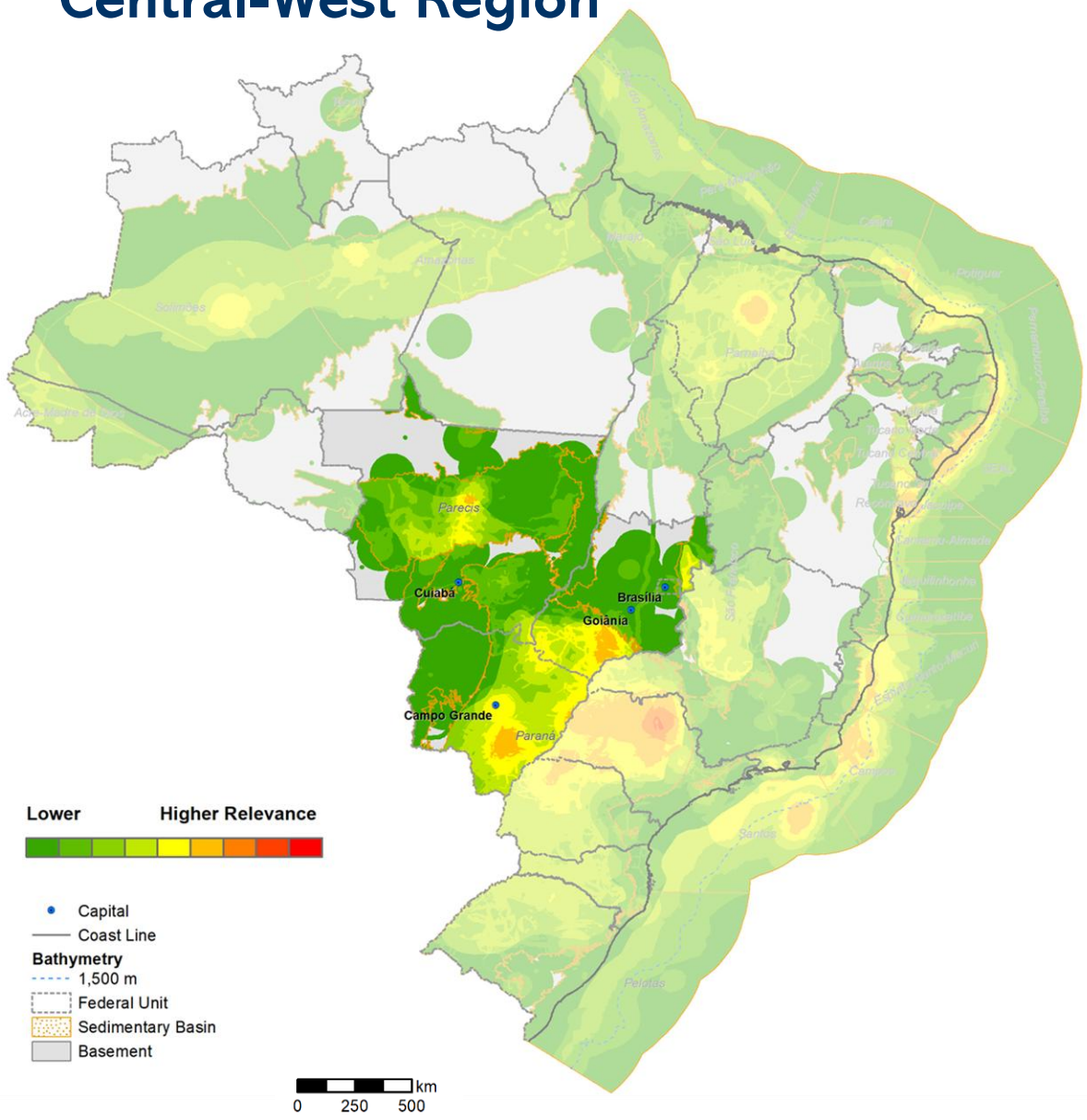
In the **South region**, the relevance of areas for the implementation of carbon capture and storage routes ranges from **low to intermediate**, with a **progressive increase toward the north**, near the border with São Paulo. This trend reflects the **presence of sites** associated with the **Paraná Basin**, particularly **basalts with mineralization potential**, combined with **good coverage of geological and geophysical surveys**. The region also benefits from **robust infrastructure** - highways and pipelines - located **near important emitters** such as **power-generation units** and **pulp-and-paper plants**.

In this same **northern portion**, there is also **strong potential** for leveraging **biogenic CO_2** from **sugarcane fermentation** and, to a lesser extent, from corn, in addition to CO_2 associated with **biomethane**. The convergence of **abundant biomass**, **established logistics**, and **access to potential reservoirs** creates opportunities for **BECCS**.

In the **remainder of the region**, although **relevance levels are lower** due to the reduced expected quality of potential storage sites — largely because of **limited geological and geophysical data** - there is still room for the development of CCS/CCUS solutions supported by the **extensive transport network**. Sectors with potential demand include **steel and chemicals** in Rio Grande do Sul; **cement** in Paraná; **refining and power generation** in both Rio Grande do Sul and Santa Catarina; and the **pulp-and-paper sector** across all three states. It is also worth noting that **the South region concentrates a significant share of Brazilian agribusiness**, being the **national leader in pork production** and **exports**, and **hosting major hubs that convert grains into animal protein** - value chains that may benefit from CCS routes to enhance competitiveness and **reduce the carbon intensity of exported products** (IBGE, 2025).

Additionally, the South has maintained, for decades, a **solid research environment focused on geological storage and carbon-capture technologies**, supported by the commitment of its academic institutions. This ecosystem is exemplified by the **DAC.SI Project**, carried out by PUCRS in partnership with Repsol Sinopec Brasil, responsible for installing the **first direct air capture (DAC) system in Latin America** (PUCRS, 2024). Complementarily, the region's participation in the development of the **CCUS Brazil GIS Platform** (a partnership between Petrobras and PUCRS) contributes to strengthening the national technical foundation for future CCS hubs (PUCRS, 2025).

Central-West Region



In the Central-West region, although **low relevance predominates** - a reflection of the **more limited set of geological and geophysical data considered relevant** for the present assessment and the **restricted variety of transport infrastructure** - there are **zones of medium relevance near corn-producing areas** (especially in the **northern portion**, but present across all three states) and sugarcane-producing areas (particularly in the south and east). In these areas, ethanol derived from these feedstocks enables **BECCS solutions**. It should be noted, however, that the results presented here **reflect a historical limitation in subsurface knowledge of local reservoirs**, as the region's **sedimentary basins were, for many years, not a significant focus of the hydrocarbons industry** - the main driver of subsurface research in the country. With **expanded targeted surveys**, it is likely that **the relevance of these basins may be reclassified to higher levels**.

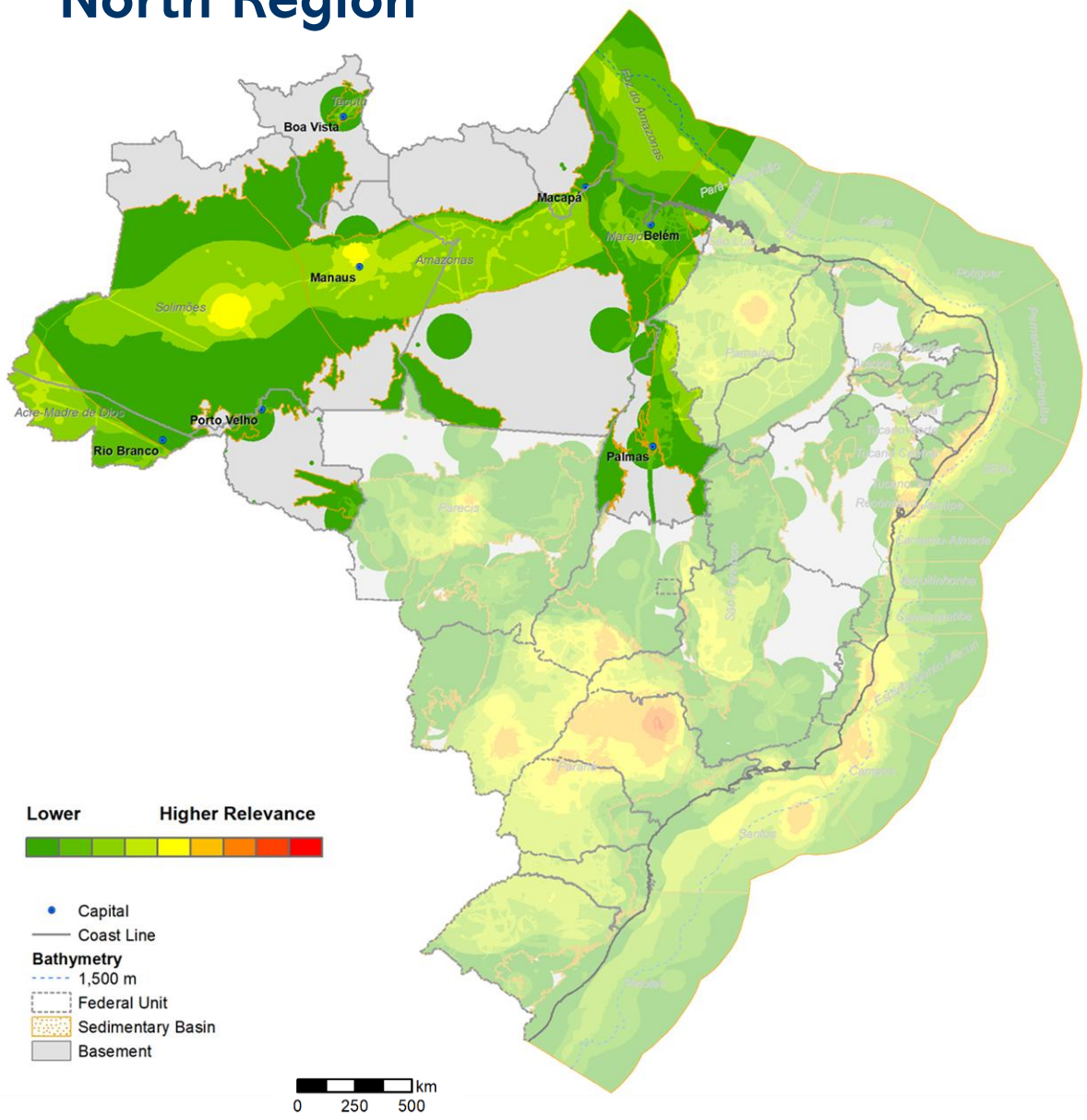
This context has gained strength with recent regulatory advances. In **August 2025**, **ANP authorized FS** - Brazil's largest corn-ethanol producer - **to drill in Lucas do Rio Verde (MT) to assess the feasibility of geological CO_2 storage,** a decisive step toward the implementation of the country's first full BECCS project. In parallel, the **Brazilian Development Bank (Banco Nacional de Desenvolvimento Econômico e Social - BNDES) approved BRL 384.3 million** to build FS's CO_2 capture, compression, and injection unit, capable of removing and storing 423 thousand tCO_2/year, **placing the Central-West at the technological frontier of negative emissions** within the biofuels sector (MARCELINO, 2025a; 2025b).

The strategic importance of the region is reinforced by the **weight of its agribusiness sector in Brazil and globally,** as it **leads national production of grains, animal protein, and agro-industrial inputs**, in addition to its crucial role in the global corn-ethanol market (IBGE). **CCS routes can enhance the competitiveness of Brazilian exports** by allowing biofuels and agricultural products to comply with increasingly strict carbon requirements in international markets.

These technologies also align with **emerging regional opportunities**, such as **low-carbon hydrogen production and the development of nitrogen-fertilizer plants**, which can benefit from stable streams of pure CO_2 and shared capture and transport infrastructure, strengthening regional industrial integration (EPE, 2025).

To consolidate this potential, it will be **essential to expand the transport network, deepen the geological knowledge framework** of the region's basins, and **strengthen local research centers** capable of conducting exploratory and monitoring activities. Building local technical capabilities is crucial to sustaining the new negative-emissions industry that may take shape in the country.

North Region



In the **North region**, areas classified as having **low relevance predominate**. This outcome is linked to the presence of a **unique forest cover**, which has **historically imposed challenges for the development of transport infrastructure** and **limitations in acquiring information on deep reservoir layers**. In this context, **nature-based carbon capture solutions (NbCS) are expected to remain the primary axis of climate action in the region**.

However, from a **technological standpoint**, particularly in the context of CCUS, a **relevant complementary pathway emerges**. For **hard-to-abate sectors** that **require storage alternatives** that are **rapid to deploy**, **long-lasting**, and **less vulnerable to climate extremes**, or for **industries interested in using captured CO_2** as an input for **new products**, CCUS can play a **strategic role**. Thus, although limited in number, **medium-relevance areas appear near established industrial** and **energy infrastructures** - such as **natural-gas fields**, **thermal power plants**, **cement plants**, and **pelletizing units** - across the states of Amazonas, Pará, and Maranhão.

Additionally, the region presents the possibility of forming "**isolated hubs**" for carbon capture and storage, particularly in the **state of Amazonas**, where the spatial configuration of productive activities - concentrated in clusters disconnected from major national logistics networks - **favors autonomous arrangements** for carbon capture, utilization, and storage. **These hubs can integrate specific industrial emissions** with nearby storage solutions or CO_2 utilization routes, fostering **local innovation and reducing logistical dependencies**.

The region is also beginning to **attract investments from major industrial players** focused on the **use of captured CO_2**. One example is **Vale**, which **invested in Circlua**, a company dedicated to **developing low-emission cement from mining waste**. A project is currently underway to install a Circlua facility in **southeastern Pará**, which will use tailings from the Carajás Complex as feedstock, **enabling the production of low-carbon cementitious materials and significantly reducing clinker use** - the main source of CO_2 in cement manufacturing (BRASIL MINERAL, 2025). This strategy reinforces the **potential of the North region to integrate circular-economy practices and industrial innovation**, broadening the **range of opportunities associated with the carbon capture and storage** value chain.

Key Conclusions

There has been a notable increase in interest across the different routes for carbon capture, transport, utilization, and geological storage, particularly regarding their **applicability across multiple industrial sectors** and the opportunity to employ a **variety of storage sites throughout the country**.

The integration of selected information made it possible to **identify areas within the national territory where favorable geology** (based on the current state of knowledge) and **economic/logistical conditions align** - that is, **where projects, especially hubs** for carbon capture, transport, utilization, and geological storage, **are more likely to be viable**. The methodological enhancements adopted **increased the discriminatory power of the map**, reinforcing its **usefulness in guiding decision-making**.

Brazil's logistics network, **concentrated along the Southeast–Northeast coastal belt**, **favors the large-scale transport of CO_2** (particularly via **pipelines** and **ports**). However, **extending infrastructure into the interior requires robust technical and economic solutions**, as well as a **clear regulatory framework** and **risk-reduction mechanisms** - an insight consistent with international experience, where transport and storage frequently constitute bottlenecks due to high CAPEX and regulatory complexity.

The **bioenergy sector** stands out for **fitting into multiple business models** and for **combining sustainable biomass availability**, **technological maturity**, and **long-standing integration with climate-policy instruments**. These characteristics place Brazil in a privileged position to scale BECCS as a negative-emissions solution.

Key Conclusions

Emissions from hard-to-abate sectors are large and highly concentrated, especially in the **Southeast**, with the **Northeast** and **South** appearing as secondary poles - an emissions geography that **reinforces the feasibility of establishing capture hubs** close to major industrial clusters.

Although the **utilization of CO_2** is not explicitly modeled in the spatial analysis, it **tends to follow emitting clusters** and value chains capable of absorbing this input. Nevertheless, CO_2 use **should function mainly as an additional benefit** within hub configurations, rather than as the primary driver of early investment.

By integrating multiple lines of evidence, **the study reaffirms Brazil's potential** to capture, transport, and store CO_2 and sets the goal of progressing toward quantitative assessments, even amid current limitations in specific data. **Strengthening collaboration** with the **community engaged** in these alternatives is **essential** - and an irreversible step - **for Brazil to increasingly understand and project its role in the global CCS landscape**.

Brazil presents **favorable conditions** for the **advancement of CCS pathways**, with potential applications across the energy and industrial sectors, as well as synergies with other decarbonization strategies. Although challenges persist - and are not unique to the national context - the country has made **progress in structuring public policies**, many of which remain in the **implementation phase**. The realization of this potential, however, will depend on the **coordinated acceleration of these actions**, through the adoption of **instruments** capable of **reducing risks**, **supporting first-of-a-kind projects**, and **fostering market formation**, in order to enable **projects at scale** and allow the relevant sectors to effectively contribute to **CO_2 emissions reductions and removals** consistent with the country's climate commitments.

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