TECHNO-ECONOMIC ANALYSIS OF CARBON MITIGATION TECHNOLOGIES
CA21127

CCUS National Research Agenda

Country: Portugal
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Abstract

Portugal's National Research Agenda for Carbon Capture, Utilization and Storage (CCUS) highlight the role of CCUS as a complementary technology in achieving the country's climate neutrality objectives. Portugal aims to reduce greenhouse gas emissions by at least 55% by 2030 and achieve net-zero emissions by 2050, in line with European Union climate targets. Although national decarbonization efforts primarily focus on renewable energy, electrification, energy efficiency, and natural carbon sinks, CCUS is recognized as a strategic option for mitigating emissions from hard-to-abate industrial sectors such as cement, refining, chemicals, glass, and waste-to-energy facilities. The agenda identifies significant CO_2 capture opportunities within industrial clusters, particularly in the Sines Industrial and Logistics Zone, while acknowledging the absence of operational transport and storage infrastructure. Portugal possesses substantial geological storage potential, estimated at more than 7 $GtCO_2$, mainly in the Lusitanian, Porto, and Algarve basins. Current research activities focus on post-combustion capture technologies, CO_2 transport modelling, carbon utilization pathways including synthetic fuels and mineralization, and geological storage characterization. However, most initiatives remain at laboratory, pilot, or early demonstration stages. Key challenges include high technology costs, limited economies of scale, regulatory uncertainties, insufficient infrastructure, and low public awareness of CCUS technologies. The agenda emphasises the need for large-scale demonstration projects, integrated transport and storage networks, clear permitting procedures, stakeholder engagement, and stronger collaboration among government, industry, and research institutions. Future priorities include developing a national CCUS roadmap, improving economic viability, expanding storage assessments, and integrating CCUS with renewable energy and hydrogen systems. Overall, the agenda positions CCUS as an important enabling technology for industrial decarbonization and long-term climate neutrality in Portugal.

Keywords: Carbon Capture, Utilization and Storage (CCUS); Climate Neutrality; Industrial Decarbonization; CO_2 Capture; Geological Storage; Carbon Utilization; Portugal; Energy Transition; Carbon Management; Climate Policy.

Date of Submission: 30 May 2026

A. Policy and Targets

National GHG reduction targets	Portugal has set ambitious GHG emission reduction targets under the Climate Framework Law (Law No. 98/2021) and the National Energy and Climate Plan (NECP). By 2030, the country aims for at least a 55% reduction in total greenhouse gas emissions compared to 2005 levels, in line with the EU Effort Sharing Regulation. This

	target supports the EU-wide 2030 goals and is backed by specific policies on renewables, energy efficiency, and sectorial measures. For the longer term, Portugal targets climate neutrality (net-zero) by 2050, with a gross emissions reduction of around 90% versus 2005, complemented by carbon removals (mainly through LULUCF sinks). An intermediate target of 65–75% reduction is established for 2040. Some strategic documents also mention advancing neutrality toward 2045. These goals are enshrined in national law and regularly updated in official NECP reports.
Role of CCUS in Strategy	In Portugal's updated National Energy and Climate Plan (NECP 2023/2024) and the Long-Term Strategy (RNC2050), CCUS/CCU is explicitly mentioned, although in a supportive and non-central role. The documents recognise carbon capture, utilisation, and storage as relevant technologies for decarbonising hard-to-abate industrial sectors (such as cement, chemicals, and refining), referencing the EU Net Zero Industry Act and the need for further development of CO_2 storage solutions. CCUS is not considered a key or priority technology in Portugal's strategy. The NECP and national plans place the main emphasis on renewables, electrification, energy efficiency, and natural sinks. CCUS is viewed as a complementary, longer-term option for residual industrial emissions, with limited concrete deployment targets, no operational storage projects yet, and focus mainly on R&D, economic assessment, and future monitoring.
CO_2 capture potential/needs	Portugal has a moderate but strategically important CO_2 capture potential, driven mainly by a small number of concentrated industrial emission sources rather than a broad heavy-industrial base. The most relevant capture opportunities are located in industrial clusters such as Sines Industrial and Logistics Zone, where refining, petrochemicals, and power generation facilities create relatively large and continuous CO_2 streams suitable for capture. Additional potential exists in **hard-to-abate sectors such as cement, lime, and ceramics**, particularly in central and northern Portugal. However, overall national capture volumes are smaller compared to large industrial countries, meaning economies of scale are limited and CCUS deployment will likely depend on shared infrastructure and hub-based systems. In terms of **needs, Portugal requires significant advancement in capture technology demonstration, cost reduction, and system integration**. A key gap is the lack of large-scale pilot and demonstration projects that validate capture performance under Portuguese industrial conditions. There is also a need to adapt capture technologies (post-combustion, oxy-fuel, and pre-combustion systems) to integrate with renewable-heavy electricity systems and future hydrogen-based industrial processes.

	Strengthening collaboration between industry and research institutions such as “Laboratório Nacional de Energia e Geologia” is essential to develop locally optimized solutions and reduce energy penalties and costs. Ultimately, Portugal’s capture potential is technically feasible but economically constrained, requiring policy support and shared infrastructure to become viable at scale.
CO_2 transport/ storage targets	**Portugal’s updated NECP (2024) includes an indicative target of capturing and storing about 4 Mt CO_2 per year by 2030 through CCUS**, mainly for hard-to-abate industrial sectors. However, there are currently no operational CO_2 transport infrastructure, pipelines, or storage facilities in the country. Portugal has significant theoretical geological storage potential (estimated at over 7 $GtCO_2$ across basins like Porto, and Algarve), but concrete transport and storage targets remain limited to exploratory assessments, R&D, and future mapping, with no firm deployment timelines or capacities defined

B. Regulatory Framework

EU Directive transposition	**The EU CCS Directive (2009/31/EC) was transposed into Portuguese national law through Decree-Law No. 60/2012, of 14 March.** This decree establishes the legal framework for the geological storage of carbon dioxide, transposing the Directive’s provisions on exploration, storage permits, environmental protection, and liability. Subsidiary legislation, such as Decree-Law 30/2021, of 7 May, also applies in some aspects.
Permitting status	

C. CCUS Research Funding and Institutions

Main funding sources	**The primary national funding programs and agencies supporting CCUS research in Portugal are:** • **Fundação para a Ciência e a Tecnologia (FCT)**: The main national research funding agency, which directly finances CCUS-related projects, including participation in European partnerships such as the Clean Energy Transition Partnership (CETP), where it funds topics on carbon capture, utilisation, and storage. • **Portugal 2030 Framework (and associated programmes such as COMPETE 2030 or the Climate Action and Sustainability Programme)**: Provides EU co-funded support for innovation, decarbonisation, and green transition projects, including research and pilot initiatives involving CCUS technologies.

	• **Recovery and Resilience Plan (PRR)**: Supports strategic R&D projects in energy transition and climate neutrality, with some funding allocated to CCUS-related geological and industrial research. • **Environmental Fund (Fundo Ambiental)**: Finances environmental and climate projects, including studies and initiatives linked to carbon capture and storage. Additional targeted support comes through state-aid schemes (e.g., the €1 billion scheme approved in 2024 for equipment and technologies, including CCUS) and co-financing via DGEG or LNEG for specific geological storage assessments. Most CCUS research also leverages EU programmes (Horizon Europe, LIFE, etc.).
Key research institutions	*Instituto Superior Técnico* *Universidade do Porto – Faculdade de Ciências FEUP* *Universidade Nova de Lisboa – Faculdade de ciências*
Major national projects	**In Portugal, CCUS R&D focuses primarily on post-combustion capture using solvents for hard-to-abate industrial sectors (cement, glass, waste-to-energy, and refining), alongside geological storage characterisation.** There is limited activity in Direct Air Capture (DAC), which remains at very early conceptual or negligible levels. Key players like NET4CO2 (a collaborative lab between academia and industry) conduct solvent and catalyst testing at laboratory scale, while EU-funded projects (e.g., STRATEGY CCUS and PilotSTRATEGY) emphasise industrial capture routes and storage in the Lusitanian Basin. **Achievements remain at lab/pilot planning stage with no large operational capture plants yet.** NET4CO2 operates lab facilities for CO_2 capture testing. A notable 2025 pilot at Valorsul's São João da Talha waste-to-energy plant tests Hovyu's Hyperion electrified solvent-based technology (TRL 5) under real conditions. Planned pilots (target ~2028–2030) at cement (e.g., CIMPOR) and glass plants aim for up to 100 ktCO_2/year capture in cluster scenarios. Breakthroughs centre on storage site characterisation and solvent performance evaluation rather than commercial-scale deployments.

D. Focus Areas and Achievements

CO_2 capture eesearch	**In Portugal, CCUS R&D focuses primarily on solvent-based post-combustion capture** for hard-to-abate sectors such as waste-to-energy, cement, glass, and refining, with emphasis on industrial flue gases and geological storage characterisation in the Lusitanian Basin. Activity in Direct Air Capture (DAC) is negligible or at conceptual level only.**Key achievements remain at laboratory to small pilot scale.** NET4CO2 operates lab facilities for solvent and process testing. In 2025, Valorsul launched Portugal's first operational carbon capture pilot at the São João da Talha waste-to-energy plant using Hovyu's Hyperion electrified

	solvent technology (TRL 5). Planned pilots at cement (e.g., CIMPOR) and glass plants target up to 100 ktCO_2/year by 2028–2030, with breakthroughs centred on solvent performance and storage site assessment rather than large-scale deployment.
CO_2 transport research	**In Portugal, CCUS CO_2 transport R&D focuses mainly on multi-modal options** — including pipeline network modelling and optimisation, shipping, rail, and truck transport — with emphasis on cost-effectiveness, integration with industrial clusters (e.g., cement and glass), and connection to onshore storage in the Lusitanian Basin or offshore sites. Studies address pipeline routing, transport security, regulatory frameworks, and hybrid solutions (e.g., small pipelines combined with rail or ships), particularly through projects like NET4CO2, STRATEGY CCUS, and PilotSTRATEGY. **There is no national CO_2 pipeline master plan or operational infrastructure yet.** Achievements are limited to conceptual and modelling studies (e.g., COMET project pipeline network scenarios and NET4CO2 economic models for different transport modes), with indicative future cluster-based pipeline networks proposed in regional scenarios but no concrete construction timelines or dedicated backbone plans approved.
CO_2 utilization (CCU) research	**In Portugal, CCU R&D focuses on conversion of captured CO_2 into synthetic fuels (e-fuels/methanol via electrochemical and catalytic routes) and carbonated building materials (mineralization for low-carbon concrete blocks, aggregates, and construction products).** NET4CO2 leads these efforts, with projects exploring CO_2-to-methanol, synfuels, and mineralization pathways to support decarbonization of hard-to-abate sectors and the construction industry. **Achievements are primarily at laboratory and early demonstration scale.** NET4CO2 operates prototypes for CO_2-based methanol and synfuel production, alongside an active R&D project on carbonated building blocks (2025–present) assessing CO_2 uptake potential and integration into Portuguese concrete/ceramic materials. No large-scale industrial CCU demonstrations exist yet; activities remain focused on techno-economic studies, lab testing, and pilot planning.
CO_2 geological storage research	**In Portugal, CCUS geological storage R&D focuses primarily on deep saline aquifers (DSAs) in the Lusitanian Basin**, both onshore and offshore, with additional potential assessed in the Porto and Algarve basins. Studies emphasise characterisation of reservoir quality, caprock integrity, seismic risks, and mineralogical constraints, favouring offshore sites for higher capacity and better public acceptance, while exploring hybrid onshore-to-offshore solutions. **Achievements include the development of national-level storage assessments and atlases** through projects like KTEJO, COMET, STRATEGY CCUS, and PilotSTRATEGY. Portugal has estimated a theoretical storage capacity

	of around **7 GtCO_2** (with Lusitanian Basin contributing over 3 Gt), including detailed regional mapping of 17+ sites, though these remain at pre-commercial maturity (Tier 1–2) with no operational storage sites yet.

E. CCUS Value Chain

CCUS value chain component	**Key national research gaps/needs** *(What is missing?)*	**Proposed future research priority areas** *(What should be prioritized?)*
CO_2 capture	Demonstration of capture technologies in Portuguese hard-to-abate industries (especially cement, lime, and refining). • Reduction of capture costs and energy penalties. • Integration of CCUS with renewable electricity and hydrogen systems.	• Practical implementation framework for permitting storage projects. • Clarification of long-term liability and stewardship responsibilities. • Regulatory guidance for offshore CO_2 storage operations. Although legislation exists, no storage permits have yet been granted
CO_2 transport	**In Portugal, key research gaps in CO_2 transport centre on the lack of detailed infrastructure planning and network optimisation.** There is currently no national CO_2 pipeline master plan, and further studies are needed on optimal routing, multi-modal integration (pipelines combined with shipping, rail, or trucks), and cost-effective connections between industrial emission clusters and storage sites, particularly in the Lusitanian Basin. Additional gaps exist in safety standards, regulatory frameworks for transport, and techno-economic assessments for large-scale deployment. **Maritime and cross-border transport also represent important research needs**, including port infrastructure adaptation, shipping logistics, and potential international agreements for CO_2 export or offshore storage. Overall, Portugal requires more advanced modelling, risk analysis, and de-risking studies to move beyond conceptual stages such as highlighted	Social acceptance studies for CO_2 transport and storage. • Community engagement frameworks for coastal and offshore projects. • Communication strategies addressing safety, transparency, and local benefits.

	in projects such as NET4CO2 and STRATEGY CCUS — to support the indicative 4 $MtCO_2$/year capture target by 2030.	
CO_2 utilization (CCU)	• Market assessment for CO_2-derived products. • Research on synthetic fuels (e-fuels), chemicals, and mineralization pathways. • Evaluation of economic viability and lifecycle emissions of utilization routes.	• National CCUS deployment roadmap aligned with carbon neutrality targets. • Integrated modeling of CCUS, renewable energy, hydrogen, and industrial decarbonization. • Business models, incentives, and financing mechanisms.
CO_2 geological storage	Socio-economic Gaps • **Limited public awareness and acceptance** of CO_2 geological storage technologies. • **Few studies on social perception** of onshore and offshore CO_2 storage projects. • **Lack of stakeholder engagement frameworks** involving communities, municipalities, industry, and NGOs. • **Insufficient assessment of regional economic impacts**, including job creation, local development, and just-transition opportunities. • **No established benefit-sharing mechanisms** for communities hosting storage infrastructure. • **Limited national expertise and workforce capacity** for large-scale CCS deployment.	Clear implementation procedures for CO_2 storage licensing and permitting. • Clarification of long-term liability and post-closure responsibilities. • Regulatory guidance for offshore storage projects. • Alignment of Portuguese CCS regulations with evolving EU CCUS policies. Although Portugal has a legal framework (Decree-Law 60/2012), no storage permits have yet been granted.
Socio-economic & Policy	Policy and Governance Gaps • **No comprehensive national CCS deployment strategy or roadmap** linking capture, transport, and storage.	Detailed cost-benefit analyses for Portuguese storage projects. • Sustainable financing mechanisms and investment models. • Assessment of incentives (EU ETS, Contracts for Difference, Innovation Fund

	• **Uncertainty regarding long-term liability** and responsibility after site closure. • **Limited practical experience with permitting and licensing procedures**, as no commercial storage projects have yet been developed. • **Lack of clear economic incentives** specifically supporting geological storage investments. • **No established business models** for transport and storage infrastructure operators. • **Insufficient coordination between government, industry, and research institutions** for CCS implementation. • **Limited cross-border policy planning** with neighboring countries and European CO_2 transport/storage networks.	support). • Revenue models for transport and storage infrastructure.

F. Main barriers to CCUS deployment

Political	• Absence of a comprehensive national CCUS deployment strategy and roadmap. • Regulatory uncertainty regarding long-term liability for stored CO_2. • Limited experience with permitting and licensing of CO_2 storage projects. • Slow development of policies supporting CO_2 transport and storage infrastructure. • Competition with other decarbonization priorities (renewables, electrification, hydrogen).
Economic	• High capital and operational costs of carbon capture technologies. • Lack of strong financial incentives and dedicated funding mechanisms. • Uncertain business case due to fluctuating carbon prices and market conditions. • Significant investment required for CO_2 transport and storage infrastructure. • Limited economies of scale because Portugal has relatively few large industrial emitters compared with major European CCS hubs.
Technical	• Limited characterization and validation of geological storage sites. • No operational CO_2 storage projects to demonstrate feasibility. • Lack of CO_2 transport infrastructure (pipelines, shipping terminals, hubs). • Need for pilot and demonstration projects to reduce technical uncertainty. • Limited national expertise and workforce specialized in large-scale CCS operations.

Societal	• Low public awareness and understanding of CCUS technologies. • Concerns about CO_2 leakage, environmental impacts, and safety. • Potential local opposition to transport and storage infrastructure. • Lack of structured stakeholder engagement processes. • Limited research on public perception and social acceptance of geological storage in Portugal. These barriers are interconnected: without clear policy support, investment remains limited; without investment, demonstration projects are delayed; and without successful projects, public confidence and acceptance are harder to build.

G. Key facilitating factors

Industrial clusters	• Presence of major industrial hubs with concentrated CO_2 emissions, particularly the Sines Industrial and Logistics Zone cluster. • Large emitters in cement, refining, petrochemicals, and power generation that can benefit from shared CCUS infrastructure. • Potential development of CO_2 hubs that reduce transport and storage costs through economies of scale. • Strategic Atlantic location that could support CO_2 shipping networks and international storage value chains.
National expertise	Strong research capabilities in geology, energy systems, and carbon management at organizations such as Laboratório Nacional de Energia e Geologia (LNEG), Instituto Superior Técnico, and University of Nova - Lisboa. • Existing expertise from geological studies of Portuguese sedimentary basins and offshore resources. • Growing experience in energy transition, renewable energy integration, and hydrogen projects. • Participation in European CCUS research and innovation networks.
Policy incentives	• Alignment with Portuguese carbon neutrality goals and EU climate targets. • Access to European funding mechanisms, including the EU Innovation Fund and other EU decarbonization programs. • Economic incentives created by the European Union Emissions Trading System (EU ETS), which increases the cost of emitting CO_2. • Growing policy support for hard-to-abate sectors such as