



Italy's potential to deploy CDR at scale and speed

Background report

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A collaboration between

carbon gap



About the Carbon Removal Readiness Assessment project

Many governments have committed to net zero; moreover, the IPCC forecasts the need for hundreds of billions of tonnes of carbon dioxide removal (CDR) to stabilise global temperatures well below 2°C. Yet, few if any countries currently have a robust plan to develop and deploy atmospheric CDR at the capacity required to counteract remaining emissions at the point of net zero. Forecasted CDR needs are typically global in scope and do not inform CDR planning and policy design at the country level.

The Carbon Removal Readiness Assessments (CRRA) aim to fill this information gap and to support national policymakers in complementing their climate strategies with ambitious yet realistic CDR goals. The CRRA estimates the extent to which CDR countries can realistically deploy CDR using a bottom-up approach and provides country-specific roadmaps, developed in consultation with local stakeholders, to assist decision-makers in understanding the opportunities and the actions needed to realise them.

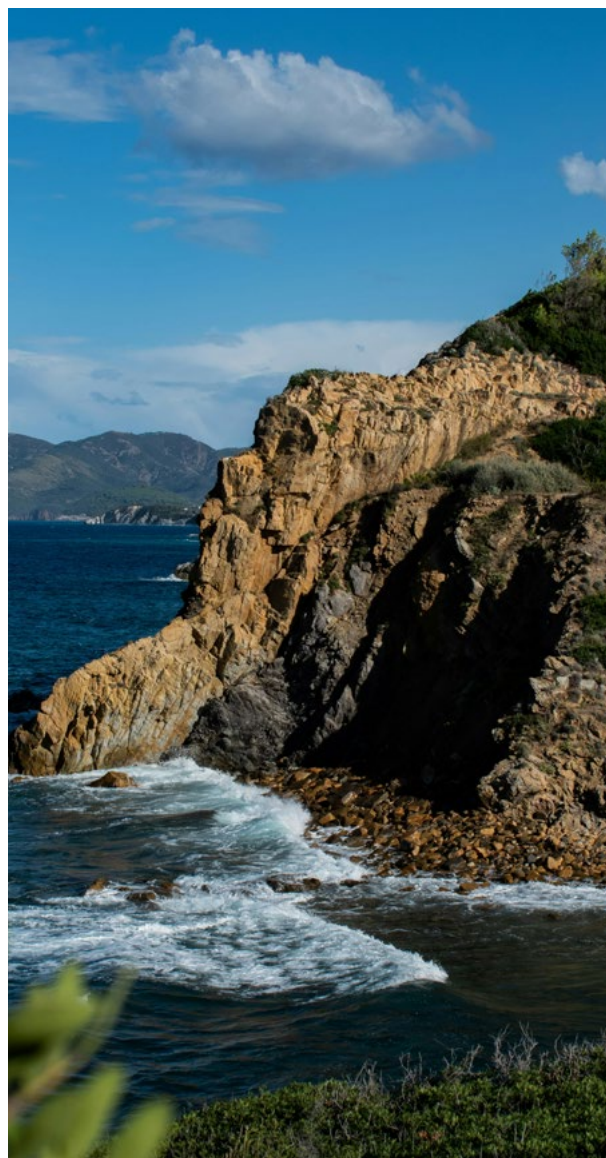
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Disclaimer

This document presents a quantified estimate of Italy's potential for deploying CDR methods. Because most of the methods assessed in this report are still in the early stages of development, the assessment is subject to significant uncertainty. Some methods may not prove viable, while others excluded from this report may develop more quickly than expected. CRRA assesses the technical and physical feasibility of CDR deployment at the country level and is not a substitute for project-level feasibility studies or techno-economic assessments.

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Executive summary

In the aftermath of COP30 in Belém, where governments reaffirmed the 1.5°C objective despite widespread recognition that a temporary overshoot is now highly probable, Europe is already experiencing the consequences of a rapidly warming climate. The summer of 2024 became the continent's deadliest on record, with an estimated 62,775 heat-related deaths, including more than 19,000 in Italy alone. This combination of accelerating Mediterranean warming and a highly vulnerable, ageing population illustrates why Italy's climate trajectory - and its ability to reduce emissions, strengthen adaptation, and scale carbon dioxide removal (CDR) - has become a strategic priority.

This moment of heightened climate risk coincides with a period of strategic uncertainty for Italy. National climate policy is evolving amid debates over the pace of emissions reductions, the implementation of the National Climate Adaptation Plan, and the emergence of carbon capture, utilisation and storage (CCUS) frameworks. Recent signals from the government have reflected both hesitations and openings on climate ambition, creating a complex backdrop for long term planning. This evolving context complicates long-term planning and makes the need for a coherent CDR pathway all the more pressing.

Italy is entering a decisive decade for CDR. Despite steady emissions reductions, current policies leave the country on a trajectory that overshoots a linear path to climate neutrality by nearly 60% by 2050, even when counting existing natural sinks. In 2023, gross GHG emissions (excluding LULUCF contributions) were nearly 385 MtCO₂e, and the most optimistic official long-term scenarios still project **68–100 MtCO₂e** of residual emissions in 2050 that must be neutralised through a mix of engineered CDR and land sinks¹. This range reflects subsequent modelling (Gaeta et al.) building on the Long-Term Strategy (LTS), spanning scenarios from near-zero emissions in the power-sector and fully electrified transport, to more conservative pathways with continued fossil fuel use in heavy industry and unconstrained aviation (upper bound).²⁴

The Carbon Removal Readiness Assessment (CRRA) for Italy evaluates the country's capacity to meet this challenge. It distinguishes between Italy's **theoretical CDR potential** - what could be deployed based on its resource capacity under a maximalist scenario - and its **realistic CDR potential**, which reflects what can be achieved when political, economic, and social

constraints are taken into account. Together, these assessments clarify both the scale of action possible and the level of action required for Italy to integrate credible CDR into its 2050 net zero strategy.

The assessment follows six key steps:

1. Identification and selection of relevant CDR methods;
2. Mapping of available resources for CDR, including renewable electricity, waste heat, biomass, land, water, and geological storage capacity, among others;
3. Estimation of the **maximum theoretical CDR potential** for 2050;
4. Evaluation of Italy's regulatory, economic, and political landscape;
5. Analysis of societal attitudes toward CDR deployment in Italy, based on stakeholder interviews and a citizen panel;
6. Estimation of the **realistic CDR potential** for 2030, 2040, and 2050 based on three scenarios (Reference, Conservative, and Ambitious).

Main results on Italy's CDR potential

The report reviews a range of CDR methods – grouped into ecosystem management, biomass conversion, geochemical, and synthetic approaches – and assesses their respective theoretical and realistic potentials based on Italy's available resources (e.g. renewable electricity, waste heat, biomass, land, water, minerals, and geological storage). This comprehensive evaluation leads to a **theoretical maximum CDR potential of ~233 Mt CO₂ per year by 2050**, assuming that all available physical and natural resources were fully dedicated to CDR purposes after discounting for priority uses as described in section 4.1. Such a level of resource mobilisation would not be attainable under real-world conditions but provides a benchmark for understanding Italy's technical capacity to remove carbon. The theoretical potential is dominated by ecosystem-based methods - over 116 MtCO₂/year excluding the existing forest sink, followed by biomass conversion methods with 78 MtCO₂/year, synthetic methods (i.e. DACCS) with 33 MtCO₂/

year, and geochemical approaches with 6 MtCO₂/year. DACCS potential is constrained by geological storage availability and assuming this was not a limiting factor, this method could add up to 148 MtCO₂/year to the theoretical potential.

Next, by applying more realistic and conservative assumptions about resource use, and incorporating policy constraints, social geography and insights from stakeholder interviews and the citizen panel, the report develops **three realistic CDR scenarios** for 2030–2050: Conservative, Reference, and Ambitious. All are anchored to Italy's official decarbonisation path, the Long-Term Strategy, with a midpoint estimate of Italy's residual emissions of 84 MtCO₂/year (the arithmetic midpoint of the LTS scenario family^{1,24}) to be counterbalanced by 2050.

In the **Conservative scenario**, slow permitting processes, weak financial incentives, and low social acceptance keep CDR deployment limited, resulting in a CDR capacity of only **18 Mt CO₂ per year** by 2050. When combined with a natural sink of around 35 MtCO₂ per year, Italy reaches a total carbon removal capacity of roughly **53 Mt CO₂ annually** - insufficient for achieving net zero emissions by 2050. This scenario reflects public scepticism toward industrial projects and large direct air capture (DAC) or marine schemes, with limited support channelled primarily into visible, local nature-based actions, while durable CDR and storage infrastructure remain underdeveloped.

The **Reference scenario** assumes coherent implementation of EU and national frameworks (e.g. PNIEC 2024, LTS, CRCF) and incremental improvements in planning, finance, Monitoring-Reporting and Verification (MRV) frameworks, and removals. By 2050, Italy reaches a CDR capacity of nearly **56 MtCO₂ per year** which, together with a natural sink exceeding 47 MtCO₂, results in a total carbon removal capacity of roughly **104 MtCO₂ annually**. The CDR portfolio is dominated by agricultural soil carbon, other land management practices, and biomass based conversion methods, while novel approaches such as ERW and DACCS contribute only a small share. The Reference scenario assumes 44 MtCO₂/year of geological CO₂ storage capacity is available by 2050, of which half is reserved for CDR (rather than CCS). The Reference scenario assumes almost 45 MtCO₂/year of CO₂ storage capacity is available by 2050, of which 23 MtCO₂/year is reserved for CDR (rather than CCS). In this scenario, EU and national frameworks, backed by incremental governance reforms, gain public support through effective project engagement. As a result, social licence for CDR is granted when it happens in places and systems where it can be closely monitored, verified, and held accountable - such as industrial clusters, well-regulated environments, and polluter-pays frameworks. When these conditions are met, CDR projects can show real local benefits and grow as part of a diverse, balanced mix of removal methods.

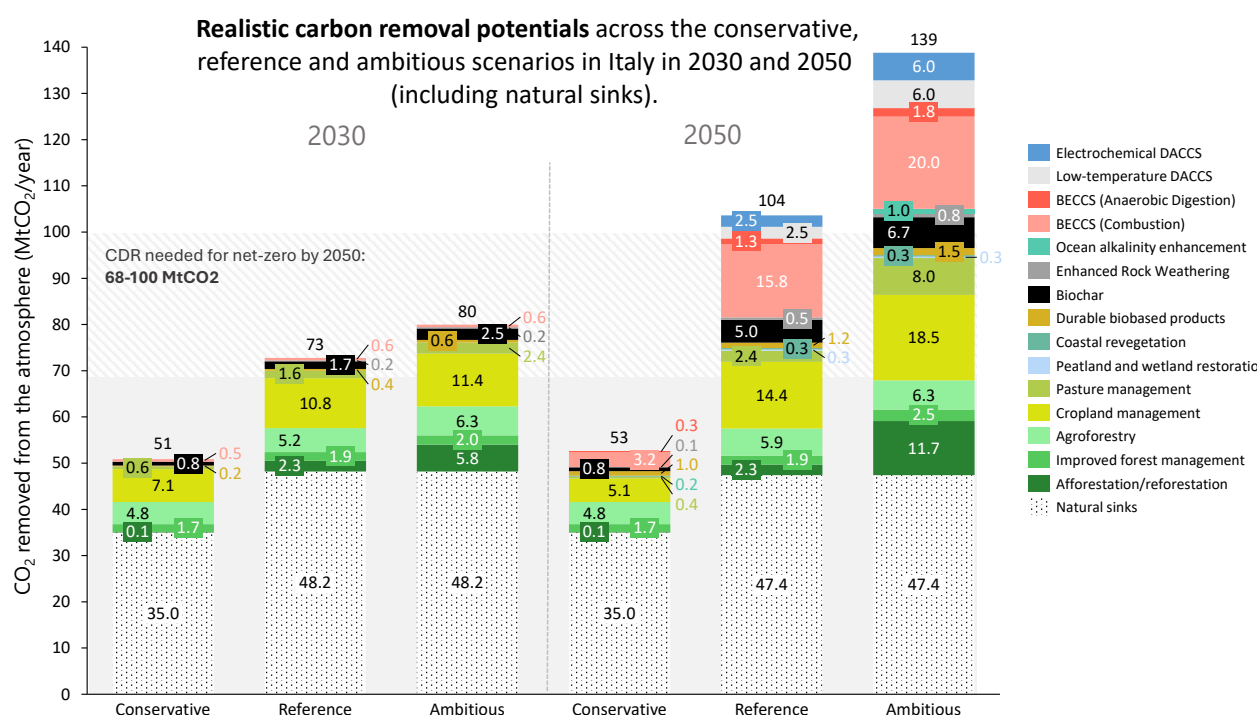


Figure 1. Italy's realistic CDR potentials across Conservative, Reference and Ambitious scenarios in 2050.

In the **Ambitious scenario**, Italy fully exploits its CO₂ storage and other resource potential, resulting in a CDR capacity of more than **91 MtCO₂** per year which, together with a natural sink exceeding 47 Mt CO₂ per year, results in a total carbon removal capacity of about **139 MtCO₂** annually by 2050. This is enabled under the assumption that, of the 74 MtCO₂/year of geologic storage available, 43 MtCO₂/year would be ring-fenced for CDR. Further assumptions include the full mobilisation of suitable biomass and mineral resources, and widespread adoption of carbon-farming practices.

The realistic potential scenarios presented in this report should not be interpreted as forecasts, but as illustrative pathways. Although all three realistic scenarios should be feasible, the actual level of CDR achieved in Italy by 2030 and 2050 will depend on significant investments, strategic political choices, the evolution of relevant markets, and socio-economic acceptance.

Carbon Gap's **CARE** (Coordinated Allocation of Removal Efforts) calculator - a burden-sharing tool that translates Paris-aligned global CDR needs into indicative national contributions using different equity principles - indicates that, depending on the scenarios (reflecting negotiations within and beyond the EU), **Italy should aim for a CDR capacity of 195 to nearly 250 MtCO₂/year by mid-century**. Understanding how much of that capacity can be realised domestically is therefore essential.

Key takeaways

1. The realistic CDR potential in Italy shows that CDR is essential to meet Italy's climate targets.

By 2050, both the Reference and Ambitious scenarios reveal CDR volumes (and expected natural sinks) that could enable net-zero within the expected residual emissions estimated by the Long-term strategy. Whether this happens depends on the decisions that will be made between 2025 and 2035 on storage build-out, energy-system design, implementation of the EU Common Agricultural Policy (CAP), MRV and certification frameworks, and the way CDR is communicated and governed. The choice is no longer whether to integrate CDR into Italy's net-zero strategy, but how quickly and fairly to build the institutions and infrastructures that will make it possible.

2. Most CDR methods are possible in Italy. Mobilising a diversified portfolio of CDR methods distributes risk and resource pressure.

It also provides flexibility to offtake markets and governance structures. However, a diversified CDR portfolio requires significant coordination between the government, the regions and industry to ensure that all potential methods are developed to their full potential.

3. Beyond resource availability, Italy's social geography and institutional landscape will determine whether the country will reach net-zero or not.

Stakeholders across academia, public authorities, civil society, and business converge on treating CDR as a complement rather than a substitute for mitigation and emphasise the need for rigorous MRV, strong EU alignment, and financing grounded in the polluter pays principle. Yet institutional fragmentation, skills gaps, and low trust in national institutions slow deployment. Citizen-panel participants, once informed, endorsed nature-based methods, mineralisation, and biochar, but remained sceptical of large DAC hubs and marine-based approaches unless ecological safeguards and fair benefit-sharing are guaranteed.

4. Land and agriculture are Italy's near-term backbone for CDR.

Across scenarios, managed land and agricultural practices provide half or more of total CDR by 2050. Forest and ecosystem management alone have a theoretical potential of 35 MtCO₂/year, while soil-carbon, agroforestry, and grassland management together contribute around 81 MtCO₂/year to Italy's theoretical CDR potential and 12–48 MtCO₂/year to the realistic CDR potential, depending on CAP implementation and wildfire risk management.

5. Geological storage is a critical bottleneck for permanent CDR.

Even with sufficient renewable electricity and waste-heat potentials, CO₂ injection capacity constrains permanent CDR methods like BECCS and DACCS. The assessment assumes a theoretical geological storage ceiling of 129.5 MtCO₂/year as the long-term maximum, with realistic pathways delivering 15, 45, and 79 Mt with realistic pathways delivering 14.4, 44, and 74 MtCO₂/year of annual geological storage by 2050 in the Conservative, Reference, and Ambitious scenarios. A significant amount of this geological storage is estimated to be allocated to industrial CCS based on recent market surveys. Beyond the Ravenna hub, Italy has a credible pipeline of additional CO₂ storage sites, but timely action to develop them in time will determine whether Italy can unlock BECCS and DACCS at scale.

6. Highly permanent geochemical, synthetic and biomass conversion methods operate at limited scale today but are strategic to reach net-zero. Following the like-for-like principle, methods such as ERW, OAE, DACCS and BECCS are essential to counterbalance hard-to-abate residual fossil emissions, which are expected to be around 57 MtCO₂ in 2050. Based on the like-for-like analysis in this study, only the Ambitious scenario would be able to counterbalance biogenic and fossil emissions expected in 2050. The realistic CDR potential scenarios presented in this report should not be interpreted as forecasts, but as illustrative pathways. Although all three realistic scenarios should be feasible, the actual level of CDR achieved in Spain by 2030, 2040 and 2050 will depend on levels of public and private investment, strategic choices, social acceptance and the evolution of relevant markets.

7. Italy should establish a national CDR strategy with clear milestones and pathways to clarify the expected contributions from land-use and forestry (LULUCF), biomass conversion, geochemical, and DACCS methods, ensuring each sector has a defined role. This requires integrating CDR into climate policy frameworks and aligning with EU targets, and would help provide predictability for industry, investors, and regional authorities to unlock potential funding streams. Building public confidence along the way by showing how removals complement emission reductions on the path to climate neutrality is also crucial.

Italy stands at a crossroads: it can continue on a path that exposes the country to growing economic, energy and climate risks, or it can build a strategy that makes the nation more secure, competitive and resilient by strengthening its territory, its industries and its ability to manage residual emissions. **On one side lies a** conservative path where CDR remains marginal, residual emissions greater than 50 MtCO₂/year persist past mid-century, and climate neutrality becomes an aspiration rather than an outcome. On the other hand, lies a deliberate strategy that mobilises Italy's land, biomass, minerals and industrial residues, energy, and storage assets to deliver more than 100 MtCO₂/year of carbon removals by 2050, closing the gap to net zero. This assessment shows that the second path is technically and socially feasible - but not automatic. It requires rapid, coordinated action from government, regions, industry, the agricultural sector, and civil society over the next decade.

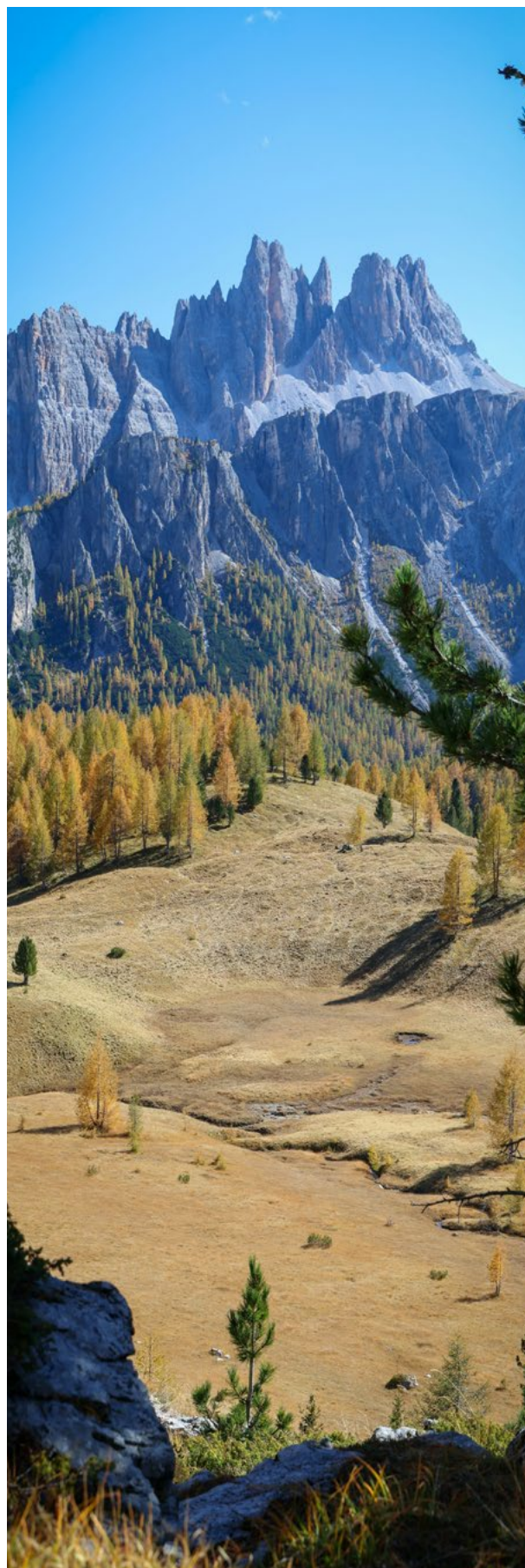


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List of abbreviations

BAU	Business as usual	ISPRA	Istituto Superiore per la Protezione e Ricerca Ambientale
bcm	Billion cubic meters	km	Kilometre
BECCS	Bioenergy with carbon capture and storage	km²	Square kilometres
CAPEX	Capital expenditures	Kt	Kilotonne
CCS	Carbon capture and storage	LULUCF	Land use, land use change, and forestry
CCUS	Carbon capture, utilisation and storage	m³	Cubic meters
CDR	Carbon dioxide removal	MASAF	Ministry of Agriculture, Food Sovereignty and Forests
CfDs	Contracts for Difference	MASE	Ministry of the Environment and Energy Security
CHP	Combined heat and power	mcm	Million cubic meters
CNR	National Research Council	MRV	Monitoring, reporting, and verification
CO₂	Carbon dioxide	Mt	Million tonnes
CO₂e	Carbon dioxide equivalent	MtCO₂	million tonnes of carbon dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation	MW	Megawatts
CREA	Council for Agricultural Research and Economics	NDC	Nationally determined contribution
CRCF	Carbon Removal Certification Framework	OAE	Ocean alkalinity enhancement
DAC	Direct air capture	OECD	Organisation for Economic Co-operation and Development
DACCS	Direct air carbon capture and storage	OPEX	Operational expenses
DOCCS	Direct ocean carbon capture and storage	PNIEC	National Energy and Climate Plan
EAFRD	European Agricultural Fund for Rural Development	PNRR	National Recovery and Resilience Plan
EASAC	European Academies' Science Advisory Council	RAF	Risk Adjustment Factor
EEA	European Environmental Agency	R&D	Research and development
EIAs	Environmental Impact Assessments	S-DAC	Solid sorbent direct air capture
ENEA	National Agency for New Technologies, Energy and Sustainable Economic Development	SET	Strategic Energy Technology
ESR	Effort Sharing Regulation	SMRs	Small modular reactors
ETS	Emission Trading System	t	Tonnes (metric)
EU	European Union	tha/kha	Thousand hectares
GDP	Gross domestic product	TRL	Technology readiness level
GHG	Greenhouse gases	TWh	Terawatt-hour
Gt	Giga-tonne	UNDP	United Nations Development Programme
GW	Gigawatts	UNFCCC	United Nations Framework Convention on Climate Change
IEA	International Energy Agency	USD	United States Dollar (\$)
IPCC	Intergovernmental Panel on Climate Change	WEM	With Existing Measures

1. Introduction

Climate change is one of the most significant challenges of the 21st century, endangering ecosystems, human health, economies, and global security. In response, the 2015 Paris Agreement committed signatories to:

Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change.²

Meeting these targets requires not only rapid and deep emissions reductions across all sectors, but also the removal of carbon dioxide (CO₂) from the atmosphere to offset residual emissions³ (IPCC, 2022). With a 70% likelihood that the 1.5°C threshold will be temporarily exceeded between 2025 and 2029⁴, CDR is increasingly a critical tool - not just for balancing emissions, but also for actively reversing temperature overshoot. Its role will be essential throughout the remainder of this century to help bring global temperatures back within safe limits.

CDR refers to anthropogenic processes used to remove CO₂ from the atmosphere and durably store it to prevent further warming. CDR is not an alternative to emissions reductions, but it is a necessary addition, particularly in hard-to-decarbonise industries such as agriculture, aviation, and heavy industry⁵ (IPCC, 2018). CDR methods range from biological and nature-based solutions to technological processes that physically and chemically separate CO₂ directly from the air and store it durably in underground geological formations.

Despite growing recognition, CDR faces significant uncertainties around technical maturity, economic feasibility, environmental risks, and public acceptance. Country-specific assessments are crucial for tailoring solutions to local socio-economic and geographical contexts, thereby enhancing the feasibility and effectiveness of these solutions.

The European Union (EU) has committed to achieving greenhouse gas (GHG) neutrality by 2050 and net-negative thereafter⁶, and as a member state, Italy must chart its own path toward this goal. This report addresses a key gap in the literature by evaluating Italy's readiness for CDR, identifying existing capacities, barriers, and opportunities. It provides evidence-based insights for policymakers, researchers, and stakeholders aiming to integrate CDR into national climate strategies and advance Italy's contribution to global climate and sustainability goals.

This report was prepared using a bottom-up approach that included desk research and the development of CDR scenario models, interviews with relevant national stakeholders, and public engagement through a citizen panel. Following this introduction, Chapter 2 outlines the relevant CDR methods and those selected for this study. Chapter 3 then describes Italy's geographical landscape, including current and prospective resources and feedstocks needed to deploy the selected CDR methods. In Chapter 4, a preliminary estimation of CDR potential is presented based only on the physical resources – the so-called “theoretical” potential. Following this, Chapters 5 and 6 outline Italy's social geography by analysing the socio-economic, regulatory, and political landscape, and by discussing the results of the stakeholder interviews and the citizen panel. Finally, Chapter 7 presents the CDR potentials across three scenarios, accounting for both physical and social geography. Chapter 8 concludes with a set of targeted recommendations, based on the main findings, for policymakers, researchers, and stakeholders seeking to scale CDR to climate-meaningful levels.



2. CDR pathways and their resource requirements

Following the IPCC⁷ definition of CDR, all the methods assessed in this report must follow three key principles:

1. The CO₂ captured must come from the atmosphere (or oceans), not from fossil sources;
2. The subsequent storage must be durable over climate-relevant timescales (typically decades to centuries or millennia), in either geological, terrestrial, oceanic, or durable products;
3. The removal must be the result of human intervention, additional to the Earth's natural carbon cycling.

It is important to clearly distinguish CDR from other related concepts, such as carbon capture and utilisation (CCU) and carbon capture and storage (CCS). While related, CCU and CCS do not necessarily result in durable net CO₂ removal. **Point-source CCS is not considered CDR**, as CDR requires atmospheric removal (net-negative balance, IPCC). Bioenergy with carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS) instead qualify, since they capture CO₂ from biogenic sources or directly from the air (Figure 2).

2.1 Diversity of CDR methods

The effectiveness of CDR methods depends not only on the amount of CO₂ removed, but also, among other factors, on the durability of storage, scalability towards climate-meaningful volumes, measurability, additionality, and social acceptability. CDR methods can be classified into four main categories: enhanced ecosystem management, biomass conversion or preservation, geochemical and synthetic CDR, as illustrated in Figure 3.

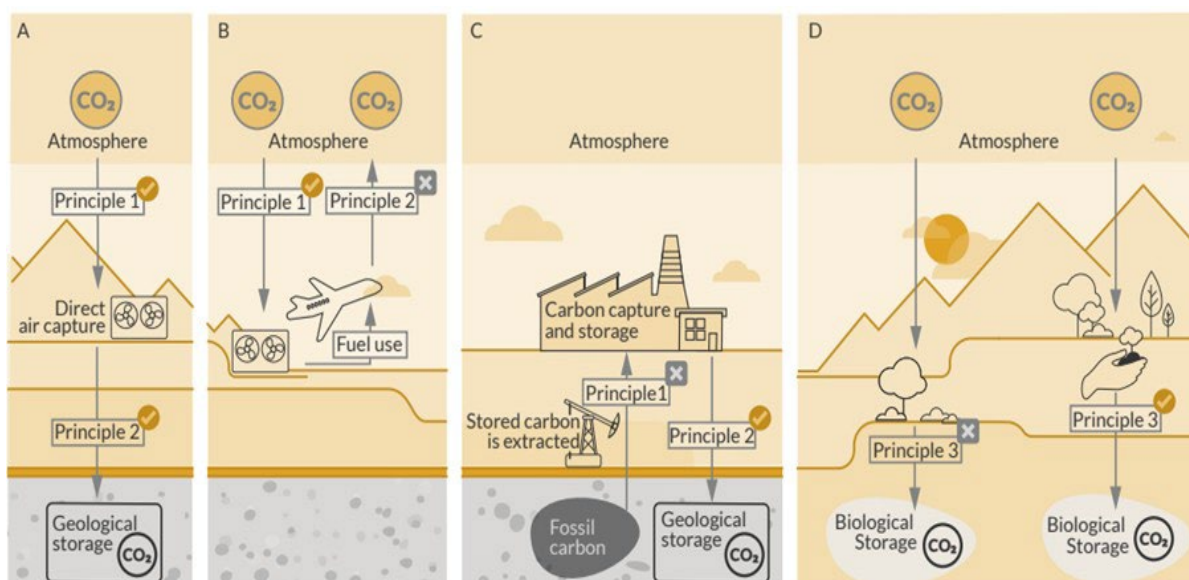


Figure 2. Differences between CDR, CCU, CCS, and natural carbon sink processes. Image A illustrates direct air capture (DAC) with permanent geological storage, a configuration that satisfies all three core principles of carbon dioxide removal. In contrast, Image B depicts DAC, in which captured CO₂ is used to produce short-lived products such as fuels, thereby failing to meet Principle 2 on durability. Image C shows the capture and geological storage of fossil-derived CO₂, which does not meet Principle 1, as it does not remove carbon already in the atmosphere. Image D presents natural processes like tree growth, which fall short of Principle 3 unless actively enhanced through human intervention (Source: the State of CDR report, 2024).⁸

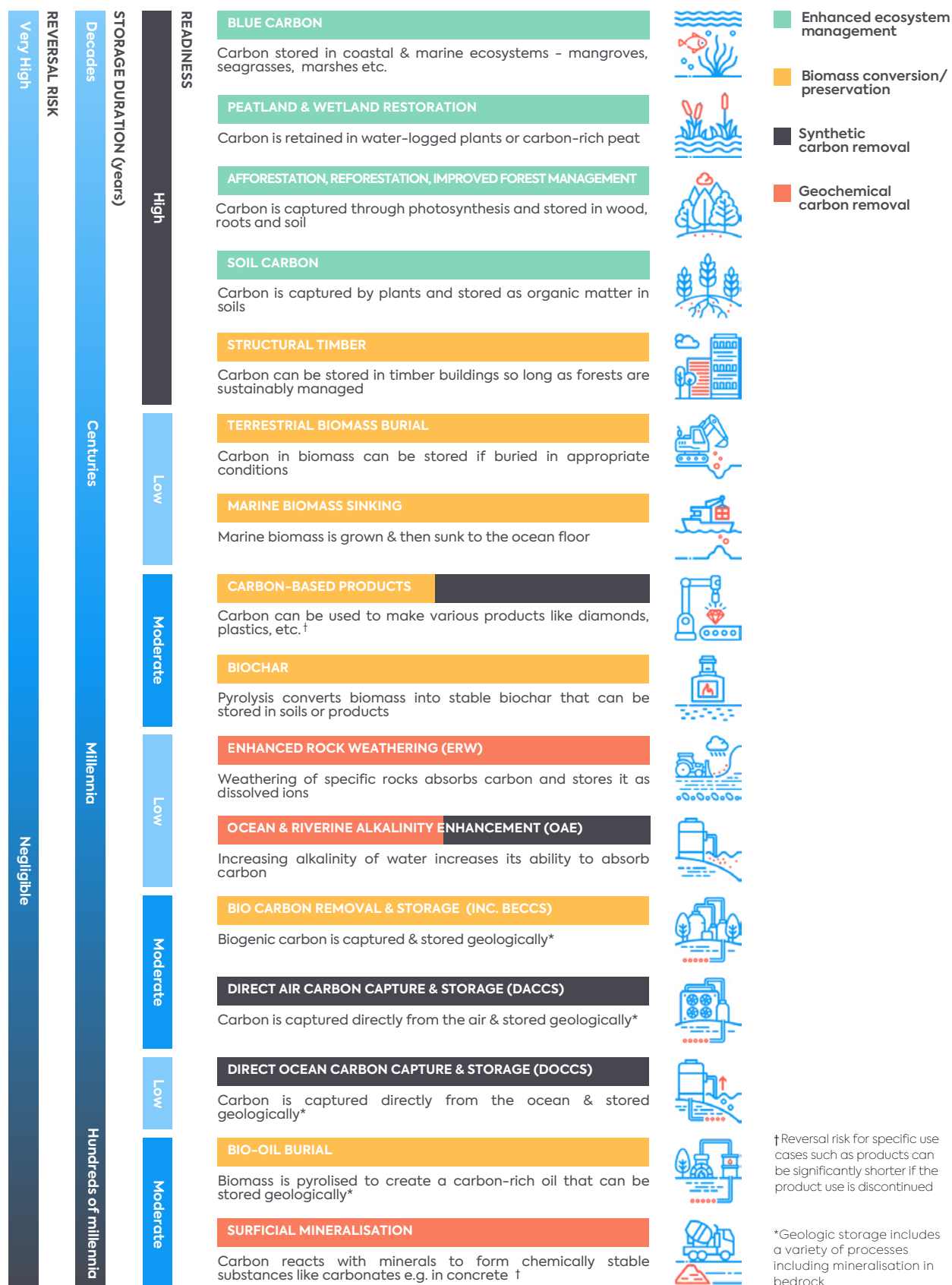


Figure 3. CDR Methods with their respective storage duration and deployment readiness (Carbon Gap).

2.1.1 Enhanced ecosystem management

CDR methods based on enhanced ecosystem management increase the amount of carbon sequestered and retained across both natural and managed ecosystems. By optimising land use or restoring degraded or altered ecosystems, these approaches strengthen the capacity of landscapes to operate as carbon sinks. Methods within this category include:

1. **Afforestation** creates new forests by planting trees on land that previously lacked forest cover, often targeting degraded farmland, grasslands, or other open areas.
2. **Reforestation** restores tree cover on land that has been deforested or ecologically degraded, helping to restore ecosystem function and carbon storage.
3. Improved forest management enhances forestry practices to increase carbon sequestration within forest ecosystems, including longer rotation periods, reduced harvesting, and conservation of old-growth stands.
4. **Agroforestry** integrates trees and shrubs into agricultural systems, combining crop and livestock production with perennial vegetation to improve resilience, biodiversity, productivity and carbon storage.
5. **Soil carbon sequestration** improves soil organic carbon through regenerative practices such as no-till farming, cover cropping, compost application, and crop rotations, reducing emissions and enhancing soil health. It can be divided into cropland management and pasture management.
6. **Peatland restoration** aims to restore the natural capacity of peatlands to store carbon.
7. **Blue carbon** focuses on the restoration and conservation of coastal ecosystems – like mangroves, salt marshes, and seagrasses – that naturally capture and store large amounts of carbon in biomass and sediments.

2.1.2 Biomass conversion/preservation

Biomass-based CDR methods harness the natural ability of plants to absorb atmospheric CO₂ through photosynthesis, storing it in their biomass – leaves, stems, roots, and other organic tissues. To prevent CO₂ from returning to the atmosphere via natural decomposition or combustion, these approaches deliberately intervene in the carbon cycle. Biomass is intentionally processed in ways that stabilise or permanently sequester the captured carbon, ensuring long-term storage. Methods included in this category are:

1. **Durable bio-based products** refer to carbon stored in materials such as timber and bioplastics. These products delay carbon release by extending the lifecycle of biomass-derived carbon.
2. **Biochar** is produced via pyrolysing biomass under low oxygen conditions, resulting in a stable, carbon-rich material. When applied to soils or materials, biochar resists decomposition and can store carbon for decades to millennia.
3. **Bio-oil storage** converts biomass via pyrolysis and injects the resulting bio-oil into stable geological formations. This method sequesters liquid carbon underground for hundreds to thousands of years;
4. **Bioenergy with carbon capture and storage (BECCS)** integrates biomass utilisation with CO₂ capture and geological storage. It prevents the release of CO₂ from biomass combustion or processing, thereby enabling net-negative emissions.
 - e. **BECCS with combustion** captures CO₂ from burning a wide range of solid biomass – including mixed feedstocks such as forestry residues and waste – in power or industrial plants, with CO₂ separated from the flue gas and stores it underground, while generating usable energy. In this report, we consider gasification as a variant of BECCS combustion because both rely on similar biomass feedstocks, require large scale infrastructure, and ultimately involve separating CO₂ from mixed gas streams at the end of the process. Gasification can be used to produce hydrogen or fuels, with CO₂ captured during the process.
 - f. **BECCS with anaerobic digestion/fermentation** captures CO₂ released during biological conversion of biomass into breakdown for biogas or ethanol and stores underground. production, diverting it to secure geological storage. Fermentation is typically deployed at smaller, more dispersed facilities and produces a nearly pure CO₂ stream, making it fundamentally different in scale, complexity, and integration requirements from BECCS with combustion or gasification.
5. **Terrestrial biomass burial** involves harvesting plant biomass and burying it in engineered, low-oxygen environments to prevent decomposition. This method locks carbon absorbed via photosynthesis into stable storage for extended timescales.
6. **Marine biomass sinking refers to the cultivation or collection of seaweed and other marine biomass**, which is deposited in deep ocean layers (greater than 1000 m). This accelerates the natural carbon pump and sequesters carbon for centuries to millennia.

2.1.3 Geochemical carbon removal

Geochemical and ocean-based methods accelerate or enhance naturally occurring chemical interactions between CO₂ and reactive rocks or minerals. In nature, such reactions unfold slowly over geological timescales. However, by increasing the surface area of reactive materials – typically through grinding – and applying them to terrestrial or marine environments, the rate of CO₂ conversion and storage can be significantly enhanced. Key methods include:

1. **Enhanced rock weathering (ERW)** applies finely ground minerals to soils, where they react with CO₂ and water, causing partial dissolution. The reaction converts atmospheric CO₂ into stable bicarbonate ions that are then transferred through the riverine network to the ocean, sequestering carbon over long timescales. It can be either terrestrial (grounded rocks spread on land) or coastal (grounded rocks spread on shoreland). Strong scientific evidence backs the use of silicate rock or minerals to perform ERW. Carbonates can also be used but that pathway still faces more uncertainty on efficiency and additionality.
2. **Ocean alkalinity enhancement (OAE)** increases seawater alkalinity to accelerate the natural absorption of CO₂, converting it into stable bicarbonate and carbonate ions.
 - a. Mineral OAE involves dissolving alkaline minerals (e.g., olivine, lime) into seawater to boost alkalinity and enhance CO₂ uptake.
 - b. Electrochemical OAE uses electricity to modify seawater chemistry, increasing its alkalinity, and therefore its capacity to absorb and retain CO₂.
3. Ocean fertilisation adds nutrients to ocean regions to stimulate phytoplankton growth and CO₂ uptake. It can be done with iron, nitrogen/phosphorus, or artificial upwelling. Overall, results are variable and may involve ecological risks and rapid carbon re-release.

2.1.4 Synthetic carbon removal

Synthetic carbon removal encompasses engineered systems designed to extract CO₂ from the atmosphere or oceans and store it permanently. Two principal approaches in this category are Direct Air Carbon Capture and Storage (DACCS) and Direct Ocean Carbon Capture and Storage (DOCCS). Both offer the advantage of long-term, measurable carbon sequestration.

1. Direct air carbon capture and storage (DACCS)

involves capturing CO₂ directly from ambient air – usually using solid sorbents or liquid solvents. Once captured, the CO₂ is released through the application of heat, pressure, or chemical reactions, yielding a purified CO₂ stream. This concentrated CO₂ is then compressed and stored in geological formations or other long-term sequestration sites.

- b. **Electrochemical DACCS** utilises electrochemical reactions to selectively capture and release CO₂.
- c. **Moisture-swing DACCS** employs sorbents that adsorb CO₂ in dry conditions and release it when exposed to moisture.
- d. **Mineral looping DACCS** captures CO₂ by reacting it with Calcium or Magnesium-rich minerals, forming stable carbonates such as calcite or magnesite.
- e. **Low-temperature DACCS** (lower than 100 °C) uses solid amine sorbents or alkaline solutions, often powered by low-grade or waste heat, to capture CO₂.
- f. **High-temperature DACCS** (higher than 300 °C) techniques, such as calcium looping operate at elevated temperatures, enabling rapid CO₂ capture.

2. Direct ocean carbon capture and storage (DOCCS)

targets CO₂ dissolved in seawater, where it exists in large quantities as part of the ocean's inorganic carbon pool. The pH swing method alters chemical equilibria to release CO₂ from solution, enabling its capture and permanent storage.

2.1.5 CO₂ storage geochemical pathways

Besides the methods presented above, carbon mineralisation is a storage pathway rather than a CDR method per se. However, it uses CO₂ captured from other sources to be stored using a (geo) chemical approach.

1. **In-situ mineralisation** refers to CO₂ being injected into ultramafic or basaltic rock formations, where geochemical reactions with calcium, magnesium, and iron silicates form stable carbonate minerals underground.
2. **Ex-situ mineralisation** entails the aboveground reaction of captured CO₂ with crushed alkaline minerals or industrial alkaline residues, producing solid carbonates that can be permanently stored or valorised in construction and other material applications.

2.2 Selected CDR methods

Italy offers a diverse and promising landscape for CDR deployment, supported by its varied geography and resource availability. The CDR methods in this report (Figure 4) were selected according to their relevance to the national context, technological readiness level (TRL), scientific evidence of effectiveness, and ecological risks.

Italy's established agricultural sector, extensive forests, and long coastlines provide favourable conditions for all ecosystem-based CDR approaches; therefore, none were excluded. Biomass conversion methods also align well with national conditions due to abundant residual biomass. Terrestrial biomass burial, however, was excluded because of risks related to leakage, methanogenesis and potential contamination of soil or groundwater^{8,9,10}. Marine biomass sinking was similarly excluded due to concerns about deoxygenation and reduced phytoplankton^{8,11}, while bio-oil storage was excluded because of extremely limited market presence.

Italy's varied landscape also offers a solid foundation for geochemical methods. All were included except ocean fertilisation, which was excluded due to uncertainties around ecosystem disruption and the risk of harmful algal blooms^{8,12}.

The country's industrial clusters of cement, steel, and refining provide strategic advantages for synthetic carbon removal, including access to waste heat, technical expertise, and suitable geological storage. Moisture-swing DACCS was excluded because of its low TRL and insufficient impact data, particularly regarding water use¹³. High-temperature DACCS was excluded despite its medium TRL, due to life-cycle impacts, such as water depletion and high energy demand, which could lead to fossil fuel impacts depending on the energy source¹⁴. Direct ocean carbon capture and storage (DOCCS) was excluded because of ecological risks, including potential harm to marine organisms entrained in the pumping process and low TRL^{8,15}.

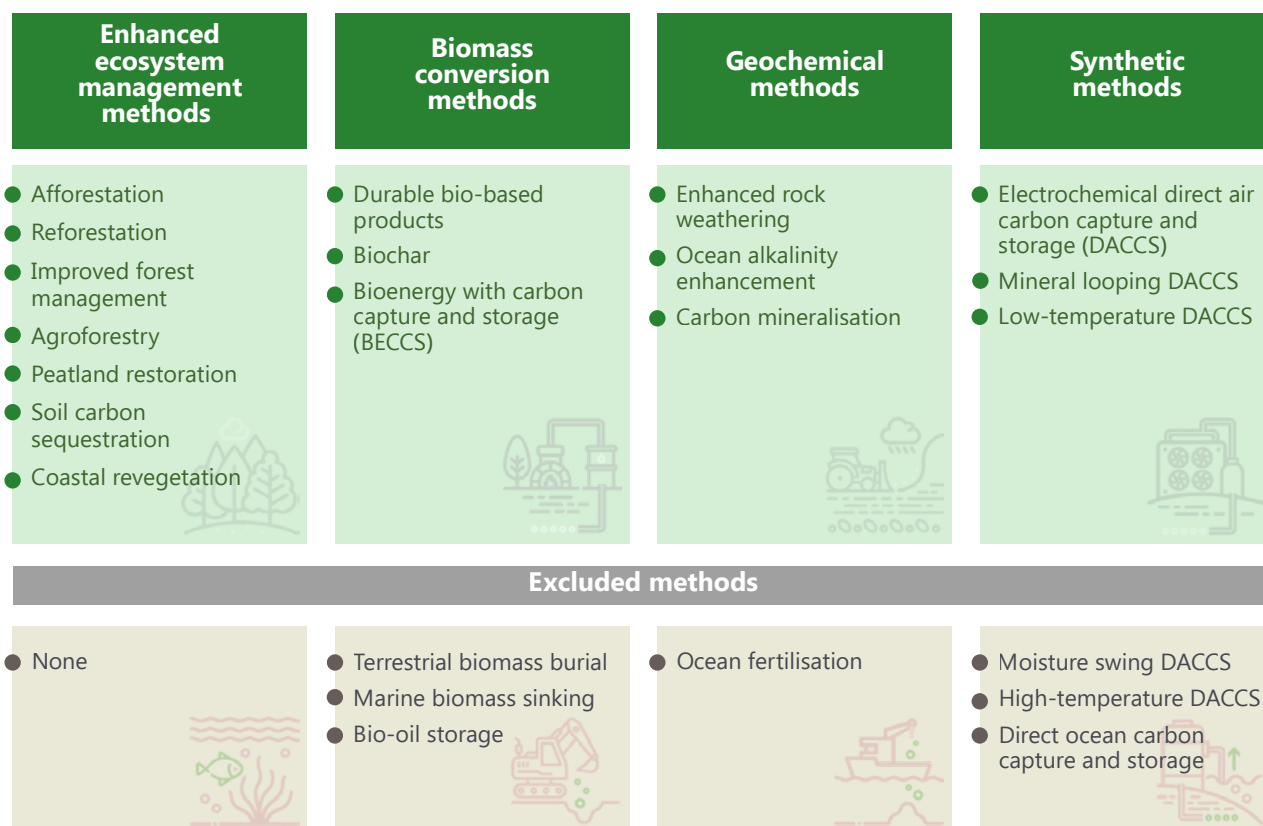


Figure 4. Summary of the CDR Methods included and excluded from the assessment.

2.3 Resource requirements for selected CDR methods

To assess the deployment potential of each CDR method, it is essential to understand their resource requirements - such as water usage, land area, and energy consumption - per net tonne of CO₂ removed. However, accurately quantifying these inputs presents two key challenges:

- The diversity of CDR methods, each with multiple variants that differ significantly in design, scale, and operational parameters.
- Limited availability of reliable data, as most methods remain in early stages of development and lack robust field-based evidence.

Moreover, comparing methods requires a consistent basis. Since all CDR approaches generate some GHG emissions during operation, resource requirements must be evaluated on a per-tonne-of-CO₂-removed basis, accounting for emissions subtracted from gross removal volumes. This makes life cycle analysis (LCA) a crucial tool for evaluating the data meaningfully.

The scientific literature offers valuable insights, particularly due to its methodological transparency and rigorous peer review. However, most studies rely on laboratory-scale experiments or modelling, often based on limited datasets. As a result, their applicability to real-world conditions remains uncertain, and only few include comprehensive LCAs.

Operational data from companies - those developing pilot projects or commercial-scale deployments - is rare but increasingly available.

For instance, application files submitted to the Frontier fund provide performance metrics from actual projects. While these figures reflect current technological capabilities more accurately, they are often self-reported and lack peer review, making them "declarative" in nature.

To overcome these limitations and build a robust database of resource requirements, Carbon Gap partnered with the Rocky Mountain Institute (RMI). The resulting dataset is grounded in three complementary sources: peer-reviewed scientific literature, publicly available Frontier fund applications (across three cohorts), and direct surveys conducted with active CDR operators.

The database will continue to evolve after the publication of this report, but at the time of publication, it includes:

- 442 data points obtained from 129 scientific articles;
- 200 data points obtained from 113 Frontier files;
- 330 data points obtained from 57 survey responses.

The database is accessible from the [CRRRA website](#).

The data was compiled to produce consolidated values for each of the resources required for CDR methods. These values are used throughout the remainder of the report to estimate the potential of CDR methods based on available resource feedstocks. When values are unavailable in the database, or alternative values are more relevant to the national context, they are explicitly reported, along with their sources.



3. Italy's resources and feedstocks

This chapter assesses the availability and future potential of key resources in Italy, estimating the share that can be mobilised for CDR after accounting for competing uses, constraints, policies, climate change impacts, and – where possible geographical distribution. Drawing on official, industry, and academic sources, it finds that Italy has a strong resource base to support a broad portfolio of CDR methods.

Extensive agricultural and forest land supports land-based CDR, while abundant residual biomass enables pathways such as BECCS and biochar. Despite significant renewable electricity and waste heat potential, Italy remains heavily reliant on imported fossil fuels, posing challenges for energy-intensive methods such as DACCS, which require low-carbon energy to be net-negative. Abundant availability of mineral resources and industrial residues offer opportunities for geochemical methods, while geological CO₂ storage capacity – already in operation at the Ravenna CCS hub – could enable large-scale deployment of BECCS and DACCS if fully developed and not fully allocated to CCS.

3.1 Energy

As of 2023, Italy's total energy supply was **1,525 TWh**, with 79% derived from fossil fuels, namely coal, oil and natural gas. A significant portion of these fossil sources (79.6%) is imported. Domestic renewable energy production totals 296.6 TWh, representing 76% of total national energy production. Despite progress in renewables, the country remains heavily dependent on imported fossil fuels.¹⁶ Importantly, Italy does not have domestic nuclear power, however this may change in the future with the introduction of Small Modular Reactors (SMRs) (Box 1).

Final energy consumption totals **1,275 TWh**, with oil products accounting for 41%, natural gas for 27%, and renewables for 29%. The largest energy-consuming sectors are transport (34%), residential (24%), and industry (21.5%).¹⁶ Figure 5 summarises Italy's current energy landscape.

Current energy landscape (2023)

Coal Oil Natural gas Heat Hydro Wind & solar Electricity Biofuels & waste

Total energy supply: 1525.4 TWh



Total final consumption: 1275.8 TWh



Current landscape by sector (2023)

Industry Transport Residential Commercial & public services Agroforestry Other Non-energy

Total final consumption by sector: 1275.8 TWh

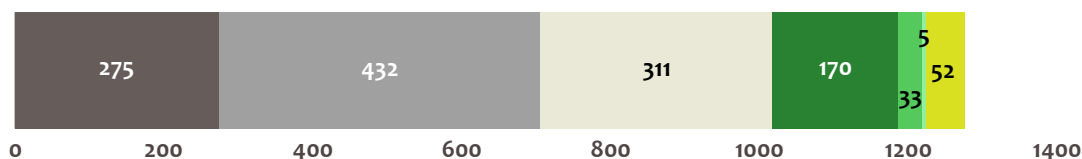


Figure 5. Summary of Italy's current energy landscape (adapted from IEA-2023).¹⁶ Final energy consumption corresponds to energy consumed after grid losses and exports.

This section describes the possible trajectories for Italy's renewable energy generation, focusing on electricity and thermal energy. Different scenarios are drawn from scientific and official sources to provide estimates of how much energy can be allocated to CDR methods.

As of 2023, all energy produced domestically and imported is consumed nationally. However, dedicated uses of energy for CDR methods are unaccounted for in reports, despite BECCS and DACCS pilots emerging. An analysis of the potential energy production suggests that Italy could, in a transformative, yet realistic scenario, generate energy dedicated to CDR amounting to **52.5 TWh of electrical energy** and **72.6 TWh of high temperature waste heat** by 2050.

3.1.1 Electricity scenarios

Electricity plays a pivotal role in enabling CDR deployment and, more broadly, in achieving any emissions reduction objectives. In alignment with EU climate objectives, Italy's National Energy and Climate Plan (PNIEC) and power sector consortia have outlined a highly ambitious 2030 scenario in which renewable energy accounts for 75% of electricity generation and 65% of final electricity consumption^{18,21}.

Between 2040 and 2050, Italy could reach 80-100% renewable electricity generation²². Official projections from PNIEC-2024¹⁸ and ISPRA-414²³ indicate that this trajectory implies an annual **electricity production** capacity of **over 620 TWh** by 2050 under a high decarbonisation scenario, or up to **490 TWh** under a Baseline (BL) or Business-as-Usual (BAU) scenario extrapolated from current trends.

The above mentioned PNIEC decarbonization scenario projections align with **Italy's Long-Term Strategy (LTS-2021)**^{1,24} which outlines an energy pathway combining deployment of CCS and CCU with secure electricity supply for national consumption and hydrogen production. This pathway involves a phased reduction of fossil-based electricity generation, a major expansion of solar and wind power generation infrastructure, nationwide deployment of biomass power plants, and sustained geothermal generation. As electrification and electrolysis scales up, **electricity consumption** is expected to reach **620-700 TWh** by 2050, with nearly 80% of electricity generated used for civil uses, industry, hydrogen energy products, and transport.²⁴

Box 1 – Note on nuclear Small Modular Reactors (SMRs) in Italy

Italy phased out nuclear energy after public referenda in 1987 and 2011 due to strong public opposition, reflecting deep concerns about safety, waste management, and seismic risks¹⁷. However, the updated [PNIEC-2024 \(Italy's National Energy and Climate Plan\)](#)¹⁸ signals a shift in policy, with Italy now considering the reintroduction of advanced nuclear technologies - specifically SMRs - as part of its long-term decarbonisation strategy, beginning from 2035.

This phased deployment could reach a total production capacity of 16 GW. Assuming average capacity factors of 85-90%, SMRs could generate an estimated **60-65 TWh of electricity annually**. In a conservative, slow-development scenario, only half of this capacity may be realised¹⁹. Beyond electricity, SMRs are also significant sources of **waste heat**,²⁰ which under the assumption that 35% of the emitted heat is usable, can yield **30-35 TWh/year**.

To evaluate Italy's capacity to generate surplus electricity that could support CDR deployment by 2050, this study extracted baseline production and consumption trajectories from models that extend the PNIEC 2030 national trend toward 2050, drawing on official projections and simulations from agencies such as [PNIEC-2024](#),¹⁸ [Terna-Snam 2024](#),²¹ [Gaeta-2022](#),²⁴ [HRE4-2018](#),²⁵ [Carbon-Free Europe-2024](#)²⁶ (see Annex D for details on the scenarios). For each scenario, the resulting energy surplus was then calculated by discounting estimated consumption and projected hydrogen demand. The analysis identified the most energyefficient 2050 pathway - aligned with PNIEC and LongTerm Strategy targets of 80-100% renewable energy - while comparing assumptions across scenarios to ensure consistency and robustness.

Despite the differences between the scenarios, they all acknowledge the central role of renewables over time (including foreseeing a massive 7-15x increment in photovoltaic capacity), as well as the need for flexible and resilient grids with the growing importance of electrification. What sets the different scenarios apart is the scale and speed of transformation, grid expansion, advanced storage technologies, projected electricity consumption, and decisive policy frameworks to unlock investment and societal commitment. These scenarios are shown in Figure 6.

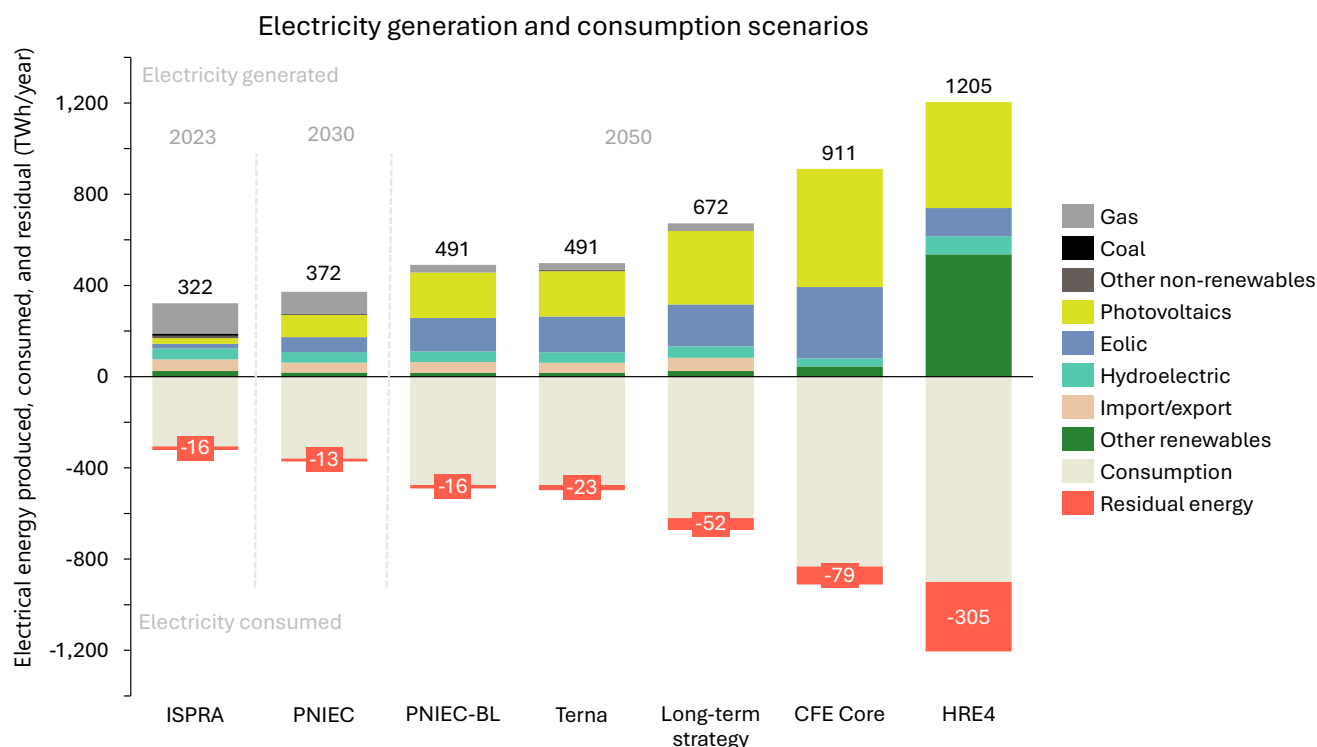


Figure 6. Estimated maximum electricity production and consumption scenarios (see Annex D for details).

Under the most ambitious scenario (HRE4-2018²⁵), Italy could theoretically generate a surplus of over **305 TWh/year** of electrical energy by 2050 that could be used for CDR. In contrast, a more realistic energy production scenario based on the Long-Term-Strategy (LTS) would yield a surplus of **52.5 TWh/year** (Gaeta et al. 2022²⁴) after accounting for hydrogen Power-to-X demand relative to the PNIEC baseline. If Italy's projected nuclear expansion adds an additional **60 TWh/year** of generation, the total surplus available for CDR would reach roughly **364 TWh/year** in the HRE4 scenario and about **112.5 TWh/year** in the LTS scenario (which is the one used in the theoretical CDR scenario). Subsequent analyses in Chapters 4 and 7 take the 112.5 TWh benchmark from the summed LTS and nuclear electric energy resource for CDR deployment.

3.1.2 Thermal energy

Heating and cooling are the largest single energy use in Italy with nearly **700 TWh** demand (64% of final energy demand of 2023). The main uses include space heating (55%), process heating (28%), hot water (5%), and cooling (5%) (HRE4-2018²⁵, IEA-2023¹⁶, PNIEC-2024¹⁸). Most of thermal energy (79%) is sourced from fossil fuels - primarily natural gas, which alone accounts for 63% of the total. Renewable heat sources, including biomass, heat pumps, geothermal, and solar thermal, contribute only around 20% of the total consumption¹⁶. According to the Heat-Roadmap (HRE4)²⁵ total

heat demand will remain stable at **600-650 TWh to 2050**, but a 22% decline in space and process heating alongside a near doubling of cooling demand increases the importance of waste heat in meeting future needs.

District heating is underdeveloped, covering just 2.7% of civil heat demand (~11 TWh in 2023). Supply is still dominated by non-renewables (>72%), with smaller shares of renewables (26%), heat pumps (0.9%) and recovered industrial waste heat (0.8%)²⁷. Key challenges include decarbonising both individual heating and district heating, improving efficiency and electrification, and scaling waste heat recovery. By 2050, scenarios foresee a balanced system from large heat pumps (**75 TWh**) plus recovered heat (**45 TWh**), alongside widespread individual heat pumps (**150 TWh**), reducing emissions and biomass reliance^{28,29}. Industrial reintegration of waste heat is central, offering a cost-effective and sustainable solution³⁰, with EU estimates suggesting that at least 10% of industrial waste heat could be recovered.²⁵

Currently, though official balances show that there are 11.3 TWh of unutilised waste heat (data from 2022, Terna-Snam 2024²¹), recent studies report a much larger pool. Recoverable waste heat is estimated at 51 TWh from power plants, 35 TWh from industry, 31 TWh from wastewater treatment, 5.5 TWh from biomass reactors, 3.6 TWh from waste-to-energy³². EU-level analyses further refine this by linking waste heat to temperature ranges across industries (Papapetrou et al 2018)³¹.

Combining these datasets and grouping heat by temperature relevant for CDR (Figure 7, left) shows that most waste heat (**100.7 TWh**) is low-temperature (<100 °C), mainly from power, biomass, waste to energy, and wastewater - well suited for district heating, but not for CDR applications. Higher-temperature heat comes primarily from

heavy industry (metals, minerals), food, paper, and chemicals: **48.3 TWh** at 100–300 °C (medium temperature) and **25.6 TWh** above 300 °C (high temperature). These temperature ranges are suitable for CDR applications. Figure 7 (right) maps the main recoverable waste heat sources across the country (Denaire et al 2021)³².

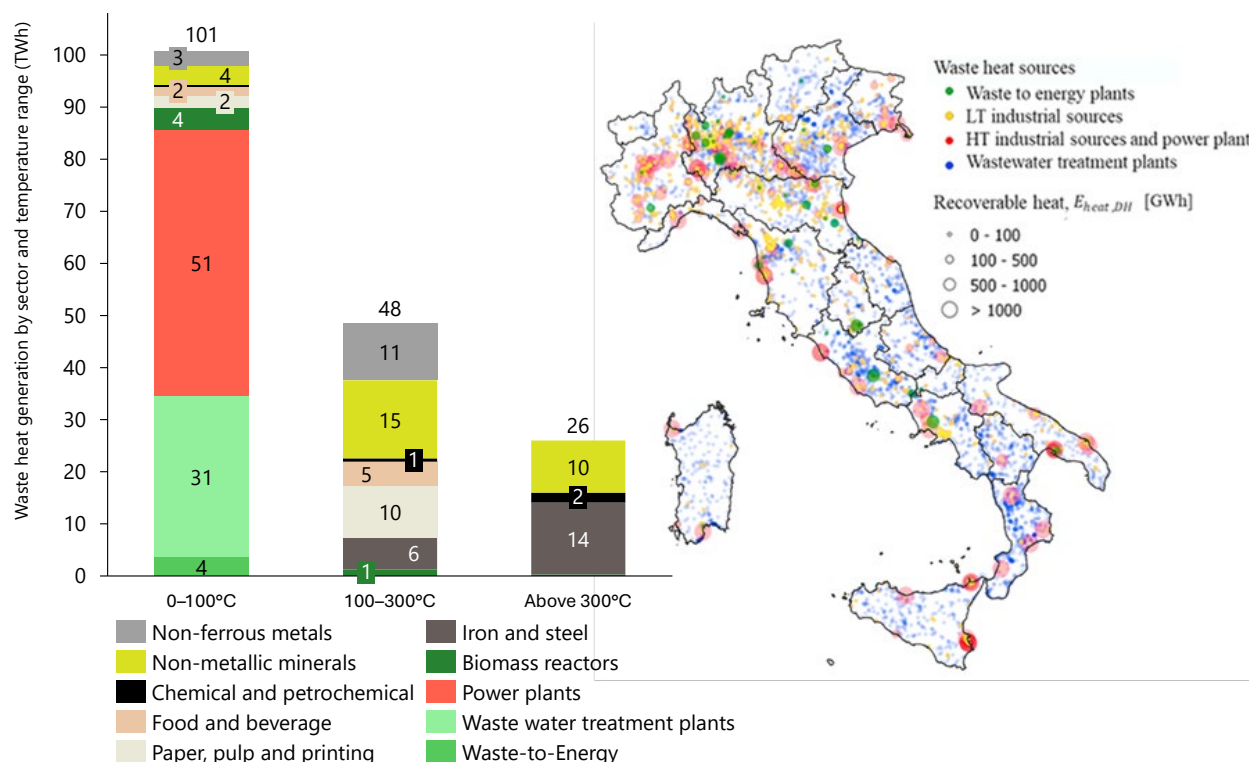


Figure 7. (Left) Waste heat generation by sector and temperature range as per 2015 (Papapetrou et al 2018³¹). (Right) Geographic distribution of low temperature (LT) and high temperature (HT) waste heat sources recoverable for district heating (Adapted from Denaire et al 2021³²).

3.1.3 Thermal energy scenarios

To estimate waste heat available for CDR by 2050, this report combined official and academic data into a model that maps waste heat sources to their feasible uses. It examined how wasteheat production and demand were expected to evolve, considering both established sectors and emerging ones such as PowertoX, bioenergy, and nuclear. Expected uses - such as district heating, industrial reuse, and losses - were subtracted to estimate the share realistically available for CDR. Waste heat was then categorised into three temperature bands – Low (25–100°C), Medium (100–300°C), and High (>300°C) – selected to match the requirements of key CDR methods. In this framework, S-DACCS and BECCS rely primarily on medium heat, while L-DACCS and mineralisation processes require high temperature heat.

This model represents possible theoretical flows of waste heat that could be directed towards CDR **only after** meeting the estimated demand for district heating and industrial reuse. As such, results are subject to significant uncertainties, unforeseeable constraints and losses. Figure 8 presents three allocation scenarios reflecting different levels of industrial heat reintegration, based on the following assumptions:

Waste heat generation from industry, power generation, biomass reactors, waste-to-energy, and wastewater treatment is assumed to remain consistent with literature estimates (Papapetrou et al 2018³¹; Denaire et al 2021)³².

- **Bioenergy** production is conservatively projected to triple by 2050^{18,24}
- **Waste heat reintegration** into local industrial processes is assumed to reach 20%, 40%, and 60% of all waste heat (excluding bioenergy and wastewater treatment plants as they are already reusing waste heat), in line with the Renewable Energy Directive (RED III (2023/2413))³⁰.
- **Emerging sectors contribute additional waste heat:** hydrogen production (power-to-X) is expected to generate 69.4 TWh, while small modular nuclear reactors 35 TWh. Power-to-X facilities are estimated to produce mainly low-temperature (37.7 TWh) and medium temperature (31.7 TWh) waste heat,³³ while SMRs primarily generate low-temperature waste heat³⁴.
- **District Heating** demand is projected to reach 114 TWh, of which 45-79.6 TWh could be supplied by industrial waste heat, waste-to-energy plants, and wastewater treatment facilities operating below 150°C^{29,32}.

In the allocation logic, 60% of industrial waste heat (excluding bioenergy production and wastewater treatment plants) is first assigned to industrial reuse. Low temperature heat from near urban wastewater treatment is then prioritised for district heating (up-to 79.6 TWh³²), with remaining district heating needs supplied by medium temperature waste heat. Although waste heat cannot always be repurposed at its original temperature, the model represents an idealised redistribution based on consensus estimates from official and scientific sources.

Collectively, under the presented assumptions, **Italy could redirect up to 72.6 TWh of waste heat to CDR applications:** 59.9 TWh in the mediumtemperature range (100–200 °C), 2.5 TWh in the mediumhigh range (200–300 °C), and 10.2 TWh in the hightemperature range (>300 °C). The effective use of this waste heat for CDR will ultimately depend not only on technologies for capturing and repurposing it, but also on geographical factors particularly the proximity between viable CDR sites and the wasteheat sources themselves.

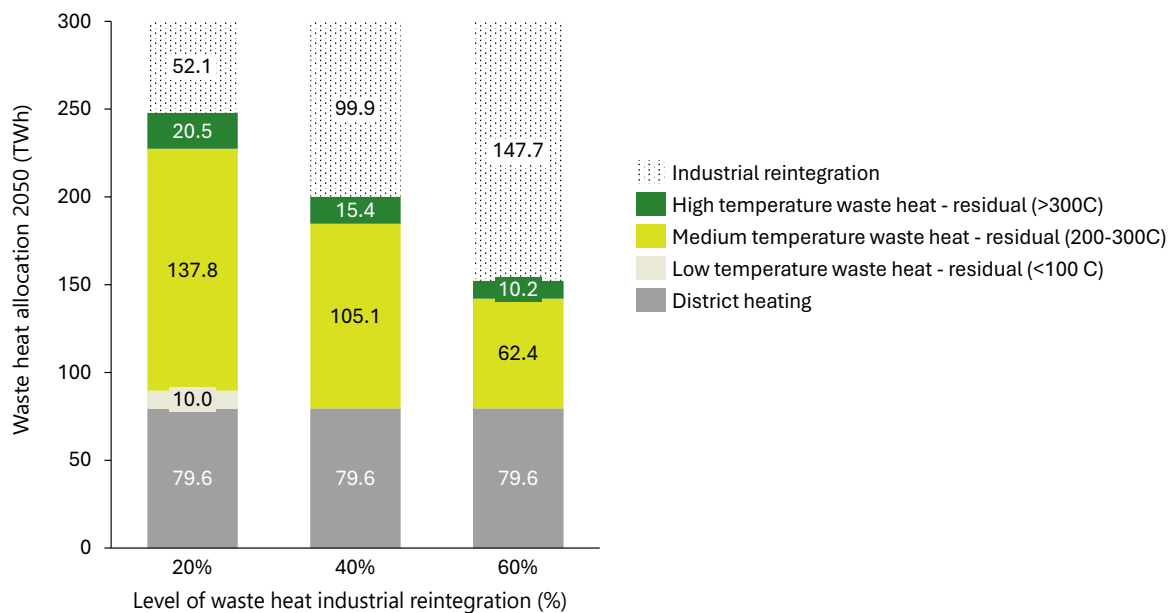
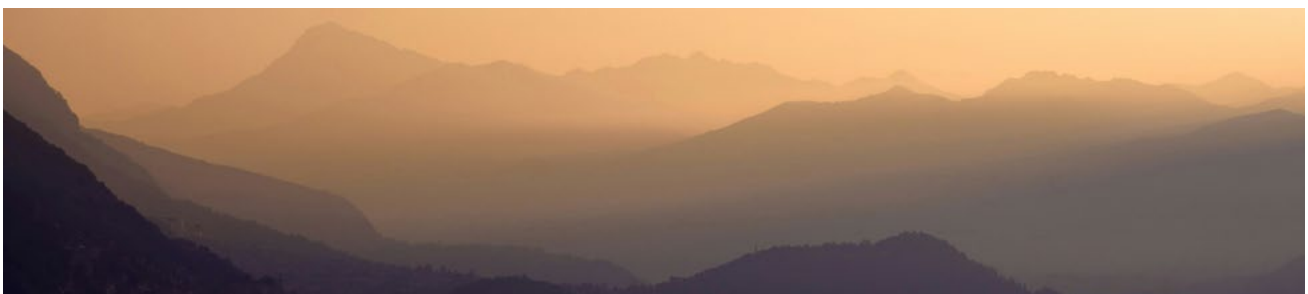


Figure 8. Waste heat allocation scenarios under three waste heat industrial integration scenarios. Industrial reintegration waste heat is captured and reintegrated into local industrial processes and therefore unavailable for CDR.



3.2 Water

Many CDR methods rely on water availability for their implementation, and their water needs vary dramatically. Biochar, BECCS, afforestation and reforestation can be highly water-intensive, while DAC and ERW generally use far less water.

Italy's total renewable freshwater resources average around **191 billion m³ (bcm) per year**, with 72% sourced from surface water and 28% from groundwater. Precipitation results in 300 bcm per year on average. Total annual withdrawals are around **28 bcm** (15%)^{35,36}. This suggests that there is enough water that can be used for CDR today, though many geographical factors affect the ability to collect and distribute ground, precipitation, and surface water³⁷.

To assess renewable freshwater availability, this study first determined current and projected withdrawals for each macro sector. Potential freshwater surpluses were identified, including those derived from irrigation efficiency gains, network leakage reduction, re-use scaling, and rainwater harvesting. Finally, the analysis accounted for variations in freshwater availability resulting from climate fluctuations, ensuring that estimates reflect both risks and opportunities in future supply.

Water withdrawals are expected to remain relatively stable up to 2050 even when assuming population growth because of efficiency gains in irrigation, rainwater harvesting and water recycling. Table 1 illustrates projections of future water withdrawal and their assumptions.

By 2050, three major avenues of water savings could unlock significant volumes of water for CDR:

- **Optimised irrigation and land use.** Smart irrigation systems could reduce irrigated land by 15-25% on average from 2020 levels^{230,231}. Combined with roughly a 20% reduction in arable land without affecting crop production, this could free up an estimated 2 bcm per year by mid-century (FAO⁴²).
- **Rainwater harvesting.** Policies such as the DL 39/2023⁴¹ envision large-scale rainwater collection programmes, which could contribute nearly 2 bcm per year by 2050.
- **Efficient networks and re-use scaling.** Leveraging existing (PNRR M2C4)⁴³ and new policies, Italy could cut leakage losses in public supply networks by 42%. This translates into savings of about 3.4 bcm per year, complemented by an additional 4.7 bcm per year from water re-use programs (ISTAT-2024)⁴⁴.

Taken together, these measures would allow Italy to continue withdrawing water sustainably while saving nearly **12.1 bcm** per year by 2050 - a volume that could be redirected to support CDR at scale. However, climate change will likely undermine overall freshwater stability. Shifts in precipitation, reduced runoff, altered groundwater recharge, and rising risks of droughts, floods, and heatwaves mean future availability is uncertain.³⁷ Under a Business-as-Usual scenario with a 1.7°C average temperature

Sector	Withdrawal volume (bcm)			Assumptions
	2023	2030	2050	
Agriculture	17.1 (61%)	16	15	Assumes 10-15% efficiency gains in irrigation from €880 M investment by the National Recovery and Resilience Plan (Piano Nazionale di Ripresa e Resilienza, PNRR ³⁸)
Households	6.5 (23%)	6.7	7	3-4 million population growth in addition to envisioned 15% reduction in losses via €900M PNRR leakage program ³⁹
Industry	4.5 (16%)	4.7	3	Industries shift to water recycling and closed-loop systems partially due to EU reuse directive ⁴⁰
Rainwater harvesting	0.2 (0.7%)	0.8	2	Rainwater harvesting increase based on evidence and enabling policies like DL 39/2023 ⁴¹
Total	28.3	27	27	

Table 1. Water withdrawal volumes for 2023, 2030 and 2050 (FAO⁴² & ISTAT-2024³⁶).

increase by 2050, water stress periods are expected to rise significantly, and renewable freshwater could decline 5-15%, with even sharper summer deficits in central and southern regions³⁷. As a result, annual water availability for CDR at the national level would fall from 12 bcm to about **10.2 bcm** by 2050.

Italy **faces pronounced regional disparities in water security** across north and south related to climate, rainfall patterns, and water infrastructure. Northern regions benefit from abundant surface and groundwater resources, extensive reservoirs, and lower distribution losses, ensuring more reliable supply. In contrast, Southern regions and the islands face chronic scarcity driven by limited natural availability, aquifer overuse, high network losses (over 40%), and insufficient infrastructure for storage, reuse, and rainwater harvesting (ISPRA-2023²²⁸). These structural challenges raise concerns about Italy's longterm water security in certain regions and their ability to generate surplus water for CDR. Water use must therefore be integrated into territorial water plans, particularly in Southern Italy, where water scarcity coincides with high land availability for regenerative agriculture and carbon farming.

This alignment of CDR and water resilience represents a key intersection of Italy's climate neutrality goals and national adaptation strategy (PNACC-2023)²³⁸, especially under the European **Green Deal** and the **Water Framework Directive**²³⁹.

3.3 Land

3.3.1 Land area

Italy's current inland territory covers **30.4 Mha**, with land use dominated by croplands (33.6%), followed by grasslands (30% including transitional woodlands), forests and woodlands (24.5%), urban and inhabited land (10%), and inland waters (2%) (ISPRA²³). Land-based CDR methods play a crucial role in Italy's current and future decarbonisation pathways.

Currently, nearly 1.2 Mha of forestland is certified under sustainable management, and at least one CDR-promoting method is being used on over 4.08 Mha. Certified or improved forest management refers to areas audited by independent third parties against recognised Sustainable Forest Management (SFM) standards, primarily PEFC and FSC²⁷⁷. While certification ensures that forests are properly planned, monitored, protected, and governed, it does not necessarily imply the generation of carbon credits, which are typically issued by other parties.

According to official reports (ISPRA-414²³, PNIEC-2024¹⁸), there has been a historical increase of nearly 25% in total forested cover between 1990 and 2025, and this is expected to continue until 2030 at the expense of croplands and grasslands. Figure 9 illustrates historical, current, and projected land use distribution, depicting a stabilisation of land use with virtually no variation in urban lots from 2030.

The success of land-based CDR methods hinges on enhanced land management practices across forests, grasslands, and agricultural areas, aligned with the anticipated changes in land distribution. These changes include the linear increase in forested land until 2030, a gradual stabilisation of croplands by 2040 at the expense of grasslands, and no significant changes to wetlands and urban areas²³.

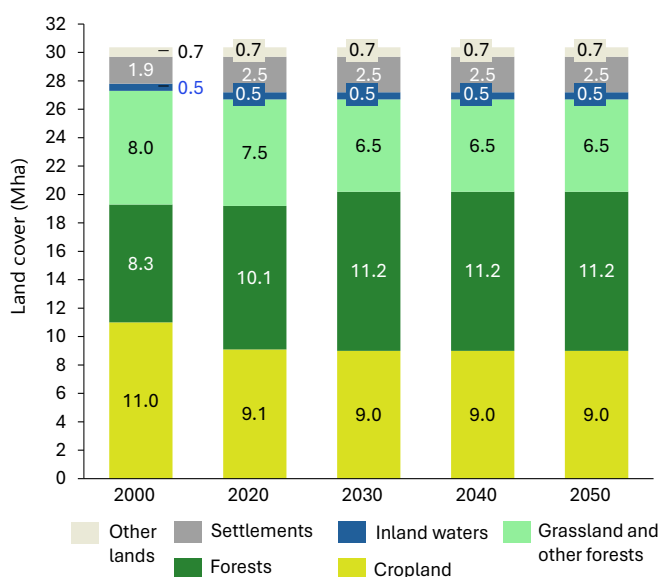


Figure 9. Past and projected land distribution. "Other lands" correspond to land that is sparsely vegetated, abandoned crop/grassland, or under natural succession. Urbanised and other constructed lands cover nearly 2.5 Mha, and inland waters 0.5 Mha (adapted from ISPRA-414²³)

Box 2 – Forest expansion without a clear afforestation strategy

The current (2025) forest sink is estimated at 46.1 MtCO₂e, and LULUCF scenarios estimate that, under key forest protection and certification policies (see Annex F), this could grow to **47.4-49.4 MtCO₂e**²³.

Specifically, forest land is expected to increase from approximately 10.1 to 11.2 Mha by 2030, based on statistical growth projections drawing on data from the past two decades. However, no official policy document - neither [PNIEC-2024](#)¹⁸ nor the [National Forestry Strategy – SFN](#)⁴⁵ - outlines a clear, targeted strategy to achieve this expansion. In fact, the afforestation efforts planned under the PNRR account for only 6.6 kha, a scale insufficient to explain the projected growth.

This discrepancy indicates that the anticipated **increase in forest cover is likely to result primarily from continued land abandonment, natural ecological succession, and** reclassification into “Forest Land” under IPCC criteria, **rather than the result of deliberate afforestation initiatives**. The National Forestry Strategy itself supports this interpretation, attributing the expected 1.2 Mha increase largely to the spontaneous expansion of forests on abandoned land, rather than to planned interventions. Furthermore, only 8% of the allocated Rural Development (SR) funds (SRD15)219 have been used, while delays in payments under other (SR) interventions of the CAP have disrupted the continuity of forest management and certification schemes.

To estimate how much land could realistically be dedicated to different CDR methods, this study followed a three-step process. It began by examining recent national datasets - specifically the PNIEC-2024, ISTAT, and ISPRA reports - to trace how land use in Italy has changed over time. Building on this foundation, the study then mapped the policy landscape, identifying both existing measures and upcoming policies that could encourage CDR activities within the LULUCF sector. Finally, for each land-based CDR method, the analysis determined the type of land it requires, assessed how much of that land is currently being used for the method, and estimated the maximum area that could be allocated to it by 2050.

Under Italy's long-term decarbonisation strategy (LTS-2021¹), the LULUCF sector is expected to account for at least 50% of the country's total CDR, contributing over 45 MtCO₂e removals by 2050. To achieve these goals, the main policy instruments are the [Common Agricultural Policy \(CAP\)](#)⁴⁶ with its Eco-Schemes and second Pillar actions for Rural development (*sviluppo rurale-SR*), as well as funds from the [PNRR](#)³⁸ (see Annex E for details).

Figure 10 illustrates, for each identified CDR promoting method, both the land area currently in use and the total hectares that could potentially support these practices, alongside the incentives and actions presently funding them. Some methods overlap because they can be applied simultaneously on the same land while delivering distinct CDR benefits - for example, pollinator strips can coexist with soil organic carbon sequestration practices - and are therefore counted independently. Maintaining these practices over time is essential to ensure that their CDR potential is sustained for many years.

The projected land use changes by 2030 suggest that **7.2 Mha** of arable land is available for most farming practices that enhance soil health ([FAO-2022](#))⁵⁰. Land-based CDR is already being implemented on **3.1 Mha** of this 7.2 Mha with the support of CAP Environmental Scheme 2 (ES2). Permanent crops such as olive trees and vineyards represent some of Italy's major exports and high-quality products, hence practices to preserve landscape, promote production and regenerative outcomes are supported by CAP ES2 and 3, potentially able to cover up to **3.8 Mha** (currently **1.06 Mha**). Conservation and rotational grazing for grassland could cover nearly **3.6 Mha** through the Eco-Scheme 4 of the CAP (currently **0.2 Mha** reported). Finally, over **1.3 Mha** of agroforestry systems are currently reported in Italy (out of an estimated potential of 10.8 Mha), predominantly silvo-pastoral and largely compatible with organic agriculture ([Agroforestry EU](#))⁵¹.

In summary, land-based CDR methods can a substantial share of Italy's removals. Following a peak of 53.5 MtCO₂ removals in 2023, Italy's LULUCF sector is projected to provide steady **39-45 MtCO₂e** removed per year through 2055²³. Securing these removals will require that CDR-promoting practices are continued and enhanced with the support of a well-defined CAP, timely and flexible funding, and quantifiable forest management and monitoring goals. These actions could secure **11.2 Mha of forests**; expand CDR practices across **7.2 Mha of arable land** and **3.8 Mha of permanent cropland** and cover **3.6 Mha with conservation grazing**.

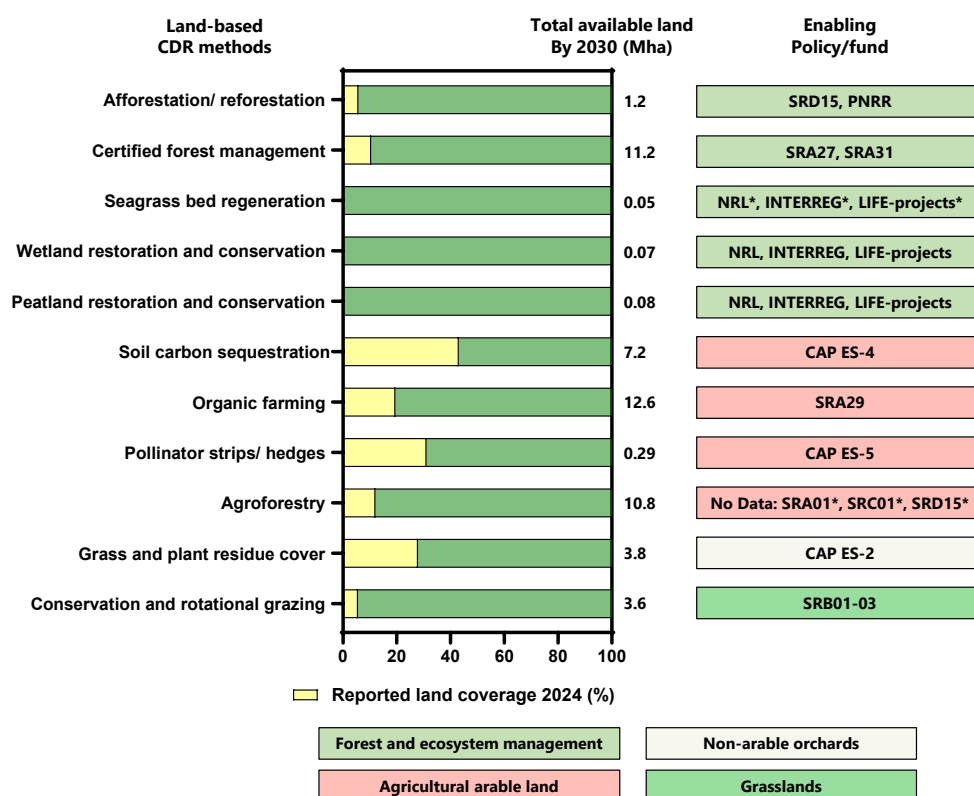


Figure 10. Current coverage of CDR-promoting practices associated with land use, land use change and forestry, and the available incentives. * Indicates potential funds yet unused.

Box 3 - A note on organic and regenerative practices

With 2.45 Mha of coverage, Italy is amongst the top EU countries for organic farming and provide 13.9% of the EU's total organic area⁵² which facilitates the adoption of additional CDR-promoting methods. The [Green Deal](#)⁶ requires a minimum of 25% (3.15 out of 12.6 Mha of agricultural land) coverage by 2030, a goal that Italy could surpass if the momentum of organic farming conversion is maintained at the national level⁵³.

Though hard to quantify, often organic practices include regenerative methods, which can enhance soil-carbon sequestration, yet due to the many principles these combine which are difficult to quantify, it was not included in this report as an official CDR method.

3.3.2 Coastal and underwater marine areas

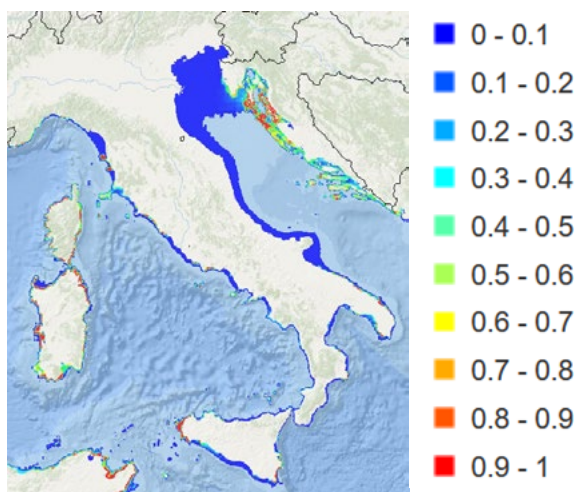
Italy has a diverse and extensive coastline stretching nearly 7,500 km, with 3,100 km of natural sandy beaches, 2,200 km of rocky coasts and cliffs, 1,300 km of artificial coasts, 650 km of protected coastal segments and 400 km of dune systems. Coastal erosion and sea level rise (1–3 mm/year from 1993 to 2022⁵⁴) have significantly reduced sandy beaches from 4,895 km to 3,100 km.

Italy hosts by far the largest portion of *Posidonia oceanica* in the EU, a seagrass species with high carbon storage capacity. Historically covering 395.3

kha (Figure 11), its extent has declined by 25% over the past decades due to sea warming, increase of invasive species, and sea level rise.⁵⁵ In Mediterranean conditions (with an average 15m depths), *Posidonia* can sequester up to 7.5 tCO₂/ha/year, depending on the basin's depth, temperature, and plant density.⁵⁶ Studies in the Mediterranean basin suggest that the total effective CO₂ burial in sediments ranges from 1-5 tCO₂/year/ha today, with some of the most effective sequestration rates found in islands of the Tyrrhenian sea such as Sardegna.⁵⁷

The potential of this species to contribute to Italian CO₂ removal needs is high. The [Marine Ecosystem Restoration Project](#)⁵⁸ (€400 million) aims to map, monitor, and restore this seagrass. Restoring the **57.7 kha** lost since 1990 is possible, but it requires suitable sites, protection from anchors, and long-term care.⁵⁹ This is a realistic scenario which could add nearly **288.5 ktCO₂ removed per year** to the current 1.04 Mt CO₂ sink. Biomass from *Posidonia* naturally accumulates on beaches (around 10-53% of total production) and could offer further CDR potential⁶⁰ by valorising it to an equivalent of **10.23 ktCO₂/year** - additional to the CDR volumes achieved through seagrass restoration.

Posidonia oceanica occurrence probability distribution (0-absent, 1-present)



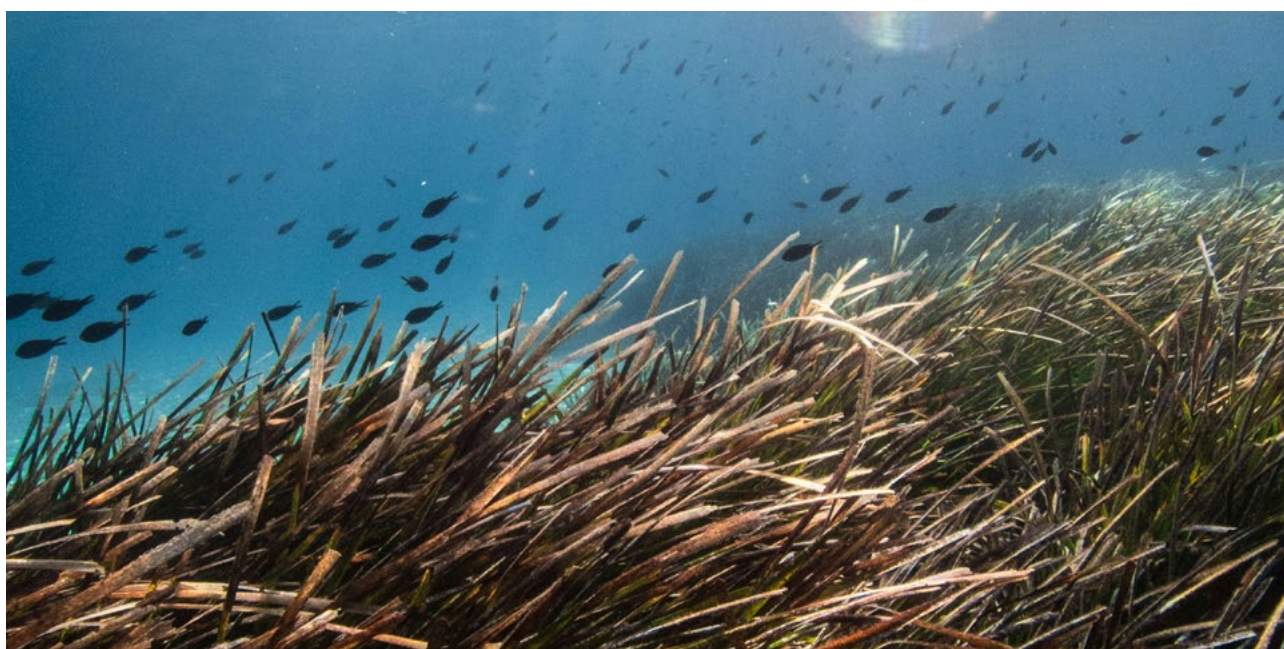
3.3.3 Wetlands and peatlands

Italy's wetlands of special interest include 57 Ramsar sites (incl. the Venice Lagoon), with 9 additional sites pending approval, collectively covering **79.83 kha**.^{62,63} These encompass coastal lagoons, salt marshes, temporary wetlands, and lakes. A recent survey by ISPRA and WWF reveals that 47.6% of these sites are in precarious condition, 31% are inadequate, and only 4.7% are in favourable conservation state.⁶⁴ This implies that about 95% (**75 kha**) of these lands require restoration to recover their full CDR potential as described in Chapter 4.

Italy also hosts around 75 kha of peatlands, primarily in the Alpine region, with mire areas accounting for 12 kha.^{65,66} Peatlands within mediterranean countries remain understudied and poorly monitored, with 70-90% estimated to be in a declining condition,⁶⁷ indicating a widespread need for restoration of **67.5 kha**.

Currently Italy, alongside [WWF](#),⁶⁸ [AIPO](#)⁶⁹ (Po river authority), and EU funding, has committed over €350 million to restore 1500 ha of wetlands and 340 ha of forests in the Po river basin, resulting in an estimated **2-5 ktCO₂ removed per year**. Building on this momentum and aligned with the 20% nature recovery target of the [EU's Nature Restoration Regulation](#),⁷⁰ Italy could restore over **14.5 kha of wetlands**.

Figure 11. Distribution of *Posidonia Oceanica* (data retrieved in 2019 from the [EU Maritime Affairs](#))⁶¹.



3.4 Natural conditions

Italy spans a wide range of climatic and ecological zones, where annual average temperatures range from ~8°C in alpine areas to 16–20°C in mediterranean regions, with strong seasonal variability in the north and hotter, drier conditions in the south.⁵⁴ Climate change is already impacting the country, especially in central and southern regions where reduced rainfall and more frequent heatwaves are increasing water stress.^{71,72} Figure 12 describes the most critical impacts of rising temperatures has on population health, sea level, weather, resources, agriculture, and the economy^{71,72}.

Italy's climatic and geographical diversity directly shapes the suitability of CDR methods. **Northern regions** and the Po Valley (Veneto, Emilia-Romagna, Lombardia) - characterised by intensive agriculture, bioenergy production, and proximity to the Ravenna CCS hub - **are well suited for BECCS and DACCS**. **Biochar** deployment is feasible nationwide but particularly **promising in central regions** (e.g. Tuscany, Emilia-Romagna, Umbria, Lazio) due to abundant biomass feedstocks. In the LULUCF sector, **improved forest management and harvested wood products** offer additional potential, especially **in Alpine and pre-Alpine regions** (Trentino, Piemonte, and Friuli Venezia-Giulia). For **enhanced rock weathering** (ERW), mineral resources are geographically concentrated: dolomite and steel slags in the north, and basalt, serpentine, and olivine in Liguria and volcanic regions such as Campania, Lazio, and Sicily (notably Mount Etna). Southern

regions with calcareous soils (e.g. Puglia) are also suitable for alkalinity enhancement. **Ocean alkalinity enhancement and blue carbon projects could be deployed nationwide**, while southern Adriatic regions (e.g. Puglia, Abruzzo, Molise, Marche) may leverage strong solar resources to **sustainably power DACCS** and ship CO₂ to the Ravenna hub.

Italy's precipitation varies significantly - from ~500 mm/year in the south to over 2,000 mm in Alpine areas.^{37,73} Northern areas receive steady year-round rainfall, while the south follows a Mediterranean pattern of dry summers and rainy winters. This **rainfall variability affects CDR performance**.^{74,75} Afforestation and reforestation are best suited to wetter northern and central regions, while agroforestry and biochar are more effective in drier southern areas, where biochar improves water retention in dry soils, enhancing soil organic carbon sequestration and crop resilience. Enhanced weathering (e.g., basalt application) performs best in moderately wet zones (800–1,200 mm/year), such as along the Apennines. Humidity also varies (65% in the south to 80–90% in the north²⁷⁸), influencing both natural and engineered CDR. **Higher humidity supports natural sinks like forests and wetlands, while drier conditions in central and southern inland areas are more favourable for DAC** due to lower air resistance, reduced water management costs, and the potential of being powered by solar-power.

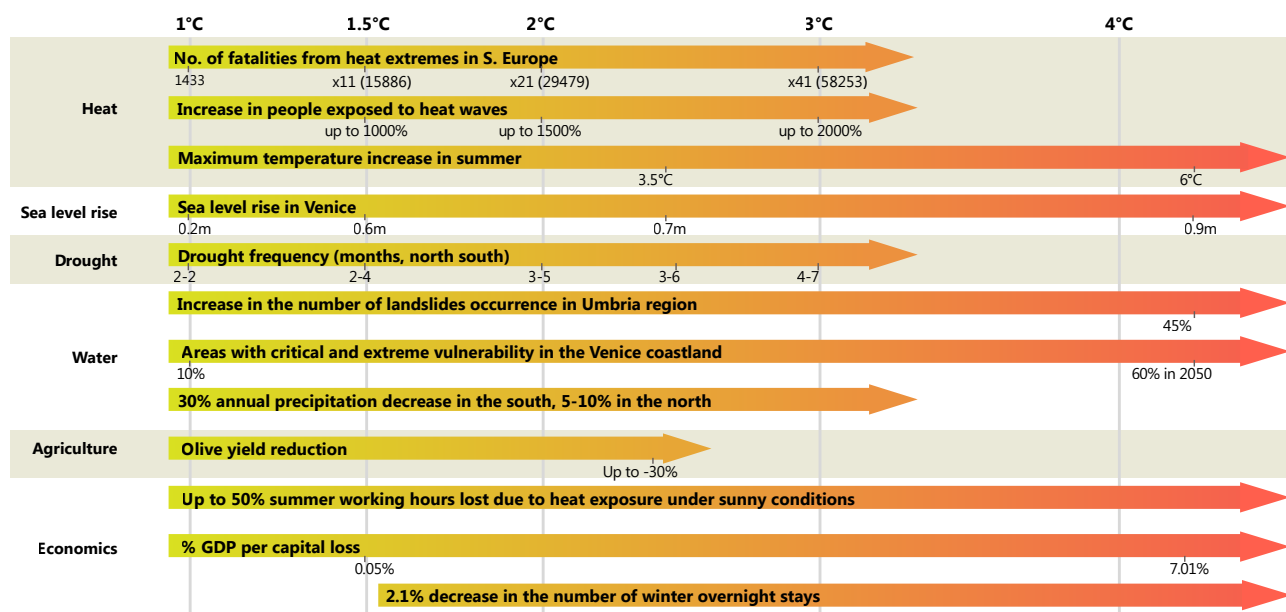


Figure 12. Projected impacts of climate change on population, sea level, weather, resources, agriculture, and economy (adapted from [climate-analytics, 2021⁷²](#)).

3.5 Biomass feedstocks

Biomass feedstocks offer significant potential for CDR in Italy. Various CDR pathways can leverage biomass, including BECCS via combustion, gasification, and anaerobic digestion, biochar production, and the durable biobased materials. To estimate biomass available for CDR in Italy, a stepwise approach was applied.

First, this study quantified **total biomass production**. Italy produces an estimated **120.53 Mt** of dry biomass annually, with forestry biomass accounting for the largest share (45.1 %), followed by agricultural residues (30.6 %), municipal waste (13.2 %), livestock manure (7.2 %), harvested forest wood and energy crops (2.5 %), and agri-food industry co-products (1.2 %).

Second, **existing uses were deducted**. Around **33.9 Mt/year** (28%) of biomass is already **used for bioenergy**. Because official statistics do not directly link biomass types to specific energy processes, biomass use was estimated from fuel inputs to different reactor types, consistent with literature values ([GSE-2021](#)⁸²). Based on this approach, approximately 11 Mt of biomass is estimated to be used for electricity generation, 20.6 Mt for heat, and 1.7 Mt for transport fuels (Figure 13).

Biomass already allocated to **bioproducts** (soil amendments, feedstock, farm inputs) and **long-lived wood materials** was also deducted from the total. These material applications may also already contribute to carbon storage. For example, currently about 3.5 Mt of municipal organic waste and over 0.6 Mt of agri-food residues are composted annually, while about 0.5 Mt of harvested wood is converted into durable biobased products such as buildings and furniture ([ISPRA](#)⁸⁰ and [FAO](#)⁸¹). In total, bio-based products and materials are produced leveraging the nearly 43.83 Mt of biomass suitable for conversion, with permanence varying depending on the applications.

Third, **biomass that cannot be feasibly collected or processed was excluded**. These constraints - physical, logistical, or technical constraints - amount to about **14.7 Mt** per year and include, for example, inaccessible forest residues and the liquid fraction of manure that cannot be easily recovered ([ENEA \(2021\)](#)^{78,79}). Regulatory factors also limit availability. For example, waste classification rules (e.g. [DM 264/2016](#)⁷⁷) restrict the use of certain feedstocks for bioenergy, and not all biomass types can be used for biochar when this is meant to be used as a fertiliser⁷⁶. Annex A.1 describes these constraints as well as the priority uses of the main types of biomass.

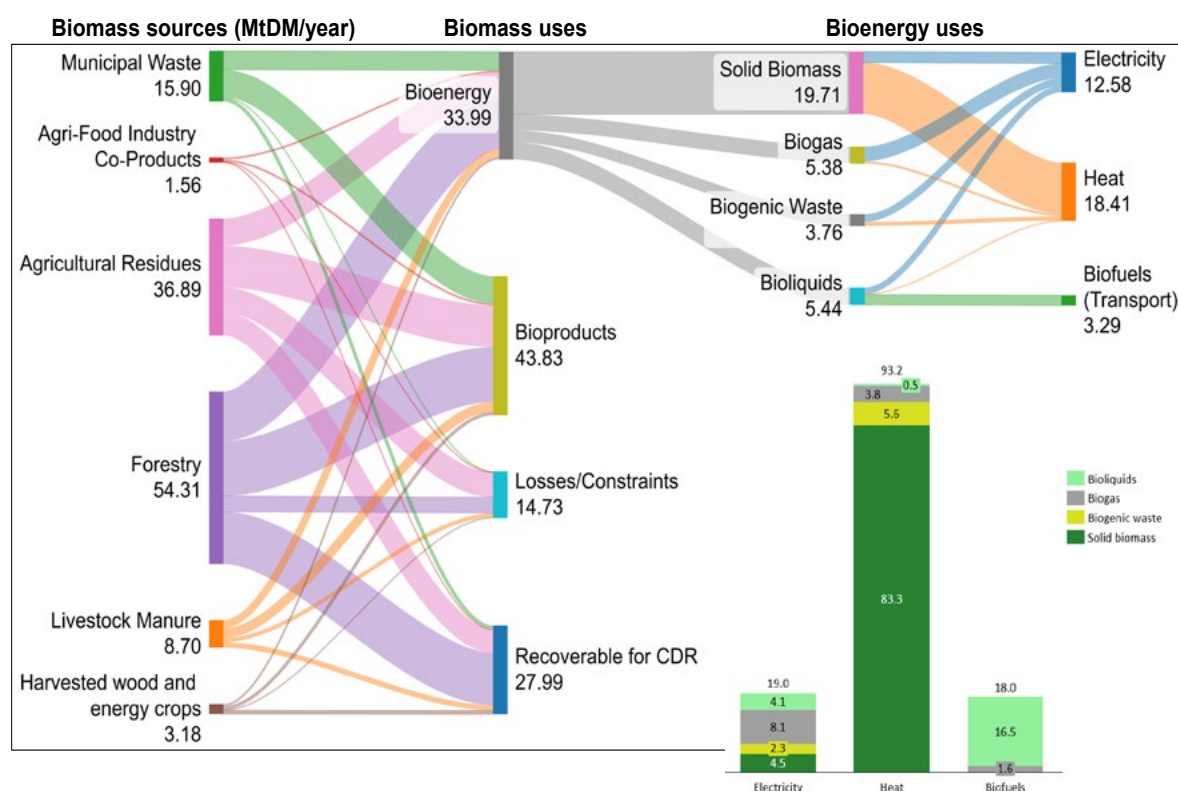


Figure 13. (Left) Summary of biomass sources and quantities (Mt dry basis per year) and their main uses, as detailed in Table A.1. (Right) Bioenergy **produced** from existing biomass plants to generate electricity, heating, and biofuels.

After accounting for these constraints and competing uses, around 28 Mt of biomass per year remains potentially available for CDR pathways. This volume represents the actual pool from which biochar production, BECCS, and durable biobased materials can draw on to deliver additional CDR. It is important to note that over **33 Mt/year** of biomass is already used in existing biomass reactors on which BECCS could potentially be deployed (see next section 3.5.1).

Italy has a well-established market for recycled wood products (over 1.7 Mt used in 2022), and sustainable housing is geared for circular feedstock usage, with over 3600 new wood-framed homes constructed in 2022. The Energy Performance of Buildings Directive (EPBD)²²³ introduced the Minimum Energy Performance Standards (MEPS) that aims for the renovation of 26% of the worst-performing non-residential buildings by 2033. In addition, the CRCF explicitly covers carbon storage in products with an expected life of over 35 years, enabling certification and monetisation of these products

Box 4 – Biochar current status and future scale-up potential

Biochar is recognised as a soil improver under Italy's fertiliser law (D.Lgs. 75/2010)⁸⁵, as amended by the Decree of 10 Oct 2022, which allows its use in **organic farming**. The biochar sector in Italy is small but growing steadily, with over 30 registered producers and around 65 approved biochar products listed in the national fertiliser registry as of 2023. An additional 7-10 pyrolysis unit providers indicate increasing market readiness⁸⁶.

Despite accelerating public and industry interest, as well as EU-wide production capacity growing quickly, **current production is limited** and application is slow. Based on available data (from gasification-only production), Italy produces about **1 kt** of biochar annually⁸⁷, corresponding to roughly **1.9 ktCO₂e/year** of CDR (using conservative conversion ratios from the [Global Biochar Market Report](#)⁸⁸). This corresponds to around 2% of total European output in 2023 (49 kt of biochar).

Growth prospects are significant. The [European Biochar Industry \(EBI\)](#)⁸⁹ projects that biochar-based CDR in the EU could reach 2.3 MtCO₂ by 2030 and scale up to 80 MtCO₂ by 2040. Italy's share is estimated at **46 ktCO₂ by 2030** and **1.6 MtCO₂ by 2040**, with potential for higher deployment given available biomass resources if policy incentives, market demand, and carbon credit uptake are accelerated.

3.5.1 Biomass plants for BECCS

In 2021, Italy had 2,985 active biomass plants for energy generation, with an installed electricity generation capacity of over 4.1 GW, and registered production of **130.26 TWh** (19.07 TWh of electricity, 93.14 TWh of heat and the equivalent of 18.05 TWh of biofuels, [GSE](#)⁸²). Biomass plants had a final energy consumption of **129.32 TWh** across electricity (14.5 TWh), heat (96.76 TWh) and biofuels (18.05 TWh). The total biomass consumption underlying this energy production is estimated based on reported outputs of electricity, heat, and biofuels, using fuel energy content and conversion efficiencies (see Annex A.2). Small-scale units (e.g. residential stoves using pellets) were not considered, as they primarily rely on dedicated feedstocks (e.g. pellets). This is why total heat consumption appears higher than reported generation.

Using this framework, **the theoretical CDR potential of BECCS from existing biomass reactors** is

estimated at around **49 MtCO₂** per year. Most of this potential (46.6 MtCO₂) comes from combustion processes, with a smaller contribution 1.9 MtCO₂) from anaerobic digestion and fermentation. Transport biofuels are excluded from the BECCS potential because combustion occurs in dispersed mobile sources.

In practice, only a subset of emissions from biomass derived electricity and thermal energy can be feasibly captured. Much of the heat generated from biomass is produced in small, distributed systems - especially in the residential sector - where carbon capture is not currently feasible. As a result, **BECCS deployment is realistically limited to larger, dedicated facilities** such as biomass power plants and combined heat and power (CHP) plants. Larger plants (with capacities above 10 MW) are more suitable for CCS, as they produce concentrated flue gas streams and can support the required infrastructure.

These plants are mapped in Figure 14 (left) using the [GSE⁸³](#) reactor atlas, alongside Figure 14 (right) showing the potential CO₂ that could be stored in either Ravenna or in other potential storage sites such as Jonio and Gela. Notably, a significant number of thermoelectric reactors above 10 MW

are located less than 300km from the [Ravenna CCS Hub⁸⁴](#) (see section 3.7 on CO₂ storage). Focusing on these larger and better-located facilities, **the realistic BECCS potential of existing reactors decreases to 13 MtCO₂e/year**.

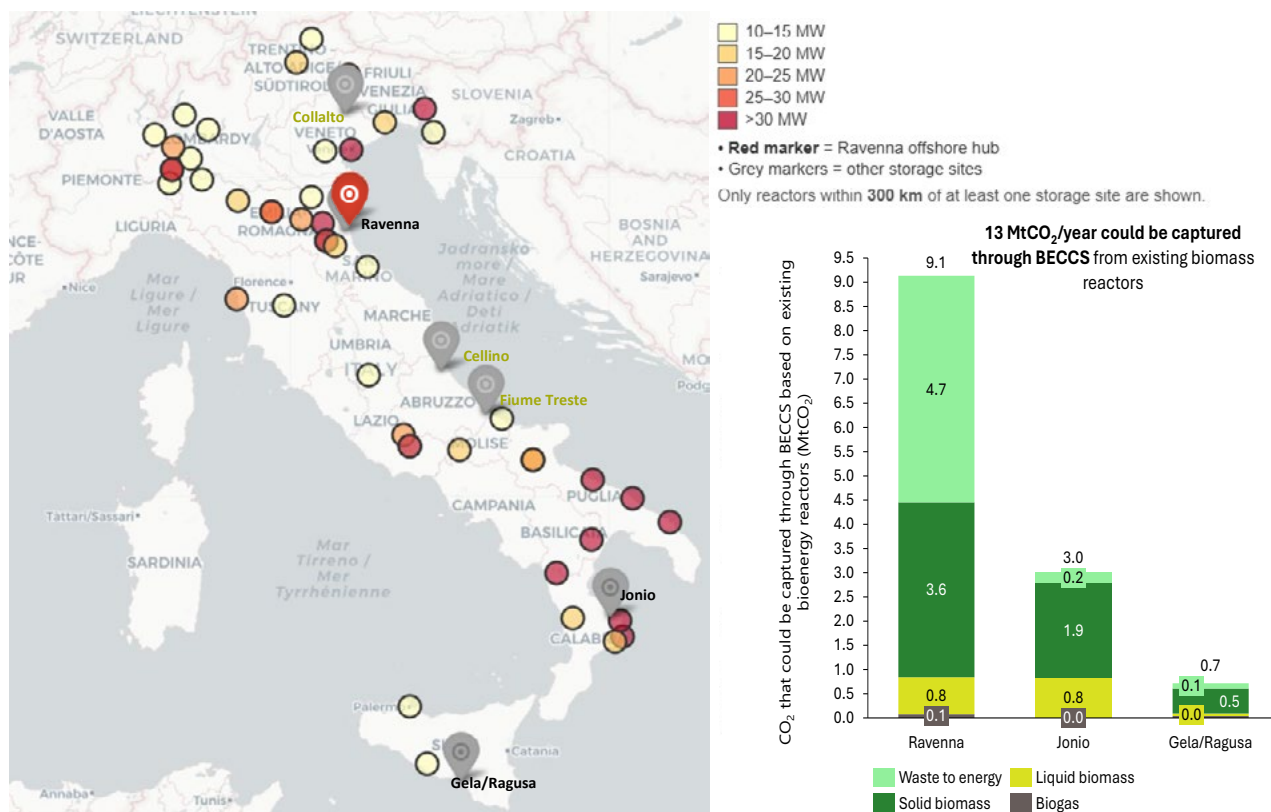


Figure 14. (Left) Location of bioenergy reactors above 10 MW and within 300 km of an existing (Ravenna hub in red) or potential CO₂ storage hub. Circle fills represent the bioenergy capacity range. Other potential CO₂ storage sites (Jonio and Gela/Ragusa) are depicted in grey. Data from [GSE⁸³](#) reactor atlas. (Right) Potential of CO₂ removed per year through BECCS from existing reactors above 10 MW divided by type of reactor most feasible CO₂ storage site.



3.6 Mineral feedstocks and industrial residues

Italy has significant reserves and production capacity for minerals suitable for CDR via enhanced rock weathering (ERW) and ocean alkalinity enhancement (OAE). Relevant minerals include silicate minerals (e.g. olivine, basalt), and alkaline industrial residues (e.g. cement kiln dust (CKD), concrete demolition waste (CDW), and steel slag). When these materials weather, they convert CO₂ into dissolved ions like bicarbonate that can store carbon over long timescales, providing permanent CO₂ storage. In contrast, the weathering of carbonate minerals (e.g. limestone and dolomite) primarily produces dissolved bicarbonates that can subsequently precipitate as carbonates, resulting in the potential release of CO₂ back to the atmosphere.

To estimate the available minerals and industrial residues suitable for CDR, this study first mapped current production levels, usage patterns, and resulting residues to understand existing material flows. Second, it projected future extraction levels to capture how availability may evolve over the coming decades. Finally, it estimated the share of residual or unused material that could be made available for CDR.

3.6.1 Limestone, dolomite and magnesite

Limestone is Italy's most abundant mineral resource suitable for CDR, with **72.8 Mt produced in 2022** (ISTAT⁹¹ Figure 15), and major extraction sites spread across Lombardy, Tuscany, Sicily, Puglia, and Calabria. It currently serves numerous industrial applications: cement and metal manufacturing (each 32%), followed by lime production (14%), flue gas desulphurisation (8%), paints and coatings (6%), agriculture (5%), feed (4%), paper (2%), and glass (1%)⁹².

By 2050, limestone demand is projected to rise by 10%, primarily driven by CDR applications such as ocean alkalinity enhancement and soil amendments⁹³. The OECD Circular Economy Report (2024) anticipates a transition from virgin to secondary raw materials, with 1-2.8% of the limestone recovered from residues potentially being redirected to CDR⁹⁴. Agricultural lime – produced by calcinating limestone into a reactive and more alkaline material and accounting for around 5% of current use – may also deliver carbon benefits if applied through regenerative practices⁹². Assuming a 10% increase in production by 2030 (reaching 80.01 Mt), and assuming 8-10% of that would be available for CDR, **Italy could supply up to 8 Mt of**

limestone annually for CDR by 2030.

Dolomite in Italy is primarily used in steelmaking, water treatment, construction aggregates, and refractory products. Because it is often co-extracted with other calcareous stones, no standalone national production estimate exists; however, reported exports provide a lower-bound estimate of 0.1127 Mt of dolomite products⁹⁵. The newly licensed 20-year *Dossenì* concession in Trentino is the only officially documented new extraction site⁹⁶.

Based on current data, expected additions from new concessions to meet export surpluses, and assuming dolomite demand grows at the same rate as limestone (10%)⁹³, Italy could make available roughly **0.124 Mt of dolomite annually for CDR applications by 2030**, with this supply remaining stable for at least two decades.

Magnesite is used for magnesium for many industries and agriculture, and is not currently mined in Italy⁹⁷. Based on the nearly 1.5 Mt historically produced in the first half of the 20th century in Tuscany, ISPRA's National Exploration Program (PNE-2024)⁹⁸ is still evaluating extraction, yet no official, audited national reserve figures are available, nor any foreseeable openings until the sites are fully characterised⁹⁹.

3.6.2 Basalt

Italy produced approximately **9.02 Mt** of basalt in 2022 (ISTAT⁹¹ Figure 15), with extraction concentrated in Sicily and Lazio. Of this volume, around 15-20% (**1.3-1.8 Mt**) consists of fine waste material already generated as by-product, ideal for ERW applications¹⁰⁰. Globally, about 70% of basalt is used in construction, and while official statistics do not disaggregate basalt production specifically, proprietary market analyses suggest demand growth of 5% annually in Italy (GVH-Basalt, PNIEC).

Based on aggregate market trends and infrastructure expansion linked to the energy transition, domestic production could plausibly increase to **13.5 Mt annually by 2033** (an increase of 4.5 Mt), subject to regional quarrying constraints. Under such a scenario, and accounting for processing and competing uses, **residual basalt available for ERW could reach approximately 2.7 Mt/year by 2033**, provided that processing infrastructure expands, especially the ability to grind basalt into very fine particles.

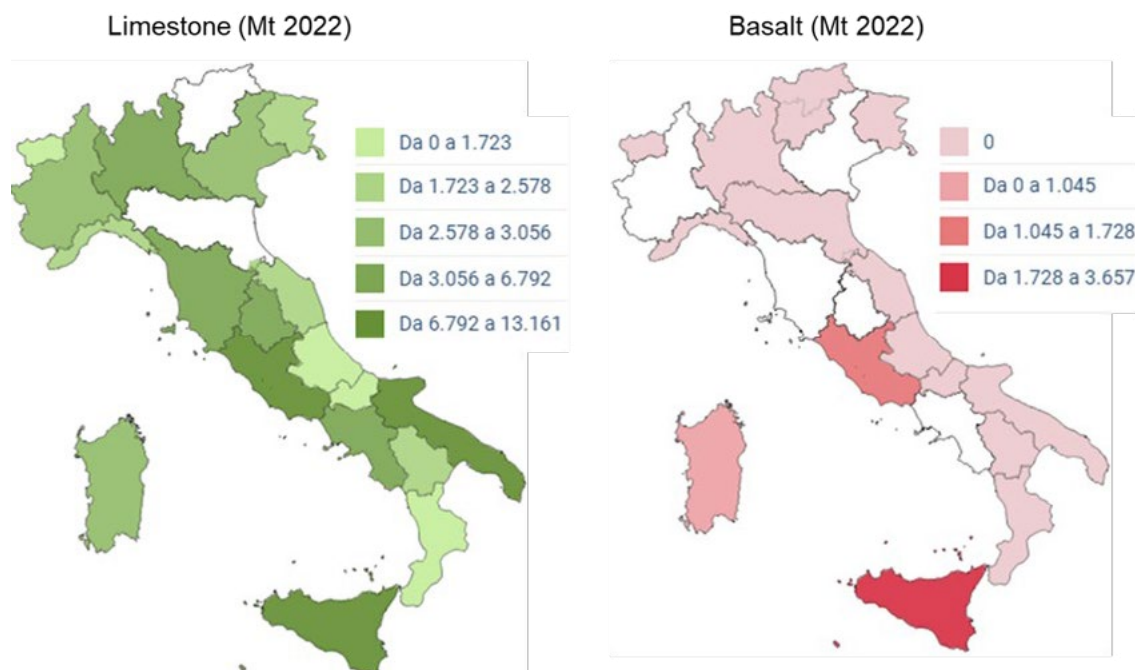


Figure 15. Geographic distribution of limestone and basalt production (ISTAT⁹¹).

3.6.3 Olivine

Italy has limited reported extraction of olivine and only one functioning mining site near Turin with a 100 Mt reserve being mined at a rate of **0.25 Mt/year**¹⁰¹. Reserves were also confirmed at Bric Carleva and Finero, estimating 300 Mt and 250 Mt respectively, for a total of nearly **650 Mt** across the three mines^{93,102}. Current uses include construction sands, soil pH amendment, filtration media, and CO₂ mineralisation feedstock.

Though no official projections exist for future production increases, a scaleup is anticipated, supported by signals such as the approved Piedmont extraction project of up to 550,000 m³ (1.8-2.5 Mt) before 2030¹⁰³, as well as rising demand from the foundry/steel and CDR markets. Based on current extraction rates and capacities - and assuming no new mines - Italy could be producing around **1.65 Mt of olivine per year by 2030**, drawing on the estimated 650 Mt of national reserves. In principle, olivine could be directed entirely toward CDR applications. For OAE, the mineral must be milled to particle sizes below 10 µm to ensure rapid dissolution, while ERW typically requires particles

below 30 µm and soil conditions around pH 4.5 to achieve effective weathering rates^{102,104,105}.

3.6.4 Cement kiln dust

Cement kiln dust (CKD), rich in calcium oxide and slaked lime, is a by-product of cement manufacturing and is a suitable input for *ex-situ* mineralisation and potentially OAE, subject to composition variability and environmental and regulatory constraints. While there are no official statistics on current or projected CKD volumes, estimates suggest that 20-250 kg of CKD are generated per ton of clinker, depending on the processing technology used¹⁰⁶.

Italy's clinker production has remained stable over the past decade at 18-20 Mt annually, implying a CKD output of about **0.36-5 Mt/year**. Most of this material is reused within cement plants as a partial substitute for raw inputs. While Italy-specific data on CKD availability is limited, EU-level evidence suggests that around 5% of CKD is not recycled¹⁰⁷. Applying this share to Italy implies that approximately **0.018-0.25 Mt/year of CKD could be available for CDR**.^{*} Under different carbonation processes (accelerated, pressurised or aqueous), CKD can sequester between 0.05-0.11 tCO₂ per ton of material^{108,109}.

*European Commission. Commission Implementing Decision of 26 March 2013 establishing the best available techniques (BAT) conclusions for the production of cement, lime and magnesium oxide (2013/163/EU). Official Journal of the European Union L100, 1-45 (2013).

Cementir Holding. Sustainability Report 2023. (2023).

Federbeton. Rapporto di Sostenibilità 2023. (2023).

3.6.5 Construction and Demolition Waste (CDW)

Italy generated **61.63 Mt of construction and demolition waste (CDW)** in 2023 (excluding excavated soil/rocks and dredging materials) (ISPRA, 2025). Of this, 81% (49.91 Mt) was recovered (ISPRA) - well above the EU 70% target - while 19% (**11.7 Mt**) was not. The recovered fraction is composed primarily of mineral materials: 44.89 Mt consists of mineral streams prepared for recycling into aggregates for construction and infrastructure, while 5.02 Mt consists of non-mineral streams (e.g. wood, glass, plastics) directed to other material cycles (ISPRA). No official data isolates the share of CDW directed towards CDR or *ex-situ* mineralisation. Policy documents (e.g. [Piano per la Transizione Ecologica](#) and the National Circular Economy Strategy) set a broad objective to reduce processing scraps, residues and waste by 50% by 2040 and highlight CDW as a priority, but they do not provide a national 2050 forward projection.

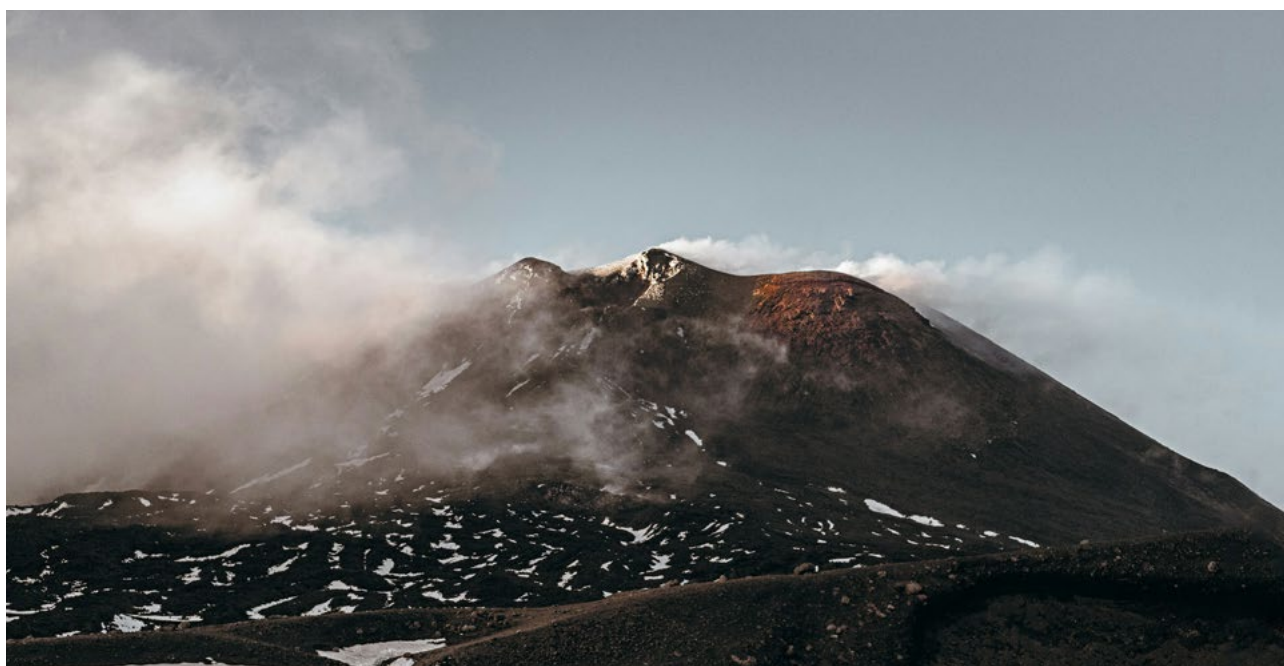
The unrecovered **11.7 Mt** of CDW could therefore be used for storage with *ex-situ* mineralisation. Given its high heterogeneity and contamination, a conservative assumption is that only ~30% can be upgraded into suitable concrete-rich feedstock (e.g. recycled concrete aggregate and fines) - equivalent to **~3.5 Mt/year potentially available for ex-situ mineralisation**. CO₂ uptake varies with composition and processing quality, but for concrete-rich CDW typical values range from 10–57 kg CO₂ per tonne, corresponding to 0.010–0.057 tCO₂ per tonne of concrete-rich CDW (Torrenti et al., 2022, Ndiaye et al., 2023).

3.6.6 Steel Slag

Italy is the second largest steel producer in the EU, with stable production of around 21 Mt per year between 2020 and 2024¹¹⁰. Production is heavily concentrated in the northern regions, particularly in Lombardy, where roughly 90% of steel mills are located. Steelmaking generates an estimated **3.5–4.2 Mt of slag annually** - equivalent to 15–20% of steel produced - which is widely used in the construction sector and as a feedstock for carbonation processes¹¹¹.

A substantial share of this slag is repurposed as a product, such as aggregates or cement feedstock, and therefore excluded from waste statistics. These statistics only account for waste from thermal treatment of ferrous metals and steel production, amounting to roughly 1 Mt annually, which represents the portion currently available for *ex-situ* mineralisation storage⁸⁰.

European steel production is projected to grow by 27% by 2030¹¹², a trend likely to extend to Italy despite recent global overcapacity concerns¹¹³. Higher production volumes would increase slag generation, expanding the pool of material suitable for soil alkalisation and mineral carbonation. Repurposing slag in this way aligns with circular economy objectives while contributing to national CDR targets¹¹³. Under these assumptions, approximately **1.27 Mt of steel slag could be available annually for CO₂ storage through ex-situ mineralisation by 2030**.



3.7 Geological CO₂ storage

CO₂ can be stored in depleted oil and gas fields, deep saline aquifers, and, in some cases, coal seams, generally at depths below about 800 meters. Depleted oil and gas fields are attractive because they are well mapped, often already have wells and infrastructure, and typically sealed by proven caprocks. Deep saline aquifers consist of porous rock formations saturated with saline water into which CO₂ is injected and stored. They are widely regarded as offering the largest theoretical storage capacity, but generally require more extensive site characterisation, appraisal, and permitting before development. Coal seam CO₂ storage is technically possible and can lead to enhanced methane recovery, but it is a more specialised and less mature storage option and therefore not considered in this report.

3.7.1 Reported capacities and legal framework

Italy's estimated cumulative geological CO₂ storage ranges from 4-20 GtCO₂¹²³. Within this range, deep saline aquifers account for an estimated 2.95–11.8 GtCO₂ (assuming a storage efficiency of 1–4%)¹²⁴, although more recent studies suggest a narrower estimate of around 4.67 GtCO₂¹²³. Additional storage potential is estimated at 1.81–3.42 GtCO₂ in oil and gas fields, and approximately 71 MtCO₂ in coal seams. Combining these components yields a total cumulative storage capacity of roughly **6.55–8.16 GtCO₂, based on the more recent and conservative estimates** across different geological formations¹²³.

Geological CO₂ storage is restricted in Italy's seismic and volcanic areas. However, the newly amended legislative decree ([DL 181/2023, now 11/2024](#))¹²⁵ lays the legal framework around geological CO₂ storage, renewable resources and energy security and streamlines elements of the CCS value chain (capture, transport, and storage), by providing **simplified permitting procedures** and establishing **measures to enable CO₂ transport networks and storage**. These provisions are intended to facilitate the emergence of CO₂ infrastructure and hub development, including conditions that can enable third-party access where applicable.

3.7.2 The Ravenna CCS Project and market interest

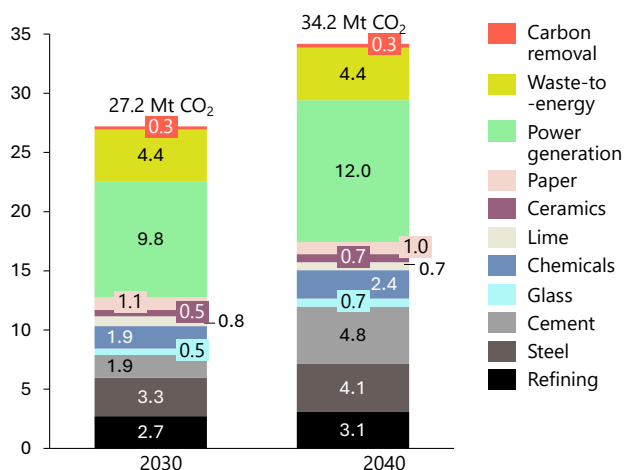
The **Ravenna CCS Project**⁸⁴, commissioned by Eni S.p.A. and Snam, represents the only large-scale working geological CO₂ storage initiative in Italy, and one of the few in the EU with potential capacities surpassing a million tons per year¹²⁶. This site can hold cumulatively over 515 MtCO₂, and it has been operating a pilot injecting 25 ktCO₂/year since 2024. **Projections estimate 4 Mt/year stored by 2030, 12 Mt/year by 2035, and 16-20 Mt/year from 2040 onwards**⁸⁴.

Figure 16 (left) shows the location of the Ravenna CCS Hub and other potential CO₂ storage sites in depleted oil & gas fields and deep saline aquifers. Figure 16 (right) summarises a market survey by Eni and Snam on industry interest in sending captured CO₂ to Ravenna. The [survey](#)¹²⁷ indicates **potential demand of more than 34 MtCO₂ by 2040 – well above the hub's planned capacity**. Non-binding expressions of interest from 61 companies across 172 sites (141 existing and 31 planned), if materialised, would exceed the annual storage capacity of 20 Mt/year, amounting to over 350 Mt of cumulative CO₂ between 2027-2040, and more than 700 Mt between 2027-2050¹²⁷. The [PNIEC-2024](#)¹⁸ also reports a cross-sector interest in deploying CCS of more than 30 MtCO₂ by 2030.

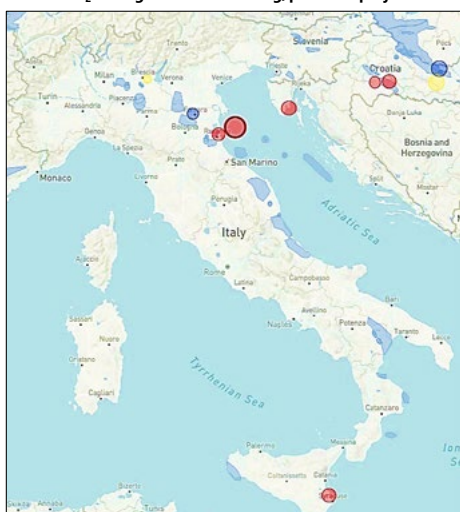
The survey indicates that **conventional pointsource CCS**, in sectors like power generation, cement, steel, and refining **will account for almost all the projected injection capacity available at Ravenna**, with a nominal interest from respondents to use a small share (indicated in red) of injection capacity for CDR methods such as BECCS and DACCS.

To estimate the share of injection capacity associated with CDR, this study combined (i) the explicit carbon removal demand (in red), and (ii) the biogenic fraction of CO₂ from waste-to-energy facilities (in yellow), which can be considered CDR when captured and stored. Assuming a 50–60% biogenic share in the CO₂ from waste to energy ([ESWET-2023](#))¹²⁸, this implies that CDR-related demand could represent around 9–11% of the CO₂ volumes intended for Ravenna in 2030 (~1% from dedicated CDR and 8–10% from the biogenic fraction of waste to energy) and **7–9% by 2040**, as total volumes of CO₂ captured are expected to increase while the amounts from waste to energy remain constant.

Market interest for industrial point-source CCS



CO₂ Storage sites and existing/potential projects



In summary, if injection capacity expands through new projects such as the Ravenna CCS hub, only a small share of it (up to 9% or 3 out of 34 Mt/year) would be available strictly for carbon removal solutions like BECCS and DACCS. Two conclusions follow. First, current and planned **injection capacity is insufficient to meet both industrial CCS demand and longterm CDR needs**. Second, **market signals are not incentivising the development of dedicated injection capacity for CDR**, suggesting that policy intervention may be required. CO₂ storage capacities will need to be significantly increased to satisfy market demand, meet Italy's Long-Term Strategy¹ ambition to reduce hard-to-abate emissions from all sectors by 2050, and provide sufficient injection capacity for other CDR methods requiring geologic CO₂ storage.

Figure 16. (Top) Active CO₂ storage sites and potential projects. The red site is the Ravenna Hub, black sites are potential storage units, and light blue areas are depleted hydrocarbon fields and deep saline aquifers (adapted from [Donda et al., 2011](#)¹²⁴, and [CATF-2023](#)¹²⁶). (Bottom) Market survey of non-binding expression of interest from 61 companies, including 172 emission sites (adapted from [ENI-SNAM-2024](#)¹²⁷).



3.7.3 Ongoing and potential CO₂ storage sites

In addition to Ravenna CCS, other CO₂ storage sites have been studied and proposed (Table 2),

though little is known about their potential injection rates^{123,129}.

Difficulty	Project/Option	Type of sink	Injectability (Mt/year)	Max cumulative capacity (Mt)	Status & notes
LOW (permitted)	Ravenna CCS Hub	Depleted offshore gas fields	4 by 2030 12 by 2035 16-20 from 2040 onwards	515	Phase 1 injection started (25 kt/year pilot at Casalborsetti/Porto Corsini).
MEDIUM (plausible by 2040–2050 with timely permitting)	Jonio Hub (offshore Ionian Sea)	Depleted offshore gas fields	4–5 (*)	130	PNIEC indicates capacity, with availability from 2040 due to ongoing production and more complex geology.
	Onshore Ravenna area	Depleted onshore fields	2–3 (*)	69	Identified by PNIEC as the next onshore option. Rates to be defined pending permitting.
	Onshore Sicily	Depleted onshore fields	1–1.5 (*)	35	Early phases possible if transport by ship is used pre-pipeline.
HIGH (needs new exploration and/or cross-border arrangements)	Residual unstudied hydrocarbon fields	Depleted fields	106.8 (*)	2750	Estimation based on the reported maximum of depleted field capacity minus the values previously analysed.
	Italian deep saline aquifers (upper/median/lower Adriatic; other basins)	Saline aquifers	181.32 (*)	Multi-Gt potential (nearly 4.7 Gt at 2% storage efficiency)	Substantial capacities with unknown injectability rates. Needs seismic/appraisal and rules under DL 181/2023 .

Table 2. CO₂ storage sites in Italy across depleted fields and saline aquifers. (*) Due to limited data availability, injection rates were estimated by applying the injection-to-capacity ratio observed at the Ravenna CCS Hub.

Combined, the studied sites of depleted hydrocarbon fields offer an estimated cumulative storage capacity of around **749 MtCO₂**, with an annual injection potential of **23–29.5 MtCO₂/year**. This represents only a small portion of the total storage capacity of oil and gas fields reported in the literature (3.42 GtCO₂)^{123,129} and suggests the need for an imminent acceleration of studies on these fields as well as of concrete proposals for the use of deep saline aquifers for CO₂ storage which have an estimated cumulative capacity of **4.7 GtCO₂**¹²³ within a wide storage range of 2.95–11.8 GtCO₂.

If all proposed depleted hydrocarbon fields and deep saline aquifers were to become operational CO₂ storage hubs, and assuming they could each achieve injection rates comparable to the Ravenna Hub (20 MtCO₂/year), **Italy could theoretically**

reach a combined injection capacity of more than 317 MtCO₂/year. Such capacity would be more than sufficient to meet projected domestic storage demand (34.2 Mt/year by 2040, rising to over 40 Mt/year by 2050), while also accommodating CO₂ storage from BECCS and DACCS. Under the more realistic scenarios outlined in Table 13 in Chapter 7, only 30–40% of high risk projects such as unstudied hydrocarbon fields and deep saline aquifers could become a reality, contributing to the equivalent of two (40 MtCO₂/year) and three (60 MtCO₂/year) Ravenna projects. Figure 17 displays the theoretical (i.e. maximalist) annual injection capacity of Italy's potential CO₂ storage sites, assuming full injectability of low and medium risk projects; plus utilisation of 40% of unstudied hydrocarbon fields (40 MtCO₂/year), and 30% of deep saline aquifers (60 MtCO₂/year). In Chapter 7, this CO₂ injection potential

will be discounted further with a Risk Adjustment Factor (RAF) to reflect more realistic deployment assumptions.

In summary, assuming that all low and medium storage projects can be realised, and that 40% of unstudied hydrocarbon fields and 30% of deep saline aquifers become active storage units over the

coming decades, Italy could reach have an annual CO₂ injection capacity of nearly **129.5 MtCO₂/year**. After subtracting the 31 MtCO₂/year allocated to industrial CCS (excluding biogenic waste and CDR) based on the market surveys, the remaining storage capacity available for CDR in 2050 would be up to **98.5 MtCO₂/year** for CDR by 2050.

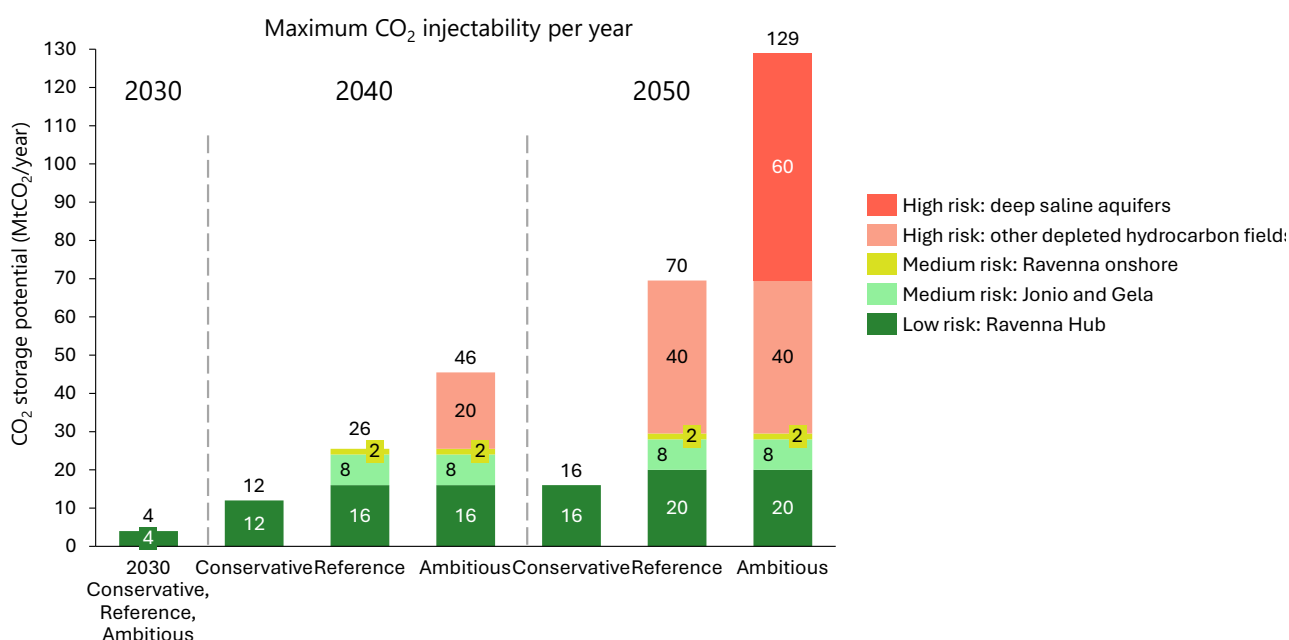


Figure 17. Theoretical injection capacity (MtCO₂/year) of Italy's existing and potential CO₂ storage sites.

Box 5 – Abandoned mines potentially suitable for in-situ CO₂ mineralisation

Abandoned mines represent a largely underused asset for CDR, as their extensive underground voids can be repurposed for in-situ CO₂ mineralisation and long-term storage. Italy hosts more than **3,000 historical mining sites**, 75 of which are curated within ISPRA's REMI network (*Rete Nazionale dei Parchi e dei Musei Minerari*)¹¹⁴. Regional and provincial authorities oversee permitting, safety and remediation under *R.D. 1443/1927*¹¹⁵, while public companies such as IGEA in Sardinia maintain technical archives and support reclamation activities¹¹⁶.

Several documented dismissed mines with substantial underground voids offer accessible subsurface space suitable for pilot in-situ mineralisation projects. These include the lead–zinc districts of Sulcis–Iglesiente (Acqueresi, San Giovanni in *Sardinia*¹¹⁷ with more than 79.5 Mm³ cumulative underground voids), the *Tuscan*¹¹⁸ pyrite mines (Gavorrano, Niccioleta with over 6.5 Mm³ of reported excavations), and the Tassullo/San Romedio dolostone mine in *Trentino*¹¹⁹ (with 0.6 Mm³ voids). Reuse requires regional environmental assessment, mine-safety compliance, and hydro-geological stability checks, with ISPRA providing technical guidance.

Together, these sites contain 86.6 Mm³ of documented voids, with potential to store up to 256.3 Mt of magnesium carbonate (**128 MtCO₂e**) or 242.5 Mt of calcium carbonate (**107 MtCO₂e**). Evidence from international pilots supports this approach. In Japan (Mikasa City), CO₂-bearing slurries injected into closed underground mines mineralised in situ while improving rock stability, and broader reviews confirm the geological feasibility of mine-based mineralisation¹²⁰.

Two geological settings are especially promising: ultramafic ophiolites such as Libiola (Liguria), suitable for true in-rock mineralisation and currently studied by *STORECO2*¹²¹; and the carbonate mine districts of Sulcis–Iglesiente and Tassullo/San Romedio, whose engineered underground spaces can host carbonation of reactive alkaline materials using existing rooms, access, and utilities¹²².

3.8 CO₂ transport infrastructure

To date, the scale of required CO₂ transport capacity has been projected for the Ravenna CCS project. Through the [Callisto project](#)¹³⁰, Italy is expected to import to the Ravenna CCS hub 1.2 MtCO₂/year from France between 2027 and 2032 (Phase 1), increasing to 2.9 Mt from 2030 onwards (Phase 2), as capacities are expanded. Italy will also be expected to export 0.2 MtCO₂/year from Sicily to Greece ([Prinos site](#))¹³¹ through the Augusta Project (Phase 1)¹³².

However, studies^{132,133} mapping the potential sinks, sources, and routes for CO₂ injection (as shown in Figure 18) indicate a potential to import further volumes from neighbouring countries such as France, Slovenia, Austria, and Croatia, yet no official figures have been proposed^{132,133}.

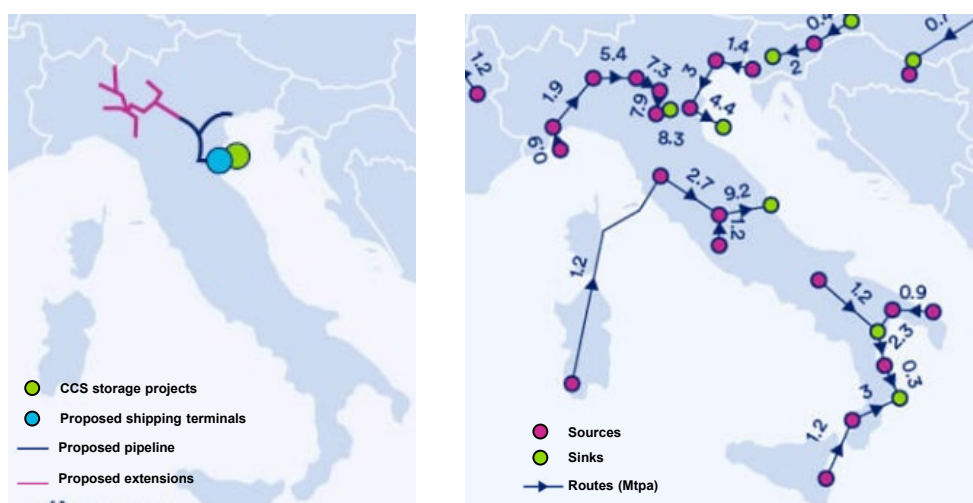


Figure 18. Proposed (left) and potential (right) CO₂ transport and storage projects and routes (adapted from: CATF¹³³).

3.9 Restrictions

Large portions of land should be excluded from CDR deployment due to environmental protection, competing land uses, and regulatory restrictions. These include protected natural areas (21–25% of the national territory, [ISPRA](#))⁵⁴; and lands of high cultural and scenic value, such as shorelines, riversides, mountain belts, and UNESCO zones protected under [D.Lgs 42/2004](#)¹³⁵, which were excluded from all scenarios due to legal and cultural constraints. Military zones (0.26% of inland territory) and urbanised land (7–8%) are also unsuitable for land-based CDR, though the latter may host engineered solutions such as DACCS or BECCS on industrial sites ([ISPRA](#))¹³⁴.

Additional constraints aim to avoid conflicts with food production by excluding prime farmland from afforestation while keeping it eligible for compatible CDR methods such as biochar, agroforestry, or ERW¹⁸. Groundwater protection zones are strictly excluded for CO₂ injection wells and CO₂ pipelines ([D.Lgs 152/2006 art. 94](#))¹³⁶. Legal frameworks further restrict CCS activities in the realistic scenarios: CO₂ storage is currently permitted only in authorised

offshore sites such as the Ravenna CCS Hub¹³⁸ ([D.Lgs 162/2011](#))¹³⁷. The 2024 amendment to the “CCS Law” introduced key updates, including experimental permits valid for up to 3 years (extendable to 6), waived financial guarantees below 100,000 tCO₂ stored, and the designation of CO₂ pipelines as public-utility infrastructure under national expropriation law. Frequent wildfires (45.8 kha burned in 2024¹³⁹) threaten the permanent of forest-based CDR. Southern regions and islands - Sicily, Sardegna, Calabria, and Campania - are particularly fire-prone and require enhanced monitoring for afforestation certification. These risks and mitigation needs were incorporated into the scenarios.

Together, these constraints significantly reduce the area and resources realistically available for CDR deployment. They help prevent landuse conflicts, protect biodiversity and cultural heritage, and ensure compliance with Italian and EU environmental law.

4. Theoretical CDR Potential

Assessing Italy's theoretical CDR potential in 2050 is an important exercise for establishing the upper bounds of the country's capacity to remove and store CO₂ emissions. This analysis is intentionally abstracted from real-world constraints, competing demands from other sectors, and societal readiness. This enables an estimate of the theoretical maximum amount of CO₂ that could potentially be removed under extreme conditions, such as a society-wide mobilisation to reduce climate change. While not practically feasible, **this upper-bound estimate serves as a benchmark** for understanding what could be achieved under extraordinary circumstances and helps frame the more realistic estimates presented in Chapter 7.

4.1 Methodology for the theoretical CDR potential

The theoretical potential was calculated using a bottom-up approach, assessing how the resources outlined in Chapter 3 could be optimally allocated to maximise overall carbon removal potential. CDR methods rely on one or more resources - such as electricity, water, or heat - to be deployed effectively, and they may compete for the same resources.

Resource allocation followed a hierarchical approach, prioritising CDR methods with higher TRLs and minimal reliance on competing resources such as land, agriculture, and biomass conversion. The theoretical potential assumes existing and new biomass reactors can deploy BECCS by incorporating CCS, with biomass first allocated to existing reactors, then to new ones for bioenergy, biochar, and biobased products.

Once the demands of energy, water and land of biomass conversion methods were quantified, the removal potentials for ERW, OAE, and DACCS were estimated. CO₂ storage capacity emerged as the primary limiting factor, even when assuming that by 2050 Italy could rely on a combined 98.5 MtCO₂ per year of geological storage potential for BECCS and DACCS, drawing on both depleted hydrocarbon fields and deep saline aquifers. Minerals and industrial residues for ex-situ mineralization could contribute an additional 212 MtCO₂/year by 2050.

Unless specified otherwise, the theoretical CDR potential (in MtCO₂/year) of each method was computed by multiplying the total amount of a resource allocated to a method by a conversion factor (MtCO₂/year per unit resource) from the Carbon Gap database of resource requirements.

4.2 Theoretical CDR potential in Italy

Italy's theoretical CDR potential is estimated at **233 MtCO₂** removed per year by 2050 (excluding natural sinks, see Box 6). This reflects the technical capacity of the available CDR methods with only physical resource and storage restrictions. Factors like economic viability, ecological trade-offs, political support, and societal acceptance are not accounted for here and will considerably reduce this potential, as described in Chapter 7. This potential is therefore **a purely theoretical and maximalist estimate**. It is achieved if all Italian resources remaining after allocation to priority uses are assigned to CDR methods.

Italy's theoretical potential is dominated by land-based and agricultural methods (~116 MtCO₂/year), mostly from agroforestry, cropland management and afforestation and reforestation. **Biomass conversion methods follow** with a total of nearly 78 MtCO₂ removed per year, with BECCS being the main contributor followed by biochar. **DACCS has considerable potential** (~33 MtCO₂/year), despite being limited by CO₂ injection capacity. **Geochemical methods** contribute with ~6 MtCO₂/year, of which ocean alkalinity enhancement represents the majority. Ex-situ mineralisation methods were also considered and were added as storage capacity (~2.12 MtCO₂/year). Table 3 shows the detailed breakdown of CDR methods contributing to the theoretical CDR potential.

Box 6. A note on distinguishing Italy's natural forest sink from CDR

Best-case scenarios from official sources (PNIEC, ISPRA-414) suggest that forest sinks in Italy could remove around **48 MtCO₂ annually** from 2030 onwards, reflecting the natural capacity of existing forests to sequester carbon through growth and soil enrichment. The maintenance of this expected sink is conditional on careful forest management through certification, afforestation, and effective wildfire risk mitigation.

However, **only anthropogenic (human-induced) interventions qualify as CDR** (IPCC⁷). **The baseline forest sink is therefore presented separately**, as it largely reflects natural processes rather than additional, intentional interventions. Only actions that represent additional, measurable, and verifiable removals beyond the natural carbon cycle such as afforestation, reforestation, and improved forest management are considered eligible.

CDR method	CDR potential by 2050 (MtCO ₂ /year)	Notes and assumptions
Ecosystem management methods: 116.44 MtCO₂/year		
Agroforestry	40	Assuming all 7.2 Mha of arable and 3.6 Mha of non-arable land are used for agroforestry (nearly 3.7 tCO ₂ /ha) ¹⁴⁰ , with a conversion factor of 0.27 Mha/MtCO ₂ /year.
Cropland management	26.88	Assuming all 7.2 Mha of arable land is deployed with cropland management practices incentivised by the CAP and other instruments (such as cover crops, conservation or zero tillage, pollinator strips, multiannual crops, and plantresidue covers), with a conversion factor of 0.42 Mha/MtCO ₂ /year, this would yield around 17.14 MtCO ₂ /year of removals. Similarly, 3.8 Mha of non-arable land hosting orchards, vineyards and olives could deliver around 9.1 MtCO ₂ /year through cover crops and plant residue management. Deploying 0.29 Mha of pollinator strips and hedges by 2030 (≈4% of arable land) could contribute a further 0.69 MtCO ₂ /year of removals.
Afforestation, reforestation	20	Assuming an additional 1.2 Mha of surface area is afforested or reforested, with a conversion factor of 0.06 Mha/MtCO ₂ /year which can be strongly affected by growth conditions and management practices. This potential is a statistical trend, partially based on the current and past natural succession of abandoned grasslands and croplands, since neither PNIEC 2024 nor the National Forest Strategy include plans to fund afforestation/reforestation to reach the projected 1.2 Mha.
Improved forest management	14.55	Assuming sustainable harvesting and enhanced forest productivity is conducted across all forested areas with 11.2 Mha of surface area managed through certified forest management. Conversion factor: 0.77 Mha/MtCO ₂ /year.
Pasture management	14.40	Assuming 3.6 Mha of grasslands with conservation and rotational grazing by 2030. Conversion factor: 0.25 Mha/MtCO ₂ /year.
Coastal revegetation	0.29	Assuming 0.06 Mha of underwater surface can be restored with seagrasses. Conversion factor of 0.20 Mha/MtCO ₂ /year. ⁵⁷
Wetland restoration and conservation	0.18	Assuming 89.5 kha of wetlands are restored - including both Po river valley wetlands (14.5 kha with an estimate of 33.8 ktCO ₂ e/year), and remaining endangered areas (up to 75 kha), sequestering nearly 2.3 tCO ₂ /ha each year ⁶⁹ . Conversion factor of 0.43 Mha/MtCO ₂ /year.
Peatland restoration and conservation	0.14	Assuming 0.07 Mha of peatlands can be restored, stabilising 67.5 kha of carbon-rich soils that otherwise risk releasing large emissions if degraded. Conversion factor of 0.50 Mha/MtCO ₂ /year.
Biomass conversion methods: 77.88 MtCO₂/year		
BECCS (combustion)	62.76	30.35 Mt of biomass already used in existing biomass reactors and 8.84 Mt of residual recovered biomass are used for BECCS with combustion, with the conversion factors listed in Annex A.2 and A.3.
BECCS (anaerobic digestion)	4.86	3.05 Mt of biomass already used in existing biomass reactors and 2.21 Mt of residual recovered biomass are used for BECCS with anaerobic digestion, with the conversion factors listed in Annex A.2 and A.3.
Biochar	8.33	10.08 Mt of residual biomass (Annex A.3) is used for pyrolysis with a conversion factor of 1.21 Mt biochar/MtCO ₂ /year. Biochar reactors are assumed to be fully dedicated to biochar production, with no bio-oil potential due to limited geological storage capacity.
Durable biobased products	1.93	6.88 Mt of fibre, wood, and carbon residues for bioproducts are used with a conversion factor of 3.57 Mt/MtCO ₂ /year (Annex A.3).

CDR method	CDR potential by 2050 (MtCO ₂ /year)	Notes and assumptions
Geochemical methods: 5.78 MtCO₂/year		
OAE total	4.97	Due to the higher efficiency of ocean liming, electrochemical OAE was not considered in estimating the theoretical potential.
with limestone	4.94	Assuming 8.01 Mt of limestone is used for ocean liming with a conversion factor of 1.62 Mt limestone/MtCO ₂ /year.
with dolomite	0.03	Assuming 0.12 Mt of dolomite is used with a conversion factor of 4.18 Mt dolomite/MtCO ₂ /year.
ERW total	0.81	
with basalt	0.59	Assuming 2.55Mt of basalt is used with a conversion factor of 4.30 Mt basalt/MtCO ₂ /year. 0.15Mt of basalt is used per year for mineral looping DACCS.
with olivine	0.22	Assuming 0.27 Mt of olivine is used with a conversion factor of 1.25 Mt/MtCO ₂ /year.
Synthetic methods: 32.93 MtCO₂/year		
Electrochemical DAC	16.03	Assuming 16 TWh of electricity is used for electrochemical DAC with a conversion factor of 0.78 TWh/MtCO ₂ /year.
Low temperature DAC	16.13	Assuming 26 TWh of waste heat with a temperature of 100-200°C is used for S-DAC, with a conversion factor of 1.50 TWh/MtCO ₂ /year.
Mineral looping DAC	0.77	Assuming 1.40 TWh of thermal energy and a conversion factor of 1.582 TWh/MtCO ₂ /year. Mineral looping DACCS is deployed to balance basalt use (0.15 Mt) between this method and ERW.
Total CDR (MtCO₂/year)		
Excl. forest sink	233	See Box 6 below.
Incl. forest sink	281	Adding 48 MtCO ₂ removals annually from the natural forest sink (PNIEC, ISPRA-414).
Ex-situ mineralisation storage potential: 2.12 MtCO₂/year		
with olivine	1.72	Assuming 1.38 Mt of olivine is used for ex-situ mineralisation with a conversion factor of 0.80 Mt/MtCO ₂ /year. Olivine was first allocated to ex-situ mineralisation due to its higher efficiency, and residual olivine quantities were directed to ERW.
with steel slag	0.25	Assuming 1.27 Mt of steel slag is used for ex-situ mineralisation with a conversion factor of 5 Mt/MtCO ₂ /year.
with cement kiln dust (CKD)	0.03	Assuming all 5% of CKD (0.25 Mt/year) is used for ex-situ mineralisation with a conversion factor of 9 Mt CKD /MtCO ₂ /year.
with concrete demolition waste (CDW)	0.12	Assuming 3.5 Mt is used for ex-situ mineralisation with a conversion factor of 29.9 Mt CDW/MtCO ₂ /year.

Table 3. Estimated maximum theoretical CDR potential in Italy by 2050.

4.3 Resource allocation notes in the theoretical potential

The **main limiting resource in the theoretical potential is CO₂ storage capacity**, which limits both BECCS and DACCS. Based on the estimated capacities in Chapter 3 (129.5 MtCO₂/year), around 31 Mt/year are expected to be used by industrial point-source CCS, while BECCS would require nearly 68 MtCO₂/year. The residual annual injection capacity for geological CO₂ storage (nearly 3330 Mt) plus the CO₂ storage potential of ex-situ mineralisation (2.12 MtCO₂/year) was divided evenly split between mineral looping DACCS, electrochemical DACCS and low-temperature DACCS. As a result, not all available energy resources – particularly relevant, for DACCS, can be fully consumed since CO₂ storage limits the scale of deployment

In addition to geological CO₂ storage, additional CO₂ storage methods were considered: in-situ and ex-situ mineralisation. In-situ mineralisation using serpentine was excluded due to insufficient data on serpentine production and mineralisation in Italy, while in-situ mineralisation in basalt formations was not considered because the country's geological characteristics are not suitable for this pathway (e.g., insufficient basaltic reservoirs, limited permeability, unsuitable depth profiles). Ex-situ mineralisation was considered and provides some storage potential as per Table 3.

To calculate the theoretical potential, **landbased CDR practices were modelled independently, even when they may cooccur on the same area of land** (e.g. different soil carbon sequestration methods applied on the same land). In the realistic scenarios instead overlaps between practices were constrained. As discussed in Box 3, organic and regenerative practices were excluded to ensure an unbiased assessment of their effective CDR contribution. It is nevertheless important to acknowledge that these approaches embody principles that, in practice, can strongly support and enhance agricultural CDR.

4.3.1 Biomass allocation and BECCS potential

Biomass already plays a significant role in Italy's biobased and bioenergy sectors, with more than **33 Mt of biomass already being used for existing bioenergy reactors** (Annex A.2). Theoretically, if CCS was applied to all existing bioenergy reactors, around **49 MtCO₂/year** could be captured.

In addition to this and after accounting for other technical, regulatory, and priority constraints (section 3.5.1), around **28 Mt/year of residual biomass remains potentially available for CDR pathways**.

This residual biomass was allocated across three main uses based on feedstock properties. Wet biomass (e.g. manure, sludge) was primarily directed to anaerobic digestion for biogas production, while dry biomass was allocated to either combustion-based bioenergy or biochar. Woody and fibrous residues can be used across multiple pathways and were therefore distributed evenly between biochar, BECCS, and biobased products. This resulted in **11 Mt of biomass allocated to BECCS** (with 8.84 Mt of solid, biogenic waste, and liquid biomass for BECCS with combustion, and 2.21 Mt of 'wet' biomass suitable for biogas/BECCS with anaerobic digestion), **10.08 Mt allocated to biochar**, and **6.88 Mt allocated to durable biobased products**.

Annex A.3 provides a detailed breakdown of this allocation. Though this represents a theoretical maximum based on today's production, changes in management of sectors like waste, agriculture, food and livestock, forestry, and energetic crops, can modify these biomass production estimates.

Using the residual biomass allocated to BECCS in new bioenergy reactors could deliver an additional **18.15 MtCO₂/year** based on average removal factors per tonne of feedstock, although the overall CCS potential depends on reactor design and feedstock characteristics, among other factors.



4.3.2 Sensitivity analysis: DACCS scenario without storage limits

Because Italy's theoretical DACCS potential is constrained more by CO₂ storage capacity than by energy availability, this study explores a sensitivity analysis in which storage is not a limiting factor. In a hypothetical future where new storage options emerge or capacity expands, Italy could leverage all its energy and water resources to potentially deploy up to **351 MtCO₂/year** by 2050, compared with 239 MtCO₂/year under current storage constraints.

In this scenario, all high-temperature waste heat (>300°C) not used for mineral looping is allocated to high-temperature DAC, while remaining electricity from low-temperature DAC, mineral-looping, and

high-temperature DAC is directed to electrochemical DAC, which becomes the largest contributor. This scenario assumes that all available energy resources are dedicated to DACCS, requiring 216 MtCO₂/year of storage capacity and consuming 4.6 bcm of water annually (around 40% of Italy's available freshwater).

This theoretical exercise shows that Italy has substantial CDR potential across multiple pathways. **With expanded geological storage capacity, the country could unlock much larger DACCS deployment**, though costs and environmental impacts - particularly water demand - could become significant constraints at higher scales.

CDR Method	CDR potential (MtCO ₂ /year)	Notes and assumptions
Electrochemical DACCS	116.67	Assuming 91 TWh of electricity is used with a conversion factor of 0.78 TWh/MtCO ₂ /year.
Low-temperature DACCS	26.00	Assuming 39 TWh of medium temperature waste heat (< 100°C) is used with a conversion factor of 1.50 TWh/MtCO ₂ /year.
High-temperature DACCS	5.00	Assuming 8.75 TWh of high temperature waste heat (>300°C) is used with a conversion factor of 1.75 TWh/MtCO ₂ /year.
Mineral looping DACCS	0.77	Assuming 1.40 TWh of high temperature thermal energy is used with a conversion factor of 1.82 TWh/MtCO ₂ /year.
Total	148.44	

Table 4. DACCS theoretical potential by 2050 without storage limits.



5. Existing policy

Italy's approach to CDR is still in its early stages, embedded within broader decarbonisation and climate mitigation frameworks rather than governed by a dedicated strategy. This chapter explores how CDR is currently reflected in national emissions trends, targets, and planning instruments. It assesses Italy's role within the EU's collective climate commitments, examines the political and legal frameworks shaping the national approach, and identifies existing support mechanisms for innovation and deployment. Finally, it outlines the key actors driving CDR-related developments and highlights upcoming policy shifts that may significantly alter the country's current trajectory.

5.1 CDR within Italy's climate strategy

5.1.1 Current emissions levels and trends

In 2023, Italy's domestic GHG emissions (excluding LULUCF) totalled **385 MtCO₂e**, reflecting a 6.8% reduction from 2022 and a 8.9% decrease compared to pre-pandemic levels. When including LULUCF, net emissions were 36.2% lower than in 1990. Between 2015 and 2022, net emissions declined by 17.5%, mainly due to emission reductions in the energy and LULUCF sectors. Projections under the current policy scenario (WM) indicate that net emissions will fall by 39% by 2030 and 48% by 2050 relative to 1990

levels. However, this path implies a 60% overshoot compared to a linear trajectory toward climate neutrality by 2050 (Figure 19), highlighting the need for more ambitious mitigation measures^{23,143}.

In 2022, Italy's per capita emissions and the GHG intensity of GDP were below the EU average. Italy registered 7 tCO₂e per person and 240 gCO₂e per EUR of GDP, compared with the EU-27 averages of 8 tCO₂e/person and 247 gCO₂e/EUR¹⁴³. According to ISPRA²³, the transport sector was the main emitter (22.7%), followed by energy industries (19.4%), non-industrial combustion (16.5%), manufacturing and construction (12.8%), agriculture (8.4%), industry (6.1%), waste (5.3%) and others.

5.1.2 Emissions Targets and CDR Strategy

Italy is committed to climate neutrality by 2050 under [Regulation \(EU\) 2021/1119](#)¹⁴⁴, with its 2030 emission reduction targets aligned with the [EU's Fit for 55 package](#)¹⁴⁵. However, current projections indicate the country is not on track to meet its EU and national goals*. Italy's 2021 Long-Term Strategy outlines pathways to climate neutrality by mid-century, assuming that residual 2050 emissions will be compensated by natural sinks and CCS¹. Current planning focuses on achieving and maintaining neutrality by 2050, without quantified milestones for a net-negative trajectory thereafter.

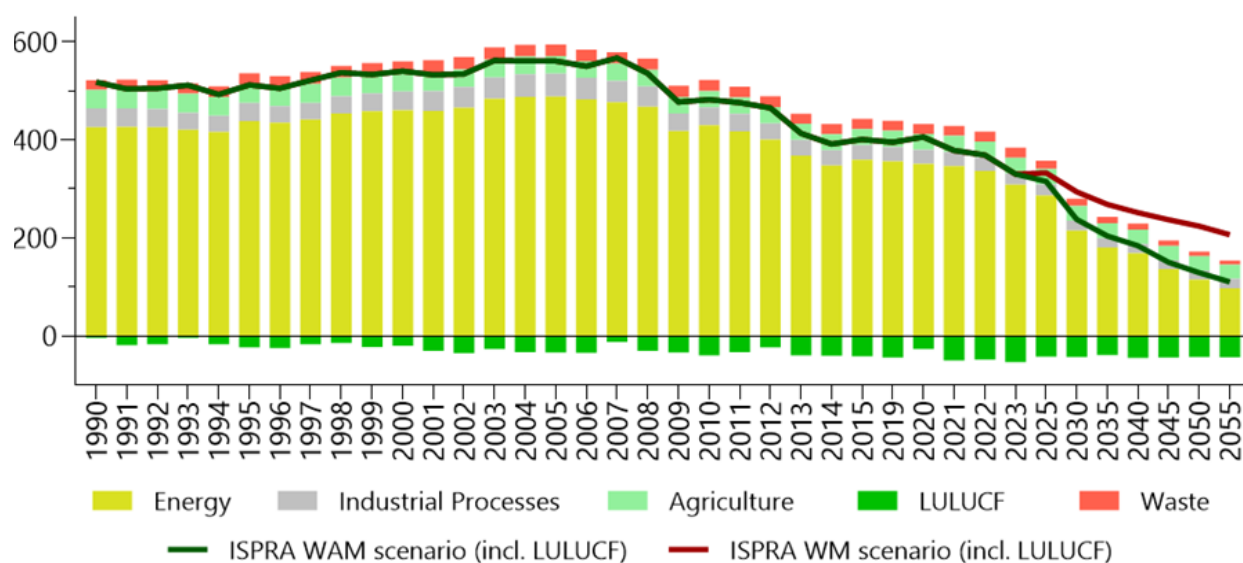


Figure 19. Italy's historical GHG emissions and 2055 projections. The green line shows the ISPRa "with additional measures" (WAM) scenario (including LULUCF), while the red line represents the "with current measures" (WM) scenario (incl. LULUCF).

*Targets: -43.7% for non-ETS sectors and -62% for ETS sectors (vs. 2005). , ISPRa23 projections show a substantial gap:-34.6% by 2030 (342.05 Mt CO₂e) and -48.1% by 2050 (271.42 Mt CO₂e) compared to 1990, leaving Italy short of EU and national goals.

Italy's Nationally Determined Contribution (NDC) is submitted as part of the joint commitment of the European Union and its Member States. The revised EU NDC, submitted in October 2023, sets a legally binding target of at least a 55% net reduction in GHG emissions by 2030 compared to 1990 levels, to be achieved exclusively through domestic measures without the use of international credits. While the EU NDC does not explicitly refer to a CDR strategy, it incorporates removals primarily through the LULUCF sector. The amended LULUCF Regulation (EU 2023/839)¹⁴⁶ sets a binding EU-wide target of 310 MtCO₂e in net removals from this sector by 2030¹⁴⁷. The NDC lacks a comprehensive framework for engineered CDR and does not outline a long-term strategy beyond 2030. This limitation is only partially addressed in the EU's Long-Term Strategy, which anticipates the need for negative emissions after 2050 but remains vague about the scale and means of achieving them¹⁴⁸. More recently, the European Council and Parliament have aligned on a binding 2040 target to cut net greenhouse gas emissions by 90% relative to 1990, with amendments to the EU Climate Law underway to clarify the role of both natural and engineered removals in achieving this 2040 pathway, with ongoing discussions on interim milestones and reporting¹⁴⁹.

At the national level, **Italy does not have specific CDR targets, instruments or timelines** for engineered removals or for achieving net-negative emissions. The National Energy and Climate Plan (PNIEC) identifies CCS as a key lever¹⁸ for achieving neutrality, while BECCS and DACCS are referenced in the Long-Term Strategy without concrete deployment volumes or timelines. In contrast, **Italy has a binding LULUCF target of 35.8 MtCO₂e net removals by 2030¹⁴⁴**, which it currently exceeds: the latest inventory data shows net removals of about -53.6 MtCO₂e in 2023.

Italy currently assumes all CDR will be delivered domestically, relying primarily on LULUCF and the development of CCS infrastructure. While CCS is not a CDR method, it is treated as a key enabling technology for future BECCS and DACCS. The potential CO₂ captured through CCS and CCUS is estimated at 20–40 MtCO₂ per year by 2050¹⁸, constrained by CO₂ storage injectivity, capacity and transport infrastructure. The Ravenna CCS hub is central to these plans.

While Italy does not currently plan to rely on imported removal credits, the PNIEC foresees **cross-border CO₂ transport and storage**. The [Mediterranean CCS Plan](#)¹⁵⁰ and related Projects of Common Interest, notably the [CALLISTO Mediterranean CO₂ Network](#)¹³⁰, which integrates the Ravenna CCS hub

as an open-access storage site for CO₂ captured in Italy and France, and the [Prinos CO₂](#)¹³¹ storage project, enable Italian and Croatian emissions to be exported for storage in Greece.

5.1.3 Position on Carbon Removal Credit Trading

The European Union allows Member States, including Italy, to use up to 5% of 1990 EU net emissions in high-quality international credits to help meet the 2040 target of 90% reduction¹⁵¹. Although EU policy continues to prioritise domestic mitigation and removals – especially in land based sectors such as LULUCF – the system is gradually expanding space for international credits. The [EU's Long-Term Strategy \(2020\)](#)¹⁴⁸ does not suggest a future reliance on imported removals, emphasising instead the development of internal capacity to achieve negative emissions beyond 2050.

At the national level, how Italy will interpret this orientation remains uncertain. Current [2025 inter-ministerial guidelines](#)¹⁵² for the National Registry of Voluntary Carbon Credits restrict agroforestry credits to the domestic voluntary market: units generated in the registry cannot be turned into Internationally Transferred Mitigation Outcomes (ITMOs), used in compliance schemes such as the EU ETS or the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), or sold to foreign buyers.



5.2 Legal Frameworks relevant for CDR

The legal framework for CDR in Italy is shaped by a combination of EU directives, national decrees, and innovation policies. Although there is no legislation dedicated specifically to CDR, several existing laws affect its implementation through permitting, environmental assessment, and financing mechanisms. Permitting responsibilities are divided between national and regional authorities, with centralised procedures for large-scale projects and simplified pathways for pilot installations. Environmental impact assessments are mandatory for geological storage, BECCS and DAC projects. The precautionary principle, embedded in both EU and national law, influences the authorisation of innovative CDR methods. While Italy's alignment with EU legislation and its use of Recovery and Resilience Facility funds provide some support, fragmented governance continues to undermine policy coherence and administrative efficiency.

5.2.1 Frameworks that benefit CDR

The programmes listed below constitute the EU's legal-financial backbone for advancing CDR innovation. The European Climate Law enshrines the 2050 climate neutrality target¹⁴⁴, setting the overall direction for Member States. The EU Emissions Trading System ETS [Directive 2003/87/EC](#)¹⁵³, revised under [Fit for 55](#)¹⁴⁵, establishes the [Innovation Fund](#)¹⁵⁴ to finance large-scale demonstration projects in CCS, BECCS, and emerging CDR technologies. Notable initiatives include the Marcegaglia "[AdriatiCO₂](#)" project¹⁵⁵, connected to the Ravenna CCUS Hub; the CUSTARD project (also referred to as "[CAPTURESTE](#)" by Herambiente¹⁵⁶); as well as [INDIGO](#)¹⁵⁷ and [Re-Tyre CO₂](#)¹⁵⁸.

The [Horizon Europe Regulation \(EU\) 2021/695](#)¹⁵⁹ complements this by providing dedicated research and innovation funding, supporting early-stage development through to demonstration. Several Italian institutions have participated in Horizon Europe projects related to CDR. Agricultural and land-based frameworks also play a central role in enabling removals. The **Common Agricultural Policy**⁴⁶, together with its second pillar, the European Agricultural Fund for Rural Development ([EAFRD](#))¹⁶⁰, allocates significant resources to eco-schemes and rural development programmes that promote carbon farming, agroforestry, and soil-carbon sequestration. Italy's CAP Strategic Plan includes measures for sustainable land management and biodiversity restoration with direct implications for carbon removals, although uptake and monitoring remain limited by evolving MRV methodologies.

Italy has transposed the **CCS Directive 2009/31/EC**¹⁶¹ through [Legislative Decree 162/2011](#)¹³⁷, which sets detailed rules for the permitting, monitoring, and liability of geological CO₂ storage. The decree requires prior site characterisation and a single storage permit issued by the Ministry of the Environment, in consultation with ISPRA and regional authorities. Operators must conduct continuous monitoring, report annually, and take corrective action in case of leakage, while maintaining financial guarantees to cover closure and remediation. Site responsibility is transferred to the State only after proof of permanent containment and a post-closure monitoring period. The framework thus aligns Italy with EU safety and liability standards for long-term CO₂ storage.

More recently, [Decree-Law 76/2020](#)¹⁶² and [Decree-Law 77/2021](#)¹⁶³ recognised CCS and CCUS as strategic pillars of national decarbonisation and streamlined environmental authorisation procedures, including environmental impact assessments. [Legislative Decree 190/2024](#)¹⁶⁴ further accelerated permitting for renewable energy projects, indirectly enabling BECCS, while the [Ministerial Decree of 21 June 2024](#)¹⁶⁵ clarified eligible areas for renewable and biomass projects.

Italy's major planning instruments – the **PNIEC** and the **PNRR** – have set in motion budget, policy measures and investment programmes to drive the green transition, innovation, digitalisation, sustainable mobility, energy sourcing, sustainable natural resource extraction and land use. These include support for CO₂ transport and storage infrastructure around the Ravenna CCS hub, positioned as a platform for future BECCS and DACCS deployment. They also include investments in afforestation and improved forest management aimed at strengthening the national LULUCF sink.

At the international level, Italy has expressed its intention to ratify the [2009 Amendment to Article 6](#) of the **London Protocol**¹⁶⁶, which would permit the transboundary transport of CO₂ for offshore geological storage, a key step toward shared regional storage hubs in the Mediterranean¹⁶⁷.

Collectively, these instruments provide the enabling conditions for scaling CCS and CDR within a policy framework that increasingly recognises removals as essential to achieving climate neutrality.

5.2.2 Frameworks that hinder CDR

Despite these advances, several aspects of the legal framework continue to hinder deployment. The **absence of a national climate law** leaves Italy without a unified mandate to coordinate CDR, resulting in fragmented governance.

The **Environmental Code** (D.Lgs. 152/2006)¹³⁶, which transposes the EIA Directive 2011/92/EU¹⁶⁸ into Italian law, requires environmental impact assessments (EIAs) for major industrial projects, including CCS, BECCS, and large-scale biochar facilities. While this framework ensures compliance with the precautionary principle (Article 191 TFEU)¹⁶⁹, it also results in lengthy and complex procedures. EIAs and the associated authorisations can extend over several years, creating significant delays in project deployment – as illustrated by the protracted approval process for the Ravenna CCS Hub.

Jurisdictional fragmentation further complicates the permitting landscape. While large-scale projects are evaluated at the national level, smaller installations and zoning decisions fall under regional authority, often leading to inconsistencies and delays. This tension is exemplified by the **Ministerial Decree of 21 June 2024**¹⁶⁵, which restricts renewable and biomass installations in protected or agricultural areas unless existing infrastructure is repurposed.

Finally, the application of the **precautionary principle**, while safeguarding ecosystems, can slow experimentation of CDR approaches with lower TRL, such as enhanced rock weathering or marine-based methods, in which scientific uncertainties remain high.

Italy's legal framework thus reflects a dual reality. On one hand, EU directives, national decrees, and innovation programs provide the tools and funding to enable CCS and CDR deployment. On the other hand, fragmented governance, slow permitting, and the lack of a national climate law create structural bottlenecks – all shortcomings also highlighted by the stakeholders consulted. Bridging this gap will require not only stronger implementation of existing frameworks but also more cohesive legislation to integrate removals into Italy's long-term climate strategy.

5.3 Support for R&D and Innovation

Italy currently lacks a dedicated policy for CDR, but several existing climate and innovation strategies offer indirect support. The PNIEC aligns with the EU net-zero target and acknowledges the role of removals, but CDR is currently addressed within broader decarbonisation and technology frameworks rather than through standalone measures. **Investor de-risking mechanisms for CDR are also limited**: while the PNIEC mentions public guarantee schemes for renewables and reforms to reduce counterparty risk in PPAs, these do not yet extend to negative emissions technologies. Pilot and demonstration projects are encouraged in principle, but very few are explicitly focused on CDR.

Italy promotes clean technology innovation through **Mission Innovation** and alignment with the **SET Plan** (Strategic Energy Technology)¹⁷⁰, supporting research on biomass, advanced biofuels, and carbon capture. The updated **PNIEC explicitly identifies BECCS and DACCS as essential for climate neutrality**¹⁸, though no dedicated research programmes for these technologies have been launched yet. **Support for bioenergy is growing**, especially for biomethane: national and EU funds back new production and the conversion of existing biogas plants. Under the 2022 Biomethane Decree, agricultural biomethane can receive tariffs of about 115 €/MWh, highlighting how strongly it is incentivised compared to fossil alternatives¹⁷¹.

Innovation is supported through a mix of national and EU instruments – including the **EU Innovation Fund**¹⁵⁴, national tax incentives, and the PNRR – which finance R&D and decarbonisation projects, particularly in energy-intensive sectors. However, there are still **no incubators or subsidies specifically dedicated to CDR**. The PNIEC notes that **Contracts for Difference** (CfDs) for CO₂ capture are **under development**, and Italy is now exploring both Carbon CfDs and CfDs as potential tools to stimulate long-term demand^{18,172}. Although these instruments have not yet been implemented, a 2025 MASE study mandated by **Decree-Law 11/2024**¹²⁵ outlines economic and regulatory options **to support the CCUS value chain** and recommends CfD-style mechanisms covering capture, transport, and storage costs, linked to the ETS price, and lasting 10–20 years to ensure adequate returns (IRR ≥ 8%). The study also proposes a non-binding target of 4 MtCO₂ captured and stored annually by 2030, focusing on industrial clusters in the Po Valley and key coastal hubs, and highlights the need for both operational and capital support to close the funding gap¹⁷³. Overall, dedicated market mechanisms for engineered CDR are still in the early stages and will require further policy development to become operational.

5.4 On the horizon

5.4.1 Analysis of the Existing Policies (SWOT)

A SWOT analysis (Table 5) was conducted to assess Italy's preparedness to deploy CDR at scale. It examines key strengths, weaknesses, opportunities, and threats across policy, governance, and implementation dimensions. The assessment draws on stakeholder interviews, national and EU policy documents, and recent developments, including the inauguration of the Ravenna CCS project and the updated PNIEC. Overall, even though Italy's approach shows strong alignment with EU objectives and financing opportunities, it remains constrained by fragmented governance and the absence of a dedicated CDR strategy.

5.4.2 CDR players in Italy

In Italy, the policy framework for CDR remains nascent and fragmented; nonetheless, an ecosystem of companies, researchers, and groups is progressively taking shape. Figure 20 presents an overview of the main actors identified as of September 2025.

The **CDR Suppliers** category includes companies that develop, pilot, or deploy technologies and processes that actively remove CO₂ from the atmosphere through biological, chemical, or engineered pathways. Most CDR suppliers are still at an early and experimental stage, with biochar producers being the most prevalent (Bi-Biochar, Nerabiochar, Natural Biochar). Alongside them, new entrants are advancing mineralisation (Resilco), ocean alkalinity enhancement (Limenet), and direct air capture (CarpeCarbon, Climeworks). Energy-focused start-ups such as Blaze and Exergy International are exploring BECCS.

Strengths

- Commitment to climate neutrality by 2050
- Inclusion of BECCS and DACCS in PNIEC
- Participation in Mission Innovation & SET Plan
- Access to EU and national funding (ETS Innovation Fund, PNRR)
- Strong incentives for bioenergy (e.g. biomethane)

Weaknesses

- No national climate law or climate neutrality objective at the national level
- No dedicated CDR strategy or roadmap at the national level
- Lack of binding targets for engineered removals
- Lack of investor de-risking mechanisms
- CDR references in legislation and policy documents remain vague and non-binding

Opportunities

- Development of CfDs for CO₂ capture
- Ravenna CCS Hub phase 2 from 2027
- Alignment with EU Industrial Carbon Management Strategy
- Potential expansion of BECCS via existing bioenergy support
- Civil society (e.g. ECCO) pressure for stronger CDR policy
- Planned CO₂ export infrastructure with Greece, opening cross-border transport and storage options

Threats

- Political instability and short-termism
- Low public awareness and engagement on CDR
- Absence of communication and consultation channels
- Overreliance on nature-based removals at risk from wildfires
- Risk of falling behind in EU CDR efforts without targeted support

Table 5. SWOT Analysis of Italy's Policy Framework for CDR. Sources: (ECCO, 2023¹⁷⁴; Meyer-Ohlendorf & Spasova, 2022)¹⁷⁵.

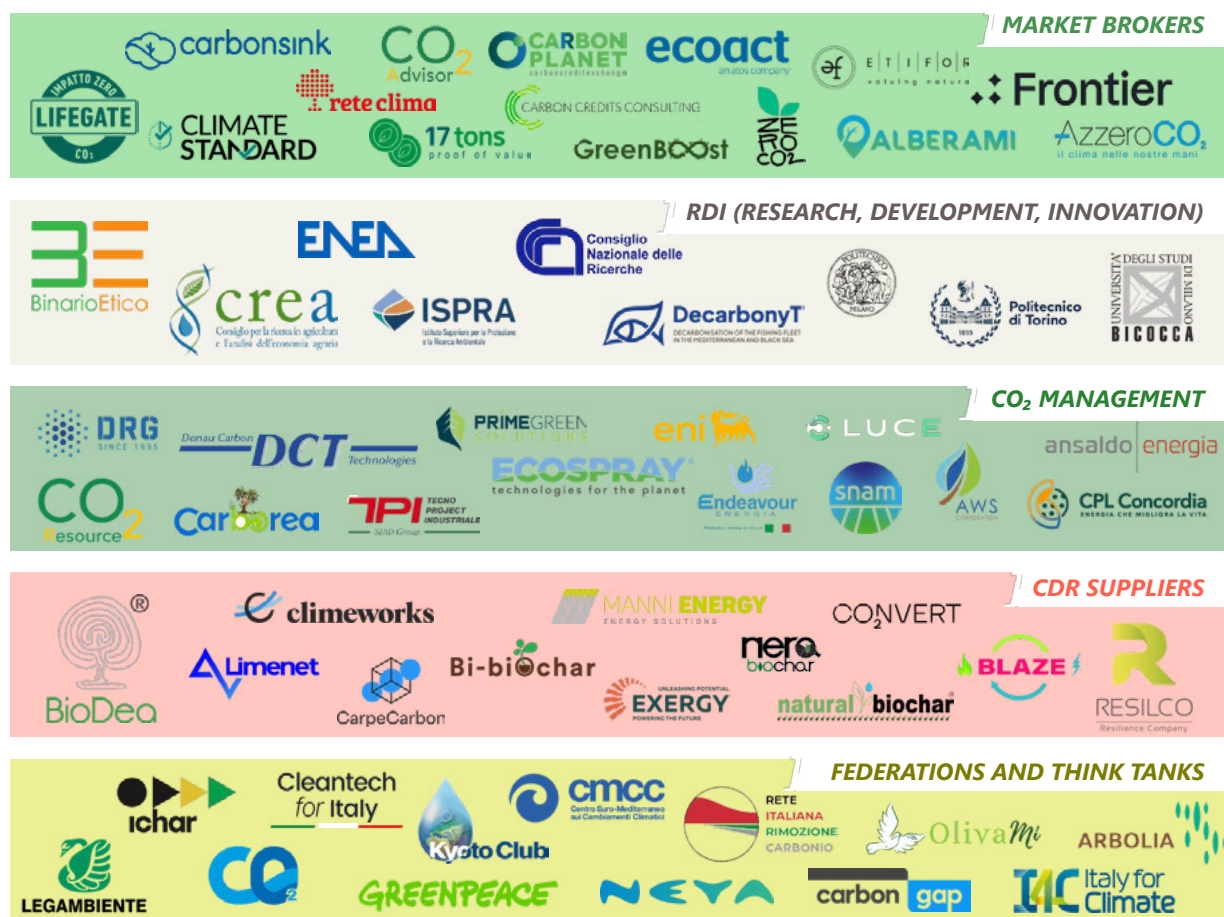


Figure 20. Key CDR players in Italy. The map is indicative, not exhaustive.

CO₂ management includes industrial and energy companies engaged in the capture, transport, utilisation, and permanent storage of CO₂ across various value chains. The sector is led by major industrial players such as ENI and Snam, alongside engineering and energy firms like Ansaldo Energia, CPL Concordia, and Endeavour Energia, which are investing in capture, utilisation, and storage technologies. Smaller technology firms, including Donau Carbon Technologies, AWS, DRG, and Manni Energy, are also entering the field, often through innovations in CCS and CCU.

Market brokers facilitate the commercialisation, certification, and trading of carbon credits, linking CDR projects to voluntary and compliance markets. Italy hosts a diverse ecosystem of such actors, ranging from established consultancies such as AzzerCO₂, Carbon Credits Consulting, Carbonsink, to platforms like CO₂ Advisor, Rete Clima, Etifor, 17tons, and LifeGate. **International players**, including EcoAct and Puro.earth, also operate in the Italian market. These organisations provide certification, offsetting, and MRV services that connect domestic projects with broader carbon markets.

The **R&D** category encompasses public research institutions, universities, and innovation centres conducting studies and pilot projects on carbon removal, utilisation, and monitoring technologies. Key institutions include ENEA, CNR, and CREA, alongside university-affiliated programs within Politecnico di Milano, Politecnico di Torino and Università Milano Bicocca. Current research focuses on carbon farming, biochar, CCS/CCUS, and bioeconomy innovations. Though still fragmented, this research base is expanding and contributing to EU-funded initiatives that strengthen Italy's innovation ecosystem.

Federations and think tanks include environmental and climate organisations such as Kyoto Club, Legambiente, and Italy for Climate, which are engaging more directly with CDR. Specialised associations like ICHAR (biochar) and Carbon Footprint Italy promote awareness, certification, and advocacy, while research-policy organisations such as the CMCC (Euro-Mediterranean Centre on Climate Change) play a central role in building the knowledge base for Italy's long-term climate strategy.

5.4.3 Upcoming policy developments and strategic shifts

Several upcoming legislative and policy initiatives are expected to influence the development of CDR in Italy in the near future. The **EU Carbon Removal and Carbon Farming Regulation (CRCF)**, approved in March 2024, will introduce a voluntary certification scheme for permanent carbon storage, carbon farming, and carbon storage in products. It aims to set minimum quality standards, measurement methodologies, and transparency requirements for CDR, which could strengthen trust and investment in Italian removal projects.

While Italy does not currently participate in international carbon removal credit trading, the establishment of a national **Agroforestry Carbon Credit Registry** under Law [41/2023](#)¹⁵² reflects a domestic effort to structure voluntary crediting for nature-based removals. These credits are recognised only within Italy's voluntary market and do not contribute to compliance systems such as the EU ETS or CORSIA. Upcoming inter-ministerial **guidelines by MASAF and MASE** will define how removals from agroforestry are certified and registered under the national system, enabling the launch of a carbon farming market^{152,174}.

Large-scale CCS is gaining prominence through the PNIEC and the Ravenna CCS project. The PNIEC foresees up to 4 MtCO₂ per year could be stored by 2030 in the Po Valley and along the Adriatic coast. The Ravenna Hub is positioned to become a key infrastructure node, capable of receiving CO₂ from both Italy and other Mediterranean countries. A recent legislative proposal (Ddl of 16 March 2026) delegates the Italian Government to create a comprehensive regulatory framework for CCUS, explicitly including DAC within the industrial chain to support national climate targets and the PNIEC. It aims to provide market stability by introducing a single permitting process for all CCUS activities and assigning ARERA responsibility for regulating CO₂ transport and storage as natural monopolies, ensuring transparent tariffs and non discriminatory [access](#)²⁷⁹.

Italy's involvement in **cross-border initiatives** such as the Callisto Mediterranean CO₂ Network and the Prinos CO₂ Storage project – both designated as Projects of Common Interest by the EU – further signals a shift toward regional integration of CO₂ transport infrastructure, strengthening Italy's strategic role in the emerging European CDR ecosystem¹⁷⁶.

Box 7. Ravenna CCS: Italy's first industrial-scale CO₂ storage facility

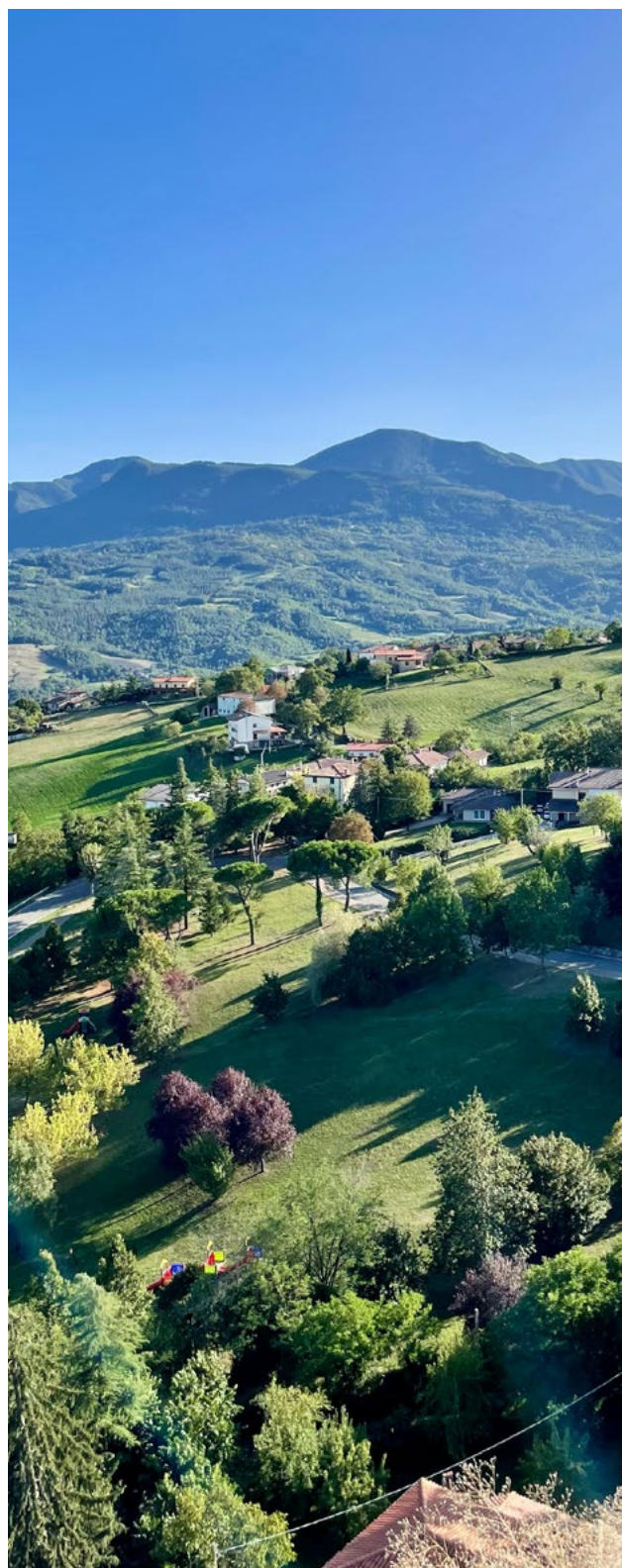
The Ravenna CCS Phase 1 project is Italy's first industrial-scale CO₂ capture and storage facility and commenced operations in August–September 2024. The project captures emissions from Eni's Casalborssetti gas treatment centre, with a capacity of about 25,000 tonnes of CO₂ per year and a capture efficiency above 90% (peaking at 96%). The captured CO₂ is transported via repurposed pipelines and stored in the depleted Porto Corsini Mare Ovest gas field, located 3,000 meters beneath the Adriatic Sea. Phase 2, scheduled to begin in 2027, aims to scale storage to 4 MtCO₂ per year by 2030, with potential to expand to 16 Mt annually depending on market demand. With an **estimated storage capacity exceeding 500 MtCO₂** in Adriatic reservoirs, Ravenna CCS is positioned to become a Southern European hub for decarbonisation. Ravenna's expansion is incorporated into the CALLISTO Mediterranean CO₂ Network, which is supported by the EU. This network envisions the permanent storage of captured CO₂ in the Adriatic reservoirs, with the exact import volumes yet to be determined, from industrial clusters in Italy and France, with a particular emphasis on the Fos-Marseille hub. Beyond Italy, another project, the Prinos CO₂ project in northern Greece, developed by Energean, will convert the depleted Prinos oil field into a permanent CO₂ storage site with a capacity of up to 5 Mt per year, marking the first large-scale carbon storage project in South-Eastern Europe.

5.5 Conclusions on existing policy

Italy's stance on CDR is evolving but remains secondary to broader decarbonisation policies. Emissions are declining, yet current trajectories fall far short of the linear path required for climate neutrality by 2050. Policy continues to rely heavily on the LULUCF sector, where net removals already exceed the 2030 target, while engineered removals are acknowledged but still lack clear targets, timelines, and delivery mechanisms. CCS is progressing – Ravenna Phase 1 is operational and Phase 2 is scheduled to expand capacity – but this has not yet been translated into measurable BECCS or DACCS deployment pathways.

EU-driven frameworks such as the Climate Law, ETS Innovation Fund, CCS Directive, and the CAP, together with national streamlining efforts provide a supportive foundation. However, the absence of a national climate law, fragmented permitting, and lengthy EIA procedures continue to slow implementation. Support for innovation and R&D is largely indirect, channelled through Horizon Europe, the Innovation Fund, and the PNRR. CfDs for CO₂ capture are being discussed but not yet formalised, and investor de-risking instruments remain underdeveloped. Upcoming reforms – CRCF implementation, agroforestry credit registry guidelines, PNIEC updates, and cross-border CO₂ transport networks – could strengthen integrity, transparency, and scalability, if paired with coherent governance and robust MRV systems.

Overall, Italy benefits from a strong land-based sink, emerging CO₂ transport and storage infrastructure, and access to substantial EU funding, but still lacks a dedicated, quantifiable CDR strategy. Closing this gap will require interim engineered-removals targets, credible MRV frameworks, CfD-style support across the entire capture-to-storage chain, streamlined permitting while maintaining the precautionary principle, alignment of Ravenna and Po Valley clusters with BECCS/DACCS off-take opportunities, and transparent, regionally tailored engagement. Without these reforms, Italy risks overreliance on land sinks and may fall behind European peers in deploying durable, high-integrity carbon removals.



6. Italy's social geography

6.1 Overview

Italy enters the CDR transition with a mixed foundation: a large, export-oriented economy gradually decoupling growth from emissions yet constrained by low productivity and small and medium-sized enterprises (SMEs) fragmentation. High public concern about climate change, coupled with a constitutional commitment to protect ecosystems, creates political openings; however, low institutional trust and pronounced North–South disparities make public support dependent on fairness, visible benefits, and credible governance.

In the near term, Italy's most viable CDR opportunities lie in existing infrastructures and material flows: construction and demolition waste for mineral carbonation and low-carbon concrete; wastewater sludge and brines for mineralisation and co-located capture; metallurgical tailings and port clusters for CCS and DAC hubs; and agricultural or forestry residues for biochar and BECCS pilots. Constraints include skills shortages, regulatory bottlenecks, high energy costs, and the need for social licence. An effective national strategy should co-locate projects in industrial clusters and ports, align them with workforce reskilling, and embed transparent, participatory governance, especially in regions with past resistance, while framing benefits in culturally resonant terms such as quality, heritage, and local value creation to secure durable public consent.

6.1.1 Economy

Italy's macroeconomic landscape showed steady, moderate growth in the post-pandemic period. In 2025, GDP reached € 2.26 trillion – an increase of 2.5 % from 2024)¹⁷⁷. Unemployment declined to 4.6 %, and labour-productivity grew by 1.43), reflecting the dominance of low-capital-intensity sectors and a highly fragmented SME base. With a Human Development Index of 0.915 in 2023, Italy ranks among the world's highly developed economies. National emissions of approximately 385 MtCO₂e (2023) correspond to a carbon-intensity ratio of 0.155 t CO₂ per USD 1,000 GDP, indicating gradual decoupling of economic growth from emissions. The economy is concentrated in manufacturing, logistics, and tourism – key export drivers but also major sources of energy demand and emissions (Table 6). Overall, while macroeconomic stability has been restored, long-term competitiveness will depend on productivity recovery and a deeper structural transition toward low-carbon, innovation-driven industries.

GDP (billion €) (2025)	2258
GDP Growth (%) (2025)	2.5
Productivity Growth (%) (2025)	1.43
Unemployment Rate (%) (2025)	4.6
Main Sectors	Manufacturing, Logistics, and Tourism
Carbon intensity (t CO₂ / k € GDP) (2023)	0.168
GDP per capita (k €)	38.3
HDI	0.915
CO₂ emissions (tons)	384.7
Trends	Moderate post-pandemic recovery with slowing productivity, stable unemployment, and gradual decoupling of GDP growth from emissions; structural reliance on SMEs persists, limiting capital intensity and innovation-driven productivity gains.

Table 6. Italy's key economic indicators. Source: ISTAT¹⁷⁸; UNDP¹⁸⁰.

Structurally, Italy combines a strong manufacturing base with an expanding services sector. Manufacturing employs about 18% of the workforce (above the EU average of 15.6 %), while services now accounts for over 40% of employment driven by growth in logistics, tourism, and professional services. Nonetheless, industrial output declined by 1.8% year-on-year as of March 2025,¹⁸¹ signalling ongoing weakness in traditional sectors. The PNRR is expected to boost investment in infrastructure, innovation, and green technologies, helping counter this stagnation.

SMEs dominate the economic landscape, representing 99.8% of Italian firms, above the EU average. They are highly **innovative**: Italy ranks 4th in the EU for SME product innovation (154% of the EU average) and 3rd for process innovation (148%)¹⁸². However, overall investment and non-R&D spending remain below EU levels, constrained by limited finance, low digital intensity (27.2 vs. EU's 34.2), and structural dependence on micro-enterprises. Many firms continue to rely on public incentives rather than pursuing proactive, self-financed green and digital transitions.

Regional disparities, particularly between the North and South, remain a major structural challenge. Southern regions face lower productivity, chronic underinvestment, demographic decline, poverty, and higher energy vulnerability, limiting participation in the green transition. Without regionally tailored support, the green transition risks widening inequalities and weakening public support for climate policy¹⁸³.

6.1.2 Political and public landscape

Politics

Italy is a parliamentary republic with a bicameral Parliament composed of the Chamber of Deputies and the Senate. The President of the Republic serves primarily as the guarantor of the Constitution, while executive power rests with the Prime Minister and the Council of Ministers, who must retain the confidence of both houses. The political system is marked by frequent government turnover and coalition politics, a pattern reinforced by Italy's mixed electoral system combining proportional representation with first past-the-post seats¹⁸⁴.

In 2022 general elections, a right-wing coalition led by Giorgia Meloni's Fratelli d'Italia, alongside the Lega and Forza Italia, secured a decisive victory, forming Italy's first right-wing administration since World War II. Meloni, the country's first female Prime Minister, has consolidated her position

through domestic reforms and active engagement in European and international affairs. Despite rising political polarisation and criticism of government policies, Fratelli d'Italia remains the leading party in opinion polls, consistently attracting support around or above 30% as shown by [Politico](#)¹⁸⁵.

Fratelli d'Italia and Lega have embraced an **"eco-nationalist" narrative**, stressed energy sovereignty and protection of domestic industries, while urging a rethink of EU Green Deal provisions including the planned 2035 phase-out of combustion engine vehicles. Both parties endorsed the EU Social Climate Fund in the European Parliament, demonstrating a policy to shield disadvantaged households and SMEs from transition costs, while remaining cautious on binding decarbonisation targets¹⁸⁶. More recently, national measures such as the *Decreto Bollette* have been interpreted as reducing the ETS incentive for industrial decarbonisation, particularly in sectors still heavily dependent on natural gas.

Public landscape

Public concern about climate change in Italy seems high and widespread. According to [Eurobarometer 538](#) (2023)¹⁸⁷ 83% of respondents consider it a "very serious" issue, and a further 13% "fairly serious", with only 3% expressing little concern¹⁸⁷. This translates into strong policy support: 89% of Italians agree that addressing climate change and environmental issues should remain a political priority despite other national challenges. The results demonstrate that climate awareness is both extensive and firmly entrenched in public expectations for governmental intervention, providing a favourable social context for advancing climate and carbon removal policies.

However, **this concern is not matched by institutional trust.** While 46% of Italians identify their national government as responsible for tackling climate change, and 51% cite the European Union, only 38% believe that their voice counts in the EU^{187,188}. This points to a gap between expectations and perceived political responsiveness. As a result, support for climate action is highly conditional - shaped by perceptions of fairness, transparency, and tangible benefits - while low trust remains a key barrier to the success of carbon removal and broader decarbonisation strategies. Addressing these public perception dynamics is essential for designing effective and socially acceptable climate policies.

Public attitudes toward CDR also vary significantly between nature-based and engineered approaches. Nature-based methods - such as afforestation and soil carbon sequestration - are generally favoured due to their visibility and

co-benefits, including biodiversity protection, rural development, and food system resilience^{189,190}. In contrast, engineered CDR methods like DACCS and BECCS, face greater resistance, often perceived as imposed, technocratic, or unnatural, with low public familiarity and limited perceived personal benefit¹⁹¹.

Regional disparities further influence public response. Differences in economic conditions, vulnerability to climate impacts, and institutional trust shape both climate awareness and the acceptability of specific policy measures and solutions. As illustrated in Table 7, past experiences with decarbonisation and storage projects (e.g. *Sulcis*, *Ravenna*, and *Porto Tolle*) show that opposition tends to arise when initiatives are

perceived as externally imposed or insufficiently aligned with local priorities. Urban areas have generally responded more favourably when projects are linked to visible greening or innovation, whereas rural communities have shown greater caution amid concerns about land competition and ownership.

Overall, **public acceptance of CDR in Italy depends less on the technological design itself than on governance quality, community engagement, and local co-benefits.** Building trust through **transparency, equitable participation, and regionally tailored incentives** are essential pre-requisites for the successful deployment of CDR in Italy.

Main public concern	Outcome	Key lesson for CDR	Actionable fix
Rural vs urban: Land competition vs. visible co-benefits (Cabeza et al., 2024)	Rural communities more cautious; urban areas more supportive of greening	Acceptance depends on perceived local benefits	Link projects to farm income; avoid "land grabs" through payments, co-ownership, and urban pilot projects
Sulcis (Sardinia): Coal job losses, identity, imposed transition (Biddau et al., 2024 ¹⁹²)	Strong resistance to coal phase-out policies	Just transition must precede decarbonisation; tailor to local economy	Targeted transition funds, retraining, and local economic diversification
Ravenna CCS: Fossil lock-in; limited public consultation (Misuraca 2024 ¹⁹³)	Sustained NGO and academic opposition	Trust and participation are critical	Ensure transparent governance, early engagement, independent MRV systems
Porto Tolle CCS: seismic risks; regulatory and coordination gaps (Kapetaki 2017) ¹⁹⁴	Project cancelled despite EU support	Regulatory clarity and local alignment are essential	Pre-screen sites, strengthen environmental assessments, and align national-local governance

Table 7. Barriers to social acceptance of CDR: key issues, lessons and actionable fixes.

6.1.3 Relationship to ecology

Italians show awareness of biodiversity and environmental issues, with **broad social consensus on the importance of conservation and restoration**. Key drivers of biodiversity loss are widely recognised, including land-use change (e.g. deforestation, urbanisation, monocultures), resource overexploitation (e.g., hunting and fishing), climate change, pollution, and invasive species. However, this awareness has not translated into effective outcomes. According to the [2024 NBFC report](#)¹⁹⁵, 68% of Italian ecosystems are in poor health. EU coastal and marine ecosystems are especially vulnerable, with the Mediterranean region having the greatest share of damaged habitats in Europe (32%).

The 2022 reform of [Article 9](#)¹⁹⁶ of the Constitution elevated protection of the environment, biodiversity, and ecosystems to constitutional rank, yet land consumption, pollution, climate change, invasive species, still outweigh current responses. Overall, Italian society regards biodiversity as a priority and a public good, but systemic pressures continue to impede its maintenance. The difficulty is to translate elevated awareness into consistent behavioural change and successful ecological stewardship. And to achieve this, the NBFC emphasises the importance of comprehensive education and knowledge dissemination so that citizens can progress from theoretical awareness to active support for preventive actions.

Activism\Initiatives

In Italy, ecological and climate mobilisation has traditionally relied on **grassroots engagement, referenda, and non-violent civil disobedience, gradually evolving to include litigation** as a strategic tool for accountability. As Zamponi et al. (2024)¹⁹⁷ note, collective action surrounding national referenda on nuclear relaunch and water privatisation demonstrated substantial civic veto power, shaping Italy's environmental politics for more than a decade. More recently, movements such as *Extinction Rebellion Italia* and *Ultima Generazione* have gained visibility through peaceful disruption, occupations, road blockades, and attention-grabbing acts of "pseudo-vandalism" targeting monuments to denounce the fossil-fuel status quo. Although polarising, these actions have succeeded in keeping climate issues on the public agenda and underscore the continued influence of youth-led climate disobedience as an agenda-setting force.

A newer frontier of environmental defence is climate litigation, through which NGOs and citizens challenge the responsibility of both governments and corporations. Two emblematic cases stand out: *A Sud v. Italy*, a civil action alleging the state's failure to protect citizens from climate risks, and the [2023 Greenpeace Italy and ReCommon v. ENI lawsuit](#)¹⁹⁸, the first of its kind in the country, claiming that the oil major's industrial strategy breaches the Paris Agreement and human-rights obligations. The plaintiffs, including twelve residents from climate-affected regions, seek to compel ENI and its public shareholders to align with a 45% emissions-reduction pathway by 2030. Together, these developments illustrate the growing diversification of Italy's climate movement, bridging street-level disruption and judicial advocacy under a shared demand for transparency, climate justice, and the redirection of national policy away from fossil-fuel dependence¹⁹⁹.

6.1.4. Human Resources

In Italy, **the expansion of green employment is already significant, yet it coexists with a persistent skills shortage**. The current workforce lacks alignment with the growing demand for green competencies, most notably in construction, transportation, and manufacturing, where upskilling and reskilling are essential. In 2022, occupations classified as "green jobs" accounted for an estimated 3.1 million workers, representing 13.4% of national employment. In 2023, demand continued to rise: nearly 2 million new contracts were issued for green-related roles, amounting to 34.8% of all new hires that year. However, more than half of these vacancies were difficult to fill,²⁰¹ reflecting a structural mismatch between labour supply and the competencies required.

At the European level, policies aligned with the Green Deal are projected to create around 880,000 net jobs by 2030, with emerging green value chains - such as hydrogen, electrification, and circular economy - expected to employ hundreds of thousands of workers²⁰². However, without a coordinated strategy that connects education, labour, and climate policy, Italy risks facing structural workforce constraints.²⁰⁰ Despite a solid academic base and a large workforce in traditional industries, OECD data reveal persistent gaps in advanced technical disciplines, weak recognition of qualifications in fields like geobiology and social sciences, and a continued outflow of skilled professionals. **Without targeted investment in training and talent retention, these limitations could hinder the development of the skilled workforce needed to scale CDR and support the transition to climate neutrality**⁹⁴.

6.1.5 Industrial Integration

Some of Italy's sectors with the highest employment and carbon intensity, construction, manufacturing, transport, and agriculture, also offer the most immediate opportunities for integrating CDR. A strategic approach would prioritise co-location near existing industrial clusters and ports, valorisation of waste and mineral streams (such as sludge, slag, fines, tailings, and biomass), and alignment with workforce reskilling and domestic supply chains. Embedding CDR within existing industrial transitions could also help avoid the boom-bust cycles seen in past clean-tech expansions, such as the photovoltaic sector.

Construction and Demolition waste

Italy's construction sector produces around 80 Mt of non-hazardous special waste annually (2022), and more than 60% of the building stock was built before 1976¹⁸. Alkaline construction and demolition wastes - such as **recycled concrete aggregates and fines - can absorb CO₂ through mineralisation and CO₂-curing**, suggesting potential for carbon-storing building materials and low-carbon binders. Together, Italy's extensive legacy building stock and concrete and demolition waste streams could provide a strong basis for such carbon-removal options, including carbonation of recycled concrete, low-carbon binders and reuse of mineral fines. Retrofitting programmes, like the [Superbonus 110%](#)²⁰³, and low-carbon building materials could serve as early testbeds for such technologies and for HVAC efficiency upgrades, but fragmented construction sites, complex permitting, and a lack of common standards constrain scale-up²⁰⁴.

Wastewater residues

Italy's wastewater sector generates about 3.2 Mt of sludge annually and over 450,000 t of defecation gypsum⁸⁰. Emerging research is exploring whether wastewater-derived residues, particularly **sewage sludge ash**, could support future carbon mineralisation pathways or be integrated into co-located CCS/DACCS pilots, though these applications remain experimental. Nonetheless, co-deployment of carbon capture at wastewater treatment plants could leverage existing infrastructure, energy recovery systems, and nutrient-recycling streams²⁰⁵.

Mining and Metallurgy

With 166 Mt of extracted material in 2018 and industrial turnover from metallurgy and aluminium combined exceeding €100 billion, this sector generates large volumes of alkaline tailings, slags and residues²⁰⁶. Evidence shows that ultramafic mine tailings and steel slags can permanently store CO₂ via accelerated mineral carbonation, sometimes producing carbonated materials suitable for construction uses²⁰⁷. European CCS hubs in industrial port areas such as Porthos²⁰⁸ and Northern Lights²⁰⁹, demonstrate how refineries and other heavy industries can share transport and offshore storage infrastructure – an approach Italy could adapt²¹⁰. However, investment remains constrained by heterogeneous site conditions, long-term liability concerns and the lack of a dedicated framework for mineral CO₂ storage and CO₂ transport.²¹¹

Agriculture

Agriculture remains central to Italy's economy, generating €42.4 billion in value added in 2024 – the highest in the EU – and employing around 900,000 workers²¹². Agricultural residues and by-products offer key feedstocks for biochar and, in some contexts, BECCS, while EU carbon-farming initiatives aim to expand soil-carbon practices despite ongoing significant MRV and permanence challenges. Near-term opportunities for Italy include residue-to-biochar conversion, pilot BECCS integration in existing biomass plants, and carbon-farming schemes, although scale up is likely to be constrained by feedstock logistics, MRV complexity, and land-use competition^{213,214}.

6.1.6 Cultural, aesthetic, religious and ethical considerations

Italian consumer culture increasingly associates sustainability with quality and ethical value. Around 70% of consumers cite product quality as the main driver of sustainable choices, followed

by environmental concerns (22%) and moral considerations (7.4%) (MAECI, 2025²⁸⁰). This suggests that CDR strategies framed in terms of improving product quality, landscapes, or community wellbeing are more likely to align with public preferences.

Cultural factors further shape acceptance. Italy's strong emphasis on heritage and aesthetics – reflected in its historic landscapes and UNESCO sites – means that environmental technologies are more readily accepted when they are visually unobtrusive and compatible with local identity²¹⁵. Evidence from renewable energy integration shows that perceived visual or cultural disruption can trigger opposition, a dynamic likely to apply to large-scale CDR infrastructure.

Ethical and religious values also shape public discourse. Catholic social teaching, deeply embedded in Italian culture, emphasises stewardship of creation and intergenerational responsibility, potentially positioning CDR as a moral obligation to safeguard future generations. Overall, Italy's cultural emphasis on quality, heritage, and ethical responsibility suggests that **public acceptance of CDR will depend not only on technical viability but also on its alignment with societal values of landscape preservation, moral stewardship, and fairness**²¹⁶.

6.1.7 Conclusions on the social geography overview

Italy enters the CDR transition with a robust, SME-based economy, high public concern for climate issues but with limited institutional trust, considerable ecological degradation challenges, skill shortages in advanced technical sectors, and abundant industrial by-product streams that could enable cost-effective removals. The most viable pathways will align with existing material systems (e.g. construction, water, metallurgical infrastructures and waste streams), they will ensure transparent and participatory governance frameworks that address justice and regional inequalities, and they will fit cultural expectations by preserving heritage and delivering visible local benefits. Without this alignment, engineered CDR is likely to face societal and administrative resistance; by contrast, a balanced portfolio that prioritises nature-based solutions and strategically located industrial integrations can foster acceptability, lower costs, and establish a platform for sustainable expansion.

6.2 Stakeholder interviews

This section summarises the insights collected from **15 semi-structured interviews** conducted between May and October 2025. The interviewees represented a broad spectrum of perspectives, including academia, public institutions, civil society organisations, and private companies active in the field of CDR and climate policy (Table 8). The

findings offer a multi-dimensional view of Italy's stance on climate action, highlighting its readiness to integrate CDR into mitigation strategies. They also shed light on the perceived opportunities and barriers associated with different CDR approaches, as seen through the lens of diverse stakeholders.

Stakeholder type	Included Stakeholders
Public entities and administrations	CREA (Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria); Lombardy Region ; ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale); Public entity.
Academia and research centres	CMCC (Centro Euro-Mediterraneo sui Cambiamenti Climatici); Politecnico di Torino ; Università Sapienza di Roma ; Università di Parma
Private companies	Resilco ; 17tons ; Snam ; Limenet
Associations and civil society	Cleantech for Italy ; ICHAR (Associazione Italiana Biochar); Greenpeace

Table 8. The interviewed stakeholders.

6.2.1 Awareness and views of stakeholders on Italy's existing climate policy

Across stakeholder groups, Italy is generally placed in the mid-to-low range of EU climate ambition. Respondents acknowledge early-2000s leadership on renewables (rapid solar and wind uptake) but agree that momentum has faded. Several stakeholders observed that Italy has at times acted as a brake on EU ambition (e.g., positions during Fit-for-55 and on 2040 targets), though some perceive a softening of this stance under current ministerial leadership.

Public entities emphasised Italy's formal climate commitments, such as coal phase-out and the goal of achieving net-zero by 2050, while identifying EU legislation as the primary catalyst of national action. They also acknowledged an uneven trajectory leaning more towards compliance with EU mandates rather than proactive domestic policy. A frequently cited source of optimism is subnational leadership, for example, Lombardy's 2025 regional Climate Law explicitly referencing CCS ([Lombardy Regional Law 18 July 2025, n. 11, "Legge per il clima"](#)²⁸¹), signalling a more targeted approach at the regional level.

Academics were the most critical, often describing Italy's PNIEC as aspirational rather than operational, a "wishlist" lacking delivery mechanisms. They linked inconsistent implementation to shifting government priorities and short-term economic or geopolitical pressures.

Private companies' views were pragmatic. Large incumbents placed Italy "in the middle of the pack", neither a frontrunner nor a laggard. Start-ups and SMEs were more negative, often rating ambition "very low," citing the absence of a national CDR framework, unclear investment signals, slow permitting, and fragmented governance as key deterrents to capital deployment.

Associations and civil society characterised policy as reactive and fragmented, with a perceived alignment to incumbent energy interests. They cautioned that prioritising gas and CCS could crowd out deeper system change unless paired with robust mitigation, demand-side measures, and nature-based action.

Across all stakeholder groups, two consistent areas of convergence emerged. First, respondents described EU alignment as a stable reference point that provides continuity and predictability amid Italy's shifting political landscape. EU directives and funding frameworks were seen as essential guardrails that sustain climate action even when domestic momentum wanes. Second, stakeholders identified local and regional initiatives as credible drivers of progress. Projects such as the "CommOn Light" energy community in Ferla²⁸² and the Lombardy Climate Law were cited as tangible examples of how decentralised governance can deliver results, nurture public trust, and maintain innovation despite national-level fragmentation.

At the same time, several **systemic gaps** were repeatedly highlighted. The most prominent was the absence of a coherent strategy for CDR, including clear targets, accounting rules, and instruments for engineered removals. Stakeholders also pointed to persistent delivery bottlenecks, notably long permitting timelines and infrastructure constraints, that erode the credibility of Italy's climate pledges. Others warned of technological overreach, cautioning that an overreliance on unproven technologies such as small modular reactors could delay near-term mitigation. Finally, participants stressed that land-use measures remain underexploited, and that external incentives and clearer planning tools are needed to unlock their potential.

6.2.2 Awareness and knowledge of CDR and the different methods

Across stakeholder groups, awareness of CDR is broad but uneven by method. Knowledge is deepest on CCS/CCUS, DACCS; land-based options are widely known; marine-based and some mineral approaches are less familiar to public bodies and segments of industry. Many respondents stressed that, even at multi-MtCO₂/year, carbon removals cannot bridge Italy's mitigation gap and should therefore complement rather than replace emissions reductions.

Public entities demonstrated **high conceptual awareness of CDR** but limited operational readiness to translate knowledge into deployment. Awareness was strongest in areas aligned with existing mandates, such as forestry, agriculture, and environmental monitoring, while engineered removals remained largely outside institutional competence. Across ministries, agencies, and regional administrations, the main constraints that were noted were regulatory uncertainty, fragmented responsibilities, and insufficient coordination between national and subnational levels. Technical expertise exists within individual bodies yet remains siloed and rarely integrated into coherent policy instruments. Weak MRV systems, unresolved accounting rules, and limited financial resources further impede the implementation of pilot projects or incentive schemes. Overall, public entities acknowledged CDR's strategic value but act within an administrative rather than proactive policy framework, resulting in slow authorisation, inconsistent governance, and reliance on EU direction rather than domestic initiative.

Academics showed high technical fluency, particularly on CCS/CCUS, DAC, and geological storage. Many judged large-scale CO₂ storage

indispensable given residual emissions and the limited potential of several methods. Land-based options (afforestation, carbon farming) are seen as politically attractive but constrained by chronic land-use competition and weak spatial planning. Biochar and enhanced rock weathering are valued for soil co-benefits, yet MRV, permanence, and scalability remain open questions. Marine approaches (e.g., ocean alkalinity enhancement, direct ocean capture) face scepticism due to costs, ecological uncertainty, and offshore legal complexity. DAC is viewed as strategically useful near industrial clusters, but energy- and cost-intensive unless tightly coupled with renewables and strong incentives. Overall, academics depict a diverse but feasibility-constrained CDR portfolio that cannot replace accelerated mitigation.

Private companies broadly **viewed CDR as an industrial necessity** constrained less by technology than by policy and market conditions. Companies identified an unpredictable regulatory environment, slow authorisation processes, and fragmented governance as the main obstacles to deployment. Economic feasibility is undermined by the absence of stable incentives, long-term financing mechanisms, and clear eligibility standards for certification or crediting. High energy costs and limited awareness among investors and financial institutions further dampen the willingness to scale. Companies see Italy's industrial infrastructure, biomass availability, and geological formations as valuable assets for developing a CDR ecosystem, yet these remain underused without stronger coordination between national and EU frameworks. Across the sector, there is agreement that progress depends on streamlined permitting, robust MRV and certification systems, and transparent communication to build public trust and attract investment.

Associations and civil society showed broad but **purpose-driven awareness of CDR**, shaped by their missions and advocacy priorities. Organisations engaged in policy and market monitoring, such as those following carbon farming, offsets, and biochar, demonstrated good knowledge of land-based and market-linked methods. Environmental NGOs displayed technical literacy on a wider range of approaches but tended to focus their scrutiny on issues of permanence, additionality, and the risk that removals could be misused to delay fossil fuel phase-out. Land-based methods were valued for biodiversity and resilience co-benefits, yet concerns over land competition, insufficient incentives, and limited programmatic support were indicated. Engineered options (DACCS/BECCS) were acknowledged but often viewed as too expensive,



energy-intensive, and politically risky given Italy's limited technical infrastructure, high energy costs, and the absence of a clear national deployment framework. Overall, associations and civil society combine CDR awareness with caution about greenwashing, fragile carbon markets, and over-reliance on removals at the expense of mitigation.

Across all stakeholders, several points of convergence emerged:

- **CDR as a complement, not a substitute.** Removals are widely seen as supporting - but unable to replace - deep mitigation.
- **Strong literacy on CCS/DACCS.** Broad familiarity with engineered options; land-based methods are broadly understood; ocean and mineral methods remain niche.
- **MRV and permanence are pivotal.** Robust monitoring and accounting determine whether a method is viable and financeable.
- **Territorial fit is decisive.** Methods gain traction when aligned with regional contexts, existing infrastructure, and local acceptance.

Despite growing awareness across stakeholder groups, several structural barriers consistently emerged, revealing cross-cutting gaps that constrain the translation of knowledge into large-scale deployment.

- **Uneven method depth.** Public bodies and parts of industry have limited expertise on ocean and some mineral methods relative to CCS and land-based ones.
- **Lack of a national framework.** The absence of clear rules, incentives and coherent governance stalls uptake despite institutional awareness.
- **Uncertain MRV and permanence.** Especially biochar, ERW, soils, and emerging marine methods face credibility and investment hurdles.
- **Cost and energy intensity.** DACCS/BECCS remain constrained without cheaper renewables and targeted policy support.
- **Land-use competition and weak incentives.** Afforestation and carbon farming are constrained by planning gaps and limited incentives for farmers.

Table 9 summarises stakeholder perceptions of key CDR methods. Cell colours follow a traffic-light scale: green for positive or familiar views, yellow for

mixed or uncertain, and red for limited knowledge or low perceived potential.

CDR method	Public entities	Academia	Private sector	Civil society	Common view
<i>Afforestation / reforestation</i>	Valued for co-benefits (air quality, cooling) in urban/peri-urban areas	High cover; low potential	Not a core CDR pathway	Risk of offset/greenwashing narratives	Valued for co-benefits but constrained by land, permanence, and planning.
<i>Soil carbon sequestration</i>	Requires farmer incentives	Limited scaling due to fragmented landholding, MRV challenges, and insufficient incentives	Needs policy support	Supportive but cautious on MRV requirements	Soil benefits recognised but fragmented landholding limits uptake; needs MRV & incentives.
<i>Peatland & coastal wetlands</i>	Acknowledged for biodiversity but remains niche				Strong co-benefits but geographically limited and with high upfront costs.
<i>Durable biobased products</i>	Potential in wood products/biomaterials	Cautious	Considered supplementary	Supportive only within robust circular systems	Useful for markets/circularity; integrity depends on product lifespan.
<i>Biochar</i>	Soil improver but faces market cost and supply issues				Promising yet constrained by biomass supply, MRV/permanence uncertainty, and low policy visibility.
<i>BECCS</i>	Noticeable potential due to biomass sector	Credible but limited by biomass competition		Linked to fossil-aligned CCS narratives	Possible via biogas/biomethane reserves; biodiversity risks and high costs.
<i>Biomass sinking & burial</i>	Not relevant for Italy	More research required	Not a short-term priority	Too experimental	Experimental; uncertainty around permanence and ecological impacts.
<i>Enhanced rock weathering</i>	Operational bottleneck		Emphasis on logistics and processing capacity	Environmental concerns	Soil co-benefits; limited by grinding, logistics, acceptance.
<i>Ocean alkalinity enhancement</i>	Too uncertain		Uncertain but strong potential recognised	High-risk/under-researched	Scientifically promising but constrained by ecological, MRV, and regulatory uncertainty.
<i>Carbon mineralisation (in/ex-situ)</i>	Dependent on geological suitability	Authorisation challenges	Strong interest; pilot projects	Open if governed tightly and risks are managed	Durable but early-stage and cost-constrained; authorisation and geology dependent.
<i>DACCS</i>	Strategic long-term role but challenged by costs and storage constraints		Strategic near industrial clusters	Politically problematic: too costly and energy-intensive	Long-run value possible near clusters with storage and clean power.
<i>DOCCS</i>	High potential but premature				Near-term unrealistic in Italy due to energy, infrastructure, marine constraints.

Table 9. Traffic-light summary of stakeholder preferences by CDR method.

6.2.3 Stakeholder views on the deployment of CDR in Italy

Across stakeholder groups, there was strong agreement that CDR must complement, never replace, emissions reductions. Utilisation pathways can create business incentives but risk short-term re-emissions, making durable storage through mineralisation or geological storage essential for any credible net-negative strategy. Deployment is seen as necessary but constrained by economics, infrastructure, governance, and, particularly for maritime-based approaches, ecological uncertainty.

Public entities recognise CDR as strategically necessary but remain institutionally unprepared to support its deployment. CCS is the only engineered removal currently reflected in the PNIEC, while other methods await regulatory definition under forthcoming EU frameworks such as the CRCF.

National authorities frame CDR mainly through compliance and accounting, reflecting an administrative rather than strategic approach.

Despite growing private interest in forest and agricultural credits, public funding, policy clarity, and binding targets are still lacking. **Regional administrations show some readiness but lack resource capacity, knowledge and coordination** needed to implement projects. Across government levels, deployment is slowed by complex permitting, fragmented ministerial responsibilities, and insufficient technical and financial resources to scale beyond pilots. Advancing deployment requires transposing EU legislation into domestic law, improving multi-level governance, and creating predictable financing and incentive mechanisms to underpin MRV and certification systems.

Academic experts view technological understanding mature across universities and research institutes but emphasise that deployment depends on an integrated national framework connecting capture, transport, and storage infrastructures. **They identify a persistent gap between Italy's planning documents and real industrial or financial feasibility, with national strategies perceived as reactive to EU pressure rather than domestically driven. Political short-termism, limited CDR literacy, and a lack of cross-ministerial coherence** further undermine policy implementation and investment. While researchers highlight Italy's geological capacity and industrial legacy as strong enablers, they note that permitting, MRV, and social acceptance remain underdeveloped. Land-based options are constrained by spatial and planning limits, whereas engineered solutions require sustained subsidies and renewable integration to become viable.

Private companies - both incumbents and innovators - stress that deployment is contingent on a predictable framework for investment and certification rather than on technology readiness. **Slow authorisations, unclear permitting procedures, and fragmented responsibilities prevent pilot projects from maturing into scalable ventures.** The **absence of long-term incentives and de-risking mechanisms** undermines investor confidence, while high energy costs and limited financial-sector awareness further restrict access to capital. Companies see potential in Italy's industrial base, geological formations, and biomass residues, but note that these assets remain underused without clear coordination between national and EU policies. Robust MRV, certification systems and transparent communication are viewed as essential to build social legitimacy.

Associations and civil society organisations express caution toward CDR deployment, warning that current policy trajectories risk entrenching fossil fuel dependence rather than driving structural decarbonisation. While acknowledging a potential role of removals within the transition, they **insist on clear regulatory safeguards, transparent accounting, and community participation.** Fragmented governance, political inertia, and the absence of a coherent national framework are seen as major barriers that prevent a balanced portfolio from emerging. The association of CCS with gas infrastructure fuels mistrust, while nature-based and circular-economy options such as biochar are viewed as more legitimate but undersupported and poorly integrated into national policy.



Table 10 summarises insights from interviews with public entities, academia, industry, and civil society. It reports average self-assessed levels of awareness, commitment, and knowledge for each stakeholder

group, using a trafficlight scale from high to low familiarity, and includes their shortterm outlook on Italy's CDR progress.

Stakeholder type	Awareness of Italy's climate policy	Commitment to decarbonise	Awareness of CDR policies	Knowledge of CDR	Short-term outlook	Summary of views
Public Entities and Administrations	High	Medium-high	Medium-high	Medium	Moderately optimistic	CDR has strategic value but operations are compliance-oriented, marked by fragmented mandates, slow permitting, and limited capacity to move beyond pilot projects.
Academia and research centres	Medium-high	Medium	Medium	High	Moderately pessimistic	Acknowledgement of Italy's strong technical expertise alongside persistent gaps between planning and implementation, calling for an integrated capture–transport–storage framework.
Private companies	Medium-high	High	Medium-high	High	Neither optimistic nor pessimistic	CDR is seen as an industrial necessity but faces unstable incentives, unclear permitting, high energy costs, and scarce de-risking tools.
Associations and civil society	Medium-high	Medium-high	Medium	Medium-high	Moderately pessimistic	Conditional support to CDR, warning against fossil dependence and advocating nature-positive, community-driven approaches.

Table 10. Summary of findings from stakeholder interviews. Assessments are aggregated by stakeholder group and reflect qualitative perceptions rather than standardised metrics; they should therefore be interpreted as indicative insights within each group, not as comparative rankings across actors.

6.2.4 Conclusions on the stakeholder interviews

The interviews revealed a strong consensus that CDR must act as a complement to emissions reductions and be anchored within a coherent national decarbonisation strategy. The central constraint is **governance**, not technology: fragmented institutional responsibilities between ministries and regions, slow and opaque permitting, and the absence of a stable long-term framework continue to delay progress. Stakeholders consistently called for policy coherence with EU regulation, predictable incentives, and robust MRV and certification systems to build investor confidence and public trust. Without these foundations, Italy's geological, industrial, and research strengths cannot translate into scalable CDR deployment.

Financial barriers - limited public sector support, weak de-risking instruments, and low awareness among lenders - further restrict investment. At the same time, gaps in coordination and knowledge transfer hinder research advances and pilot initiatives from informing policy design, while tensions remain between engineered and nature-based approaches amid uncertainty over priorities and safeguards. The results from the stakeholder interviews show a clear path forward: a **coherent national roadmap** aligned with EU regulations, more streamlined permitting and institutional coordination, durable financing mechanisms, and robust MRV and public engagement. Without governance and market reforms, respondents expect CDR deployment in Italy to continue to advance slowly and unevenly despite its strong underlying potential.

6.3 Citizen panel

This section summarises the insights gathered from a **citizen panel of 30 participants**, selected to reflect a diverse mix of backgrounds, ages, and regions, providing a sample broadly representative of the Italian population. Each group was formed based on the order of completion of a preliminary survey, which later influenced the dynamics of the discussions (Box 8). The panel explored three core dimensions: first, participants' awareness and views on Italy's existing climate policy, including perceived strengths, shortcomings, and the role of EU leadership; second, their awareness and knowledge of CDR and its natural, engineered, and hybrid methods; third, their views on how CDR should be deployed in Italy, focusing on governance, equity, feasibility, and its role as a complement to mitigation strategies.

The findings provide a citizen-level perspective on Italy's climate governance, highlighting both the opportunities and barriers to integrating CDR into national and EU climate strategies. They also illustrate how public perceptions evolve when citizens are exposed to technical information, and where knowledge gaps continue to shape attitudes toward policy and technology.

6.3.1 Awareness and views on Italy's existing climate policy

Participants in the citizen panel expressed strong concern about climate change and a general awareness of Italy's commitments within the EU framework. However, their views on the effectiveness of existing policies were ambivalent, recognising EU leadership but expressing scepticism about Italy's domestic capacity to act. Many viewed **Italy as lagging behind**, citing bureaucratic hurdles and fragmented permitting processes as major barriers. This fed into a broader perception of **weak and**

inconsistent political will, with many participants doubting that Italian institutions could follow through on ambitious climate targets without stronger coordination and enforcement. Some feared that even if citizens contributed financially (e.g., via utility bill surcharges), funds might not be allocated transparently or effectively.

By contrast, **the EU was consistently seen as the main driver** of ambitious targets and as the legitimate body to coordinate action. Participants associated Italy's targets and incentives with broader EU policies such as the Green Deal and Fit-for-55 package, underlining Europe's role as both motivator and watchdog. Some explicitly argued that only EU-level enforcement could ensure Italy delivers on its commitments, given the perceived fragility of domestic political will. Achievements were primarily attributed to the EU level, where climate ambition and coordination were seen as strongest. Failures, in contrast, were linked to the national level: slow implementation, weak enforcement, and incoherent policy frameworks (e.g., contradictions in trade and agricultural policy) were repeatedly highlighted as shortcomings.

6.3.2 Awareness and knowledge of CDR and its methods

The citizen panel revealed a **generally high interest in CDR**, with many participants acknowledging that their knowledge significantly improved during the workshop. This suggests that exposure to technical information can rapidly increase public understanding and willingness to engage with CDR discussions. Nonetheless, the **depth of familiarity varied across methods**: natural solutions were more immediately understood, while engineered approaches often required additional explanation and prompted uncertainty.

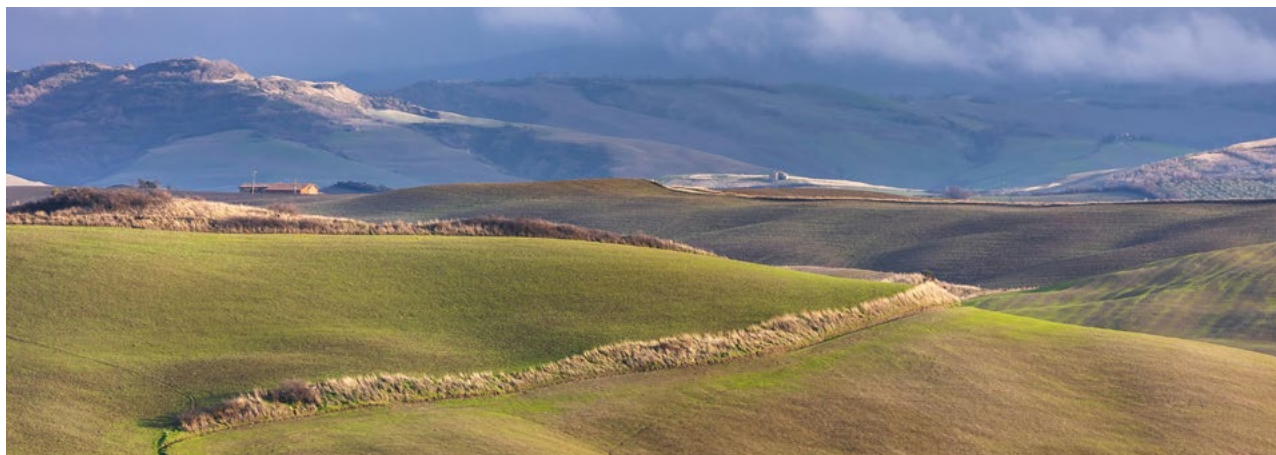


Table 11 illustrates the perceptions of CDR methods among citizen panel participants, using a 1-7 scale where higher scores indicate stronger public support and acceptability. These values reflect initial individual assessments, but they were not treated as definitive rankings. Subsequent group discussions sometimes reshaped views, meaning that methods with similar - or even slightly lower - average scores were sometimes placed in more or less favourable categories depending on the qualitative arguments participants developed during the collective exchange. Overall, natural methods (afforestation, soil carbon sequestration, wetland restoration) and

certain engineered options (biochar, carbon mineralisation) were viewed as the most viable, given their perceived safety, co-benefits, and integration potential. By contrast, marine methods, biomass burial, and large-scale DACCS faced low acceptance due to cost, environmental risk, and perceived artificiality. Many participants emphasised that deployment should focus first on methods that are already partly operational or easily integrated into existing infrastructures.

Methods	Survey Score	Perceptions
Afforestation & Reforestation	6.2	Most intuitive and attractive method. It was valued not only for carbon removal potential but also for co-benefits such as biodiversity, shading, and aesthetic improvements.
Soil carbon sequestration	6	Seen as practical and easily integrated into agricultural practices, though often recognised as providing temporary rather than permanent storage.
Wetland and peatland restoration	5.7	Appreciated for its role in biodiversity and ecosystem protection, albeit with concerns over land use and feasibility.
Biochar	5.7	Both recognised as promising for integrating waste use and circular economy practices, though concerns over permanence and re-emission remained.
Biobased carbon products	5.7	
Carbon mineralisation	5.6	Seen as practical and easy to integrate into agricultural practices, though often understood to provide temporary rather than permanent storage.
BECCS	5.6	Was acknowledged for potential co-benefits such as energy generation, though concerns about land competition and high resource needs were frequent.
DACCS	5.2	Generated cautious interest, perceived as effective in theory but burdened by concerns over costs, energy and water demand, and visual/aesthetic impacts.
Enhanced rock weathering	4.9	These methods were often seen as "too technical," risky for ecosystems, or as "burying the problem" without clear guarantees of permanence.
Biomass sinking and burial	4.8	
Ocean direct capture	4.8	
Ocean alkalinity enhancement	4.7	

Table 11. Public awareness and perceptions of CDR methods among citizen panel participants.

6.3.3 Citizens' views on the deployment of CDR in Italy and its role in fighting climate change

Across the citizen panel, participants expressed a **clear conviction that CDR will be necessary to complement mitigation efforts** if climate targets are to be met. However, their views on how CDR should be deployed were shaped by considerations of fairness, feasibility, governance, and cultural acceptance. They saw CDR as an important pillar alongside stopping deforestation and expanding renewable energy, which were identified as the three most effective strategies for addressing climate change. No single CDR method was considered sufficient; instead, **participants favoured a “portfolio approach”** where different solutions are matched to local contexts – such as mineralisation near industrial hubs, wetland restoration in coastal zones, soil carbon sequestration in rural areas. Survey results showed strongest support for integrating CDR into regulations and value chains (e.g., building codes, procurement rules, agriculture, waste treatment), and for developing it as part of the national public infrastructure, ensuring stable funding and integration into long-term planning. Opinions diverged between those favouring voluntary measures (encouraging adoption by farmers, companies, and communities) and those supporting binding obligations for certain sectors. While voluntary approaches were slightly more popular, many acknowledged that mandates could accelerate progress if applied fairly.

Governance emerged as a central concern. Participants repeatedly stressed the need for EU- and global-level coordination, given the cross-border nature of climate challenges and the limited capacity of Italy to act alone. Some proposed creating a dedicated CDR authority or multidisciplinary planning teams (engineers, scientists, economists, sociologists) to oversee deployment, ensure safety, and align incentives. Public trust in national institutions was low, with many believing that EU oversight would be more effective in ensuring accountability and consistency. **Equity considerations were equally prominent:** citizens feared that disadvantaged regions or rural communities might be overburdened, while wealthier actors avoided responsibility. There was **strong support for the “polluter pays” principle**, with most participants indicating that companies responsible for higher emissions should bear the main costs of mitigation and CDR deployment. Survey results reinforced this view: respondents most often favoured financing through government subsidies to industry and by placing primary responsibility on high-emitting companies. A minority suggested



more collective instruments such as carbon taxes or broader international collaboration mechanisms, but these were less consensual. Across discussions, citizens stressed that **climate policies must ensure affordability and fairness**, preventing a scenario where only wealthier groups can participate in or benefit from sustainable practices. They called for subsidies to prevent inequitable outcomes, alongside measures to keep sustainable goods affordable for all income groups. Some suggested symbolic citizen contributions (e.g., small levies in

utility bills), but these ideas were often accompanied by scepticism regarding how funds would be used. **Public engagement and longterm education were seen as essential** to build acceptance and avoid local resistance. Schools, civic initiatives, and mass media campaigns were viewed as critical for embedding climate responsibility and countering scepticism. Transparency and public involvement in decision-making were deemed essential to avoid resistance, particularly in local communities directly affected by new CDR facilities.

Box 8. Divergent Levels of Confidence and Technical Detail

The citizen panel was organised into five groups of six, based on the order in which participants completed the preliminary survey. This unintentionally produced two distinct discussion dynamics. Early respondents (Groups 1–3) tended to be more confident and technically familiar with CDR, offering detailed comparisons of permanence, risks, and cobenefits across methods. They engaged comfortably with concepts such as mineralisation, afforestation reversal, and the co-benefits of enhanced rock weathering, and frequently weighed tradeoffs between feasibility, safety, and longterm impacts. Later respondents (Groups 4–5), by contrast, felt less equipped to evaluate technical details and shifted their discussions toward broader systemic and strategic issues - youth engagement in climate education, territorial adaptation of CDR methods (e.g., abandoned land reuse, urban agroforestry), and the role of EU leadership as a stronger political driver than domestic politics. Their hesitancy stemmed not from disinterest or weaker educational backgrounds, but from a perceived lack of knowledge, with many preferring to defer to trusted experts to avoid making the “wrong” choice. They repeatedly emphasised that ambiguity, not a lack of care, underpinned their caution, while still recognising the importance of CDR for climate goals.

These dynamics highlighted several important considerations. Public hesitation may limit citizen engagement in technical policy debates unless supported by clearer education and communication to empower wider participation. Trusted institutions and expert guidance are essential to bridge this confidence gap and build acceptance. While the early groups contributed more technically detailed assessments, the later groups offered valuable reflections on governance, fairness, and cultural change. Together, their perspectives illustrate both the potential and the limits of citizen involvement in shaping complex CDR policy decisions.

6.3.4 Conclusions on the citizen panel

Overall, the citizen panel emphasised both the potential and the challenges of incorporating CDR into Italy's climate policy. Participants showed strong interest in the topic, quickly deepening their understanding as discussions progressed, though their views reflected both enthusiasm and caution. Citizens consistently stressed that CDR should remain a supplementary tool, deployed transparently and equitably, with costs primarily borne by major emitters and supported through EU level coordination rather than replacing mitigation.

The differences between groups highlighted how essential it is to close knowledge gaps through open communication and education, enabling a broader range of citizens to participate confidently in climate discussions. Taken together, the panel's insights suggest that public support for CDR in Italy will depend not only on the methods chosen but also on the governance, fairness, and trust frameworks that shape their implementation

7. Italy's realistic potential to deploy CDR

Building on the resources described in Chapter 3 and the theoretical CDR potential outlined in Chapter 4, this chapter revises assumptions around resource availability and selected CDR methods to incorporate stakeholder perspectives, public sentiment, and the legal and socio-economic considerations discussed in Chapters 5 and 6. Each realistic scenario in the present report requires social acceptance, political will, and quantifiable objectives, amongst other key factors. Based on this integrated analysis, the study estimates the realistic potential – defined as the volumes of CDR that can be deployed with high confidence in the near future. Within this framework, multiple scenarios emerge, mainly shaped by Italy's level of ambition. This chapter examines those pathways in detail.

7.1 Background: Italian official planning scenarios

To contextualise Italy's realistic CDR potential and assess different levels of ambition, this study compares Italy's official emissions projections with feasible CDR deployment pathways. Residual emissions for 2050 were taken from Italy's main national planning documents: ISPRA 414/2025²³; the PNIEC-2024¹⁸, the National Long-term Strategy (LTS)¹, and the Ecological Transition Plan (PTE-2023)²¹⁷. Together, these sources show that current measures fall short of net-zero and that significant post-2030 policy tightening will be required.

The LTS is the only official pathway outlining how Italy could reach climate neutrality. It starts from a reference trend similar to PNIEC and ISPRA projections – which would still leave nearly 200 MtCO₂ in 2050 – and then introduces the structural transformations needed to close this gap across all major sectors: deep electrification, a coal phase out, efficiency improvements, hydrogen deployment, industrial CCS (20–40 MtCO₂/year), and strengthened removals. **Under this pathway, residual emissions fall to 68–100 MtCO₂ per year by 2050**, a range derived from the four decarbonisation scenarios modelled by Gaeta et al. in support of the LTS: 68 Mt under the most ambitious assumptions (LTS C: hydrogen in steel, 100% renewable power, full modal shift) and 100 Mt under LTS A (fossil fuels with CCS in industry and power, unconstrained aviation growth). The LTS 2021 official headline of 65–85 MtCO₂eq encompasses the intermediate scenarios and is consistent with this range. These residuals could be balanced through a combination of LULUCF sinks and dedicated CDR methods. While the LTS and ISPRA WAM scenarios consider nuclear energy, carbon farming policies,

and 20–55 MtCO₂ of CCS, **none provide a clear CDR roadmap.** They also rely heavily on LULUCF, expected to deliver at least 40 MtCO₂ in removals.

Further details on official scenario assumptions and sectoral trajectories are provided in Annex D. The following sections examine realistic CDR deployment pathways and assess how they align with Italy's expected residual emission profile.

7.2 Methodology for the realistic CDR potential

The calculation of the realistic CDR potential in Italy employed the same methodology as that used for the theoretical potential presented in Chapter 4. However, it incorporates additional constraints, including the regulatory and economic contexts, as well as public support. The assessment of public support is based on the views gathered through the stakeholder interviews and the citizen panel described in Chapter 6.

The estimated resource availability for CDR under the realistic potential is more conservative than that in the theoretical assessment presented in Chapter 4. While the theoretical potential assumes that all available resources are allocated to CDR considering only broad physical feasibility, the realistic potential accounts for competing demands and constraints, resulting in lower projected CDR volumes. These more cautious estimates are based on the following considerations:

- **Techno-economic feasibility:** in addition to physical constraints, resource use was evaluated in terms of what is reasonably feasible from a techno-economic perspective – particularly for resources that are contested among multiple CDR methods. However, macroeconomic variables such as GDP growth, cost levels, interest rates, and existing financial support mechanisms were not included as dynamic inputs.
- **Technological deployment:** the pace and scope of technology rollout were adjusted to reflect realistic expectations. For example, adoption rates for technologies such as BECCS and DACCS were estimated based on plausible deployment trajectories.
- **Legislative constraints:** legal limitations were incorporated where they clearly and significantly limit the availability of certain resources.
- **Social acceptance** was assessed through public support, as determined by input from stakeholder interviews and results from the citizen panel.

7.3 Realistic CDR potential scenarios

Three scenarios - **Conservative**, **Reference**, and **Ambitious** - were developed to illustrate different pathways for CDR deployment in Italy to 2030, 2040, and 2050. When natural sinks are included, both the Reference and Ambitious scenarios model a future in which Italy can counterbalance all its projected residual emissions and reach net-zero by 2050.

The scenarios differ mainly in assumptions about geological storage availability, economic and financial conditions, policy developments, technological progress, and societal acceptance. Across all realistic scenarios, **geological storage is the main bottleneck**: industrial point-source CCS alone is expected to use 40-70% of the projected available capacity, leaving limited room for BECCS and DACCS. As other options plateau, **DACCS becomes increasingly important**, reflecting EU-wide modelling that shows it taking the largest share of removals after 2050 - provided clean power expands rapidly.²⁸³ **A deeply transformed power system is essential** across all scenarios, with 80-95% renewables, large power-to-x flexibility, e-fuel production and potentially nuclear power. This evolution is consistent with Italy's long-term energy studies and is a prerequisite for scaling BECCS and DACCS. **Policy credibility and MRV clarity are equally decisive**: the revised EU LULUCF Regulation (2023/839)¹⁴⁶ and the CRCF framework enable new land-based options (wetland, peatlands) and accelerate certification for biochar, enhanced rock weathering, and nearshore ocean alkalinity

enhancement - often shifting outcomes from conservative to more ambitious trajectories.

The scenarios converge on a clear conclusion: Italy needs a broad CDR portfolio to reach net-zero. No single option can scale fast enough or large enough on its own. This aligns with the [European Scientific Advisory Board on Climate Change](#)²¹⁸ which finds that maximising cheaper terrestrial options lowers system costs, but ERW, OAE, and DACCS remain essential once limits on land, other sources, and sustainability are reached.

Across all scenarios, citizens and stakeholders converge on three principles: **a portfolio-first strategy, EU-level coordination, and fairness mechanisms** to avoid land pressure and uneven cost burdens. Whether Italy follows a Conservative, Reference or Ambitious pathway largely depends on how effectively policy translates these preferences into durable institutions.

7.3.1 The Conservative Scenario

In the Conservative scenario, Italy reaches a CDR capacity of only **17.6 MtCO₂ per year** by 2050, which, together with a natural sink of around 35 MtCO₂/year (as per LTS), results in a total carbonremoval capacity of **52.6 MtCO₂ annually** - insufficient for achieving net-zero emissions by 2050. The CDR potentials in this scenario is shown in Figure 21.

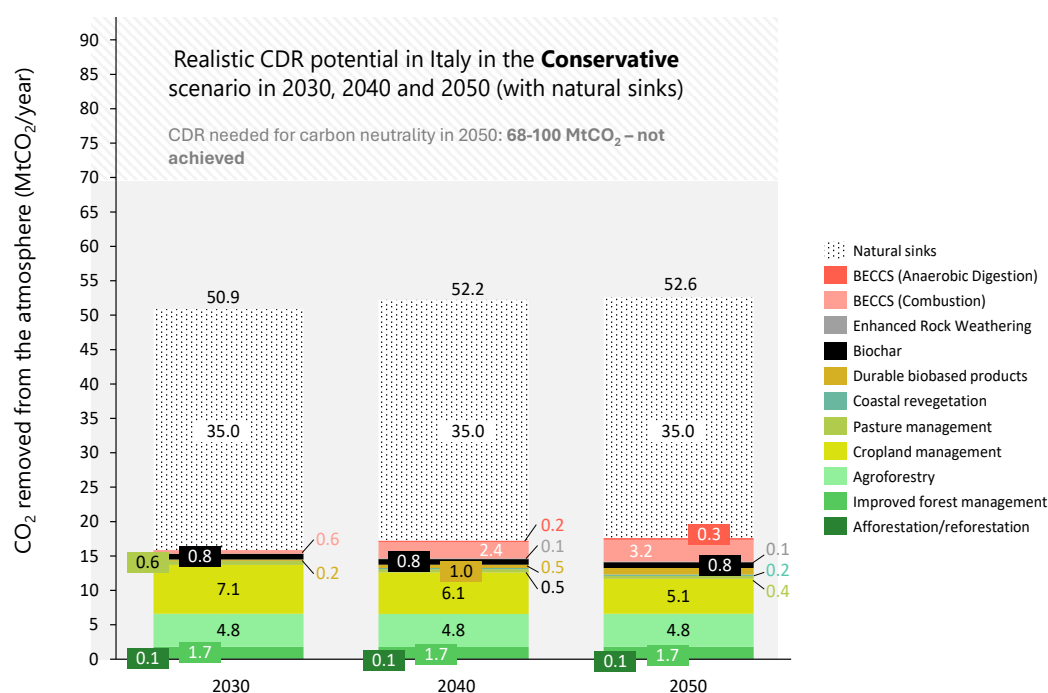


Figure 21. The Conservative scenario across 2030, 2040 and 2050

This scenario reflects low social acceptance, limited climate awareness, and a political economy that prioritises short term pressures. Public trust concentrates on visible nature-based methods and modest biochar deployment. Land sinks are gradually weakened as CAP support declines, PV expansion drives land conversion, and wildfires reduce expected forest removals and complicate certification. Suspicion toward “imposed” projects – shaped by memories of Sulcis, Porto Tolle, and contested CCS at Ravenna – reinforces resistance to large, engineered CDR, which remain marginal. Ocean approaches and large DAC hubs face scepticism over ecological impacts, costs, and visual aesthetics. Even where social acceptance exists, deployment remains slow because authorisations are split across national and regional bodies, and lengthy – sometimes opaque – permitting and environmental impact assessment procedures delay projects. At the same time, shortages of green and technical skills, combined with an industrial landscape dominated by SMEs and micro-enterprises that often struggle to finance and scale capital-intensive projects, make it difficult to build CDR supply chains at speed.

The largest CDR contributions in the 2050 Conservative scenario come from ecosystem management methods, which deliver about 11 Mt/year by 2050. **Cropland management** (5.1 Mt/year) and **agroforestry** (4.8 Mt/year) contribute the most, but this is modest compared to the Reference and Ambitious scenario due to a clear decline in the effectiveness of the CAP and farmers slowly abandoning certain CDR-promoting practices. **Afforestation, reforestation and certification of forestland** contribute only 1.8 MtCO₂/year, due to a tendency to delay payments and permitting while **coastal revegetation** and **peatland restoration** account for a minimal removal of 0.15 MtCO₂/year by 2050, assuming restoration through already funded projects and the rewetting of the Po-Valley.

In this scenario, Italy poorly develops biomass valorisation methods, which deliver only 5 MtCO₂/year in total by 2050. **Durable biobased products** (1 MtCO₂/year) are constrained by the limited range

of products eligible for storage credits, uneven regional uptake, and the continued preference for conventional materials where cost outweighs embodied carbon considerations. **Biochar** potential is limited to 0.8 MtCO₂/year of removals due to limited long-term evidence on benefits, low public support, and the absence of clear incentives and user-friendly MRV platforms.

BECCS in total removes about **3.4 MtCO₂/year** by 2050 due to limited policy support and restricted CO₂ storage capacity, largely confined to the Ravenna hub and prioritised for point-source CCS (11 MtCO₂/year), leaving only 3.4 MtCO₂/year of storage available for BECCS. Few existing bioenergy plants add CCS, which remove only around 0.8 MtCO₂/year by 2050 through BECCS with combustion. BECCS with combustion and gasification sequesters just over 2.3 MtCO₂/year, with combustion accounting for the majority, due to weak policy support for new gasification plants with CCS using residual biomass. New biomethane plants with CCS mobilise only 3.5 of 11 Mt of available feedstock by 2050. BECCS (with anaerobic digestion) also remains limited to 0.27 MtCO₂/year, with only a small number of existing biomethane plants equipped with CCS.

Enhanced rock weathering contributes only 0.1 MtCO₂/year in the Conservative scenario, limited by slow methodology development, domestic permitting lags and modest adoption that ultimately caps deployment at around 10% of olivine and basalt mineral resources by 2050. **Ocean alkalinity enhancement** does not scale. It remains limited by model-dependent MRV requirements and the need for site-specific baselines, often requiring a full year of pre-monitoring. Slow adoption of CRCF methodologies and insufficient national support stall pilot development, resulting in no OAE-based removals in this scenario.

In this scenario, **DACCS** is not a viable option due to lack of CO₂ storage capacity which is completely used by CCS and BECCS and restricted to Ravenna CCS only.



7.3.2 The Reference Scenario

In the Reference scenario, Italy reaches a CDR capacity of nearly **56 MtCO₂ per year** by 2050 which, together with a natural sink exceeding 47 MtCO₂ per year, results in a total carbon removal capacity of roughly **104 MtCO₂ annually** - sufficient to achieve net-zero emissions by 2050 when accounting for the natural sink. The CDR potentials in this scenario are shown in Figure 22. In this scenario the forest sink

projection is based on the most recent PNIEC-2024 and ISPRA-414 reports. This level of absorption exceeds today's forest reference level but remains plausible with stronger management, fire control, and harvested wood product markets.

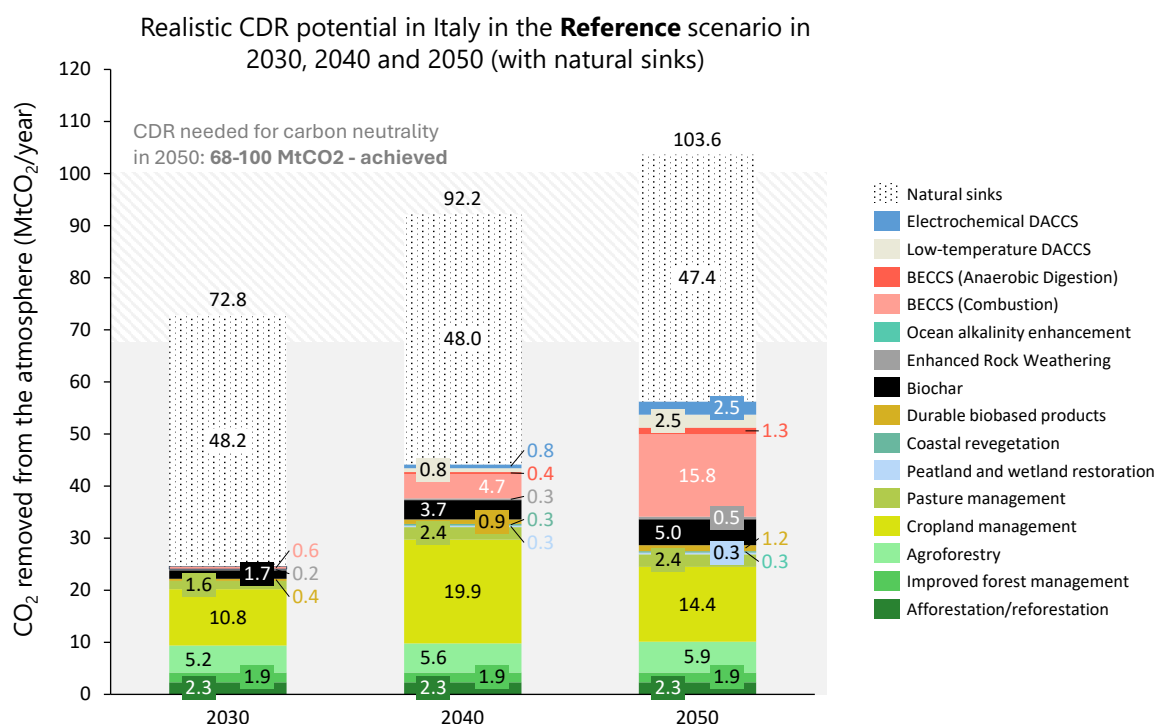


Figure 22. The Reference scenario across 2030, 2040 and 2050.

This scenario assumes a social and political context that allows EU guardrails (PNIEC/CRCF/LULUCF) to set a reliable baseline. Stakeholders broadly agree that CDR should complement, not replace, mitigation, that durable geological storage is a priority, and that CDR deployment should be anchored in clear standards (e.g., building codes, procurement) and polluter pays-based financing. Practical enablers - such as co-location in ports and industrial clusters, MRV-ready pilots that use wastewater, construction and demolition fines or alkaline residues as feedstocks for measurable and verifiable CO₂ removal, and incentive schemes for farmers – further support acceptance and implementation.

Ecosystem management methods contribute about half of carbon removal potential in the Reference scenario (27 Mt/year), with **cropland management**

(14.4 MtCO₂/year) contributing the most thanks to increased CAP incentives such as ES4. **Agroforestry** and **pasture management** follow with 5.9 Mt/year and 2.4 Mt/year respectively. **Afforestation and reforestation** contribute over 2 MtCO₂/year from 2030 onwards, supported by a responsible allocation of SR funds (80% used) which enables monitored afforestation on 10% of the projected forest area (0.14 Mha). **Certified forest management** contributes nearly 2 MtCO₂/year, supported by the use of already planned CAP funding (SRA27-31220) and the certification of newly established forests, in addition to the existing 1.2 Mha already under certification. **Coastal revegetation** of Posidonia meadows contributes 0.3 MtCO₂/year, while **wetland** and **peatland restoration** contribute with 0.14 MtCO₂/year and 0.16 MtCO₂/year respectively, thanks to policy and funding support.

In this scenario **biomass conversion methods** also play an important role collectively delivering 23 MtCO₂/year. **Biochar** sequesters 5 MtCO₂/year by 2050, supported by a strengthened CAP focused on soil restoration and sustainable food systems that enables Italy's biochar market to grow in line with global trends. **Durable biobased products** deliver up to 1.2 MtCO₂/year of removals, supported by product-storage certification under the CRCF and a bankable market that uses fibres and wood residues primarily in timber construction and cellulose-based insulation.

BECCS deployment progresses gradually - expanding through retrofits on half of the existing bioenergy plants, complemented by new gasification, thermoelectric, and biomethane facilities equipped with CCS modules to supply energy, hydrogen, and flexible fuels - to eventually provide a total of 17.1 MtCO₂/year by 2050. **BECCS (combustion)** delivers around 6.9 MtCO₂/year from existing biomass plants, supported by a gradual scale up of CO₂ storage sites across Ravenna CCS, Jonio and Gela. **BECCS (combustion and gasification)** delivers around 9 MtCO₂/year of removals, driven by residual biomass allocated to new thermoelectric plants, with a smaller contribution from gasification for hydrogen production. This pathway also supplies nearly 5% of national biomethane demand and 4-8% of hydrogen demand. BECCS (**anaerobic digestion**, new biomethane plants) scale up more slowly and deliver 1.1 MtCO₂/year removals by 2050, with the resulting CO₂ stored mostly in geological storage and partially in ex-situ mineralization).

National CO₂ storage capacity is assumed to reach 44 MtCO₂/year by 2050, with 22 MtCO₂/year allocated to CDR, as early progress in Ravenna enables additional hubs in Jonio and Gela and, later, onshore sites such as Cellino, Fiume Treste, and Collalto. In the early years, storage capacity is largely dedicated to pointsource CCS (85% in 2030), but by midcentury the system shifts toward a more balanced split with CDR (50% in 2050).

Enhanced rock weathering becomes creditable from the early 2030s as methodological certainty from CRCF methodologies enables Italy to issue accredited credits at scale, unlocking progressively larger ERW deployment, reaching 0.5 MtCO₂/year by 2050 using available olivine and basalt. For **ocean alkalinity enhancement**, regulatory progress and international guidance under the London Protocol advance in parallel with the CRCF, enabling certification pathways for OAE as pilot projects mature and measurement approaches improve. Despite this, low public acceptance - highlighted in both the citizen panel and stakeholder interviews - prevents Italy from moving forward with OAE deployment.

DACCS plays a limited role in the Reference scenario, reaching **5 MtCO₂/year by 2050**, with removals split evenly between low-temperature and electrochemical DACCS. This is the maximum that can be deployed with the remaining CO₂ storage capacity, after point-source CCS and BECCS are deducted. This trajectory aligns with EU modelling in which DACCS mainly addresses residual emissions once lower-cost CDR options are saturated.



7.3.3 The Ambitious scenario

In the **Ambitious** scenario, Italy fully exploits its CO₂ storage and other resource potential, resulting in a CDR capacity of more than **91 MtCO₂ per year** which, together with a natural sink exceeding 47 MtCO₂ per year (as per PNIEC-2024 and ISPRA-414 in the

Reference scenario), results in a total carbon removal capacity of **almost 139 MtCO₂ annually** by 2050, achieving net-negative emissions when considering the natural sink. The CDR potential of this scenario is shown in Figure 23

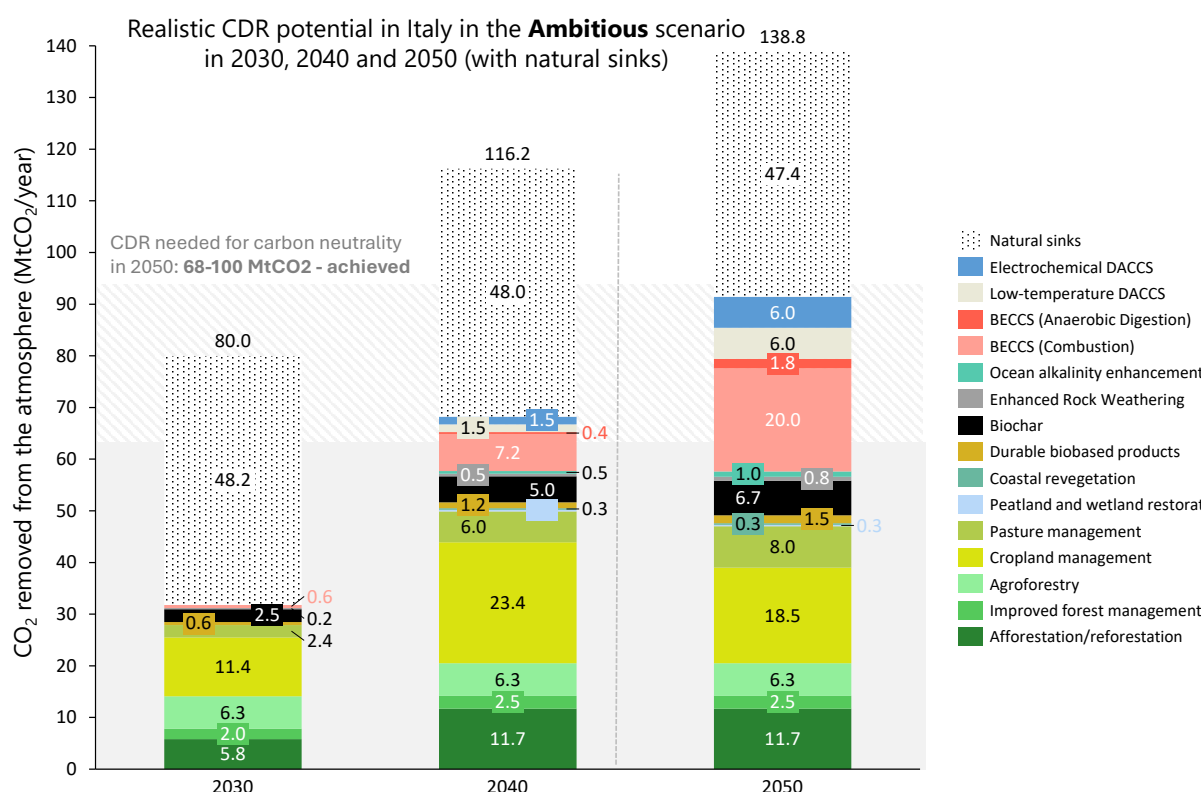


Figure 23. The Ambitious scenario across 2030, 2040 and 2050.

The Ambitious scenario sees all parameters accelerated to deliver (including the expected natural sink) much larger-scale CDR outcomes, with an early ramp-up of CDR deployment, reflecting successful policy adoption, a culture and support for soil carbon sequestration, as well proactive industrial and power decarbonisation. Italy explicitly addresses the need for social license through early, transparent public participation, strong MRV, regionally tailored benefits and just-transition jobs in southern regions potentiate the initial boost for CDR deployment. As in the Reference scenario, CDR from BECCS and DACCS are progressively given space in CO₂ storage hubs, ranging from 15% in 2030 while technologies evolve, to a balanced share with point-source CCS by 2050. Italy characterises additional depleted fields and saline aquifers, expanding storage to 74 MtCO₂/year by 2050, with 33 MtCO₂/year ring-fenced for high permanence CDR.

Ecosystem management methods collectively contribute almost 48 MtCO₂/year by 2050. **Cropland management** contributes the most (18.5 MtCO₂/year) supported by expanded CAP incentives that support soil carbon sequestration practices. **Afforestation, reforestation and certified forest management** contribute 14.2 MtCO₂/year, supported by enhanced and optimally distributed CAP-related funding, followed by Agroforestry and pasture management. **Coastal revegetation** of Posidonia meadows contributes 0.3 MtCO₂/year, while **wetland** and **peatland restoration** contribute with 0.14 MtCO₂/year and 0.16 MtCO₂/year respectively, thanks to policy and funding support

In this scenario, **biomass conversion methods** deliver around 30 MtCO₂/year by 2050. **Biochar** delivers over 6.7 MtCO₂/year of removals, supported by targeted incentives (similar to those under the CAP) for soil restoration and reinforced

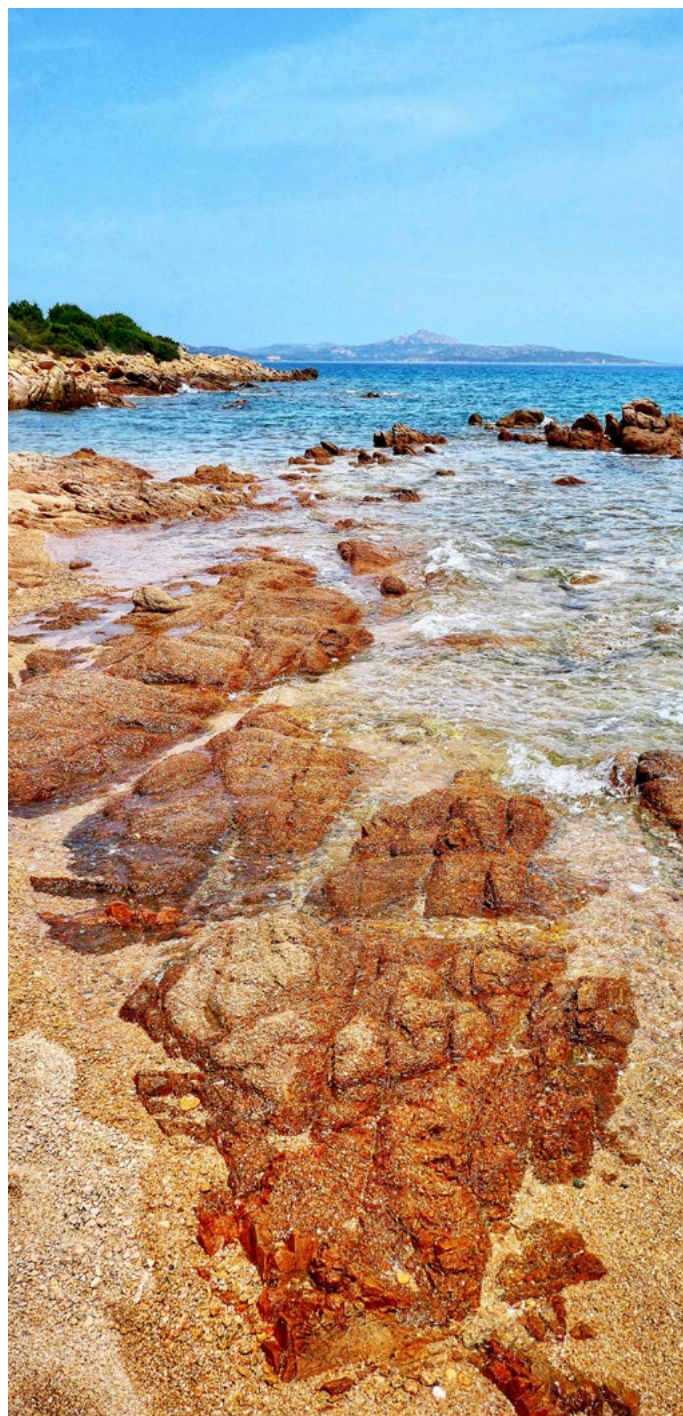
by the CRCF which unlocks institutional demand beyond voluntary markets. Biochar markets grow rapidly driven by increased national demand for agricultural applications to restore degraded soils and improve crop productivity. **Durable biobased products** contribute around 1.5 MtCO₂/year of removals, enabled by a scalable supply chain that maximises carbon storage in buildings while using biomass efficiently within sustainability limits. Standardisation, performance guarantees, and improved fire and moisture design increase confidence among insurers and lenders, while streamlined permitting supports faster deployment.

BECCS in total provides 21.8 MtCO₂/year by 2050, supported by municipal co-ownership, revenue sharing, and long-horizon incentives that de-risk private capital and unlock broader support for BECCS where biomass chains exist. **BECCS (combustion, existing plants)** contributes 9 MtCO₂/year by 2050, thanks to the expanded CO₂ storage availability not only of Ravenna CCS but also of Jonio and Gela. It is assumed that most large (>10 MW) existing bioenergy units within 300 km of storage hubs install CCS modules. Most (80%) available biomass for biomethane-with-CCS is mobilised (**1.8 Mt** of suitable feedstock), while other sources of available biomass (**7 Mt**) are successfully used for the production of green hydrogen through gasification (60%) and new thermoelectric plants (40%). **BECCS (combustion and gasification)** delivers around 11 MtCO₂/year of removals, using residual solid biomass, which is directed to new biomass plants, primarily (60%) allocated to gasification for hydrogen production and, to a lesser extent (40%), to new thermoelectric plants, all equipped with CCS. **BECCS (anaerobic digestion)** delivers approximately 1.4 MtCO₂/year of removals, by scaling through the deployment of biomethane plants with CCS that produce around 7-9% of national biomethane demand and by using 0.4 MtCO₂/year of storage capacity from ex-situ mineralization.

Enhanced rock weathering scales much faster in this scenario, reaching 0.81 MtCO₂/year by 2050, supported by rapid delivery of CRCF methodologies, robust MRV systems, and national policies that prioritise CDR. Markets for crophealth and soilamendment products using these minerals also consolidate, with CRCF credit incentives reinforcing adoption in a pattern similar to biochar. **Ocean alkalinity enhancement** using limestone is allowed to scale beyond pilots and is estimated to contribute 1 MtCO₂/year by 2050 thanks to public and political support increasing over time. This is also the result of a rapid certification processes and steady progress where infrastructure, technology, and carefully

designed projects are established near mineral processing plants. Additionality becomes a central requirement, and Italian initiatives demonstrate that using limestone and dolomite for OAE can be both economically viable and sustainable.

DACCS is deployed near clean-power clusters and contributes 12 MtCO₂/year by 2050 in the Ambitious scenario, which is the maximum that can be deployed with the remaining geological CO₂ storage capacity, after point-source CCS (41 MtCO₂/year) and BECCS are deducted.



7.4 Resource allocation

Italy has a strong resource base that can plausibly support the progressive deployment of a diverse CDR portfolio. Table 12 summarises the shares of resources allocated to CDR across the Conservative, Reference and Ambitious scenarios. The percentages refer only to the portion of

resources already deemed suitable for CDR (as assessed in Chapter 3), not to Italy's total national resources. Importantly, not all resources can be fully used in the scenarios. Social, economic and technological constraints limit how far each CDR method can scale, as detailed in Annex B.

	2030			2050		
Resources	Conservative	Reference	Ambitious	Conservative	Reference	Ambitious
Water (Mm ³)	121.31 (0.12%)	123.27 (0.12%)	143.91 (0.65%)	789.42 (0.79%)	3837.83 (3.79%)	4936.67 (4.89%)
Energy (TWh)						
Electricity	0.86 (0.77%)	2.96 (2.64%)	6.97 (6.22%)	4.2 (3.8%)	10.77 (9.94%)	19.01 (16.97%)
Thermal energy	0.51 (0.82%)	0.51 (0.82%)	0.52 (0.82%)	2.94 (4.71%)	16.39 (26.27%)	32.04 (51.35%)
Biomass (Mt) for biochar, bioproducts, and new reactors with BECCS	1.69 (6.04%)	3.38 (12.08%)	5.06 (18.08%)	6.09 (21.76%)	16.76 (59.88%)	22.40 (80.03%)
Biomass (Mt) for existing thermo- electric reactors	3 (5%)	3 (5%)	3 (5%)	5 (8.33%)	30 (50%)	45 (75%)
CO ₂ storage Capacity (MtCO ₂)	3.55 (98.6%)	3.55 (98.6%)	3.56 (98.75%)	14.40 (100%)	43.91 (99.34%)	78.41 (99.25%)
Land (Mha)						
Arable land	5.27 (73.19%)	6.2 (86.11%)	6.2 (86.11%)	4.65 (64.58%)	7.20 (100%)	7.2 (100%)
Unspecified land (afforestation)	0.01 (0.6%)	0.14 (11.67%)	0.35 (29.17%)	0.01 (0.6%)	0.14 (11.67%)	0.7 (58.5%)
Minerals (Mt)						
Limestone	0	0	0	0	0	1.74 (21.72%)
Basalt	0.13 (5%)	0.51 (20%)	0.77 (30%)	0.25 (10%)	1.66 (65%)	2.55 (100%)
Olivine	0.013 (5%)	0.054 (20%)	0.08 (30%)	0.027 (10%)	0.18 (65%)	0.27 (100%)
Dolomite	0	0	0	0	0	0
Steel Slag	0	0	0	0	0	0
Cement kiln dust	0	0	0	0	0	0
Concrete demolition waste	0	0	0	0	0	0

Table 12. Summary of the share of **resources allocated to CDR** in each realistic scenario. Absolute quantities are shown, with the percentage of each resource utilised for CDR indicated in brackets. The percentages refer to the share of resource used for CDR **out of the total resource available for CDR**.

CO₂ storage is the only resource used at its maximum across all realistic scenarios, making it the main limiting factor for durable CDR. This constraint explains why Italy cannot fully exploit its available energy and water resources for BECCS and DACCS by 2050. **Arable land is used to its maximum in the Reference and Ambitious scenarios**, assuming continued implementation of CAP and related measures. Natural succession and the planned 1.2 Mha of afforestation/reforestation depend heavily on effective fire prevention. **Biomass is deployed progressively and reaches nearfull utilisation by 2050** in both the Reference and Ambitious scenarios, yet a residual amount remains available for potential uses outside the scope of this report. **All available basalt and olivine are used for enhanced rock weathering**, while **limestone is allocated exclusively to ocean alkalinity enhancement**, reflecting inconclusive evidence for the effectiveness of carbonate minerals in ERW and growing support for its role in OAE. Cement kiln dust, concrete demolition waste, and steel slag were instead directed to ex situ mineralization to enable additional storage for BECCS with anaerobic digestion in the Reference and Ambitious scenario (details at the end of section 7.4.2).

Box 9 – Ensuring credibility in ERW and OAE deployment

ERW and OAE rely on energy and transportintensive mineral processing, and store atmospheric carbon in open systems, making rigorous MRV essential for credible credit generation. Under the EU CRCF, the European Commission has initiated the pathway to certification by laying-out key methodspecific questions for robust accounting. For ERW, accounting²²⁵ includes subtracting baseline weathering and project emissions, and monitoring soil organic carbon to demonstrate additionality. ERW credits have already been issued by private registries, but so far, most certification bodies focus on silicate feedstocks to avoid added complexity of confusing baselines with carbonate feedstock.

Certification approaches for OAE²²⁶ are also starting to emerge but remain model-dependent and face limited public acceptance. The first credits were issued in 2025 (Isometric)²²⁷, suggesting a potential scaleup trajectory by 2030 as site-specific coastal baselines and MRV models improve. Early implementation will most likely rely on coastal activities while other forms of OAE (in open ocean) still depend on the evolution of key international governance frameworks.

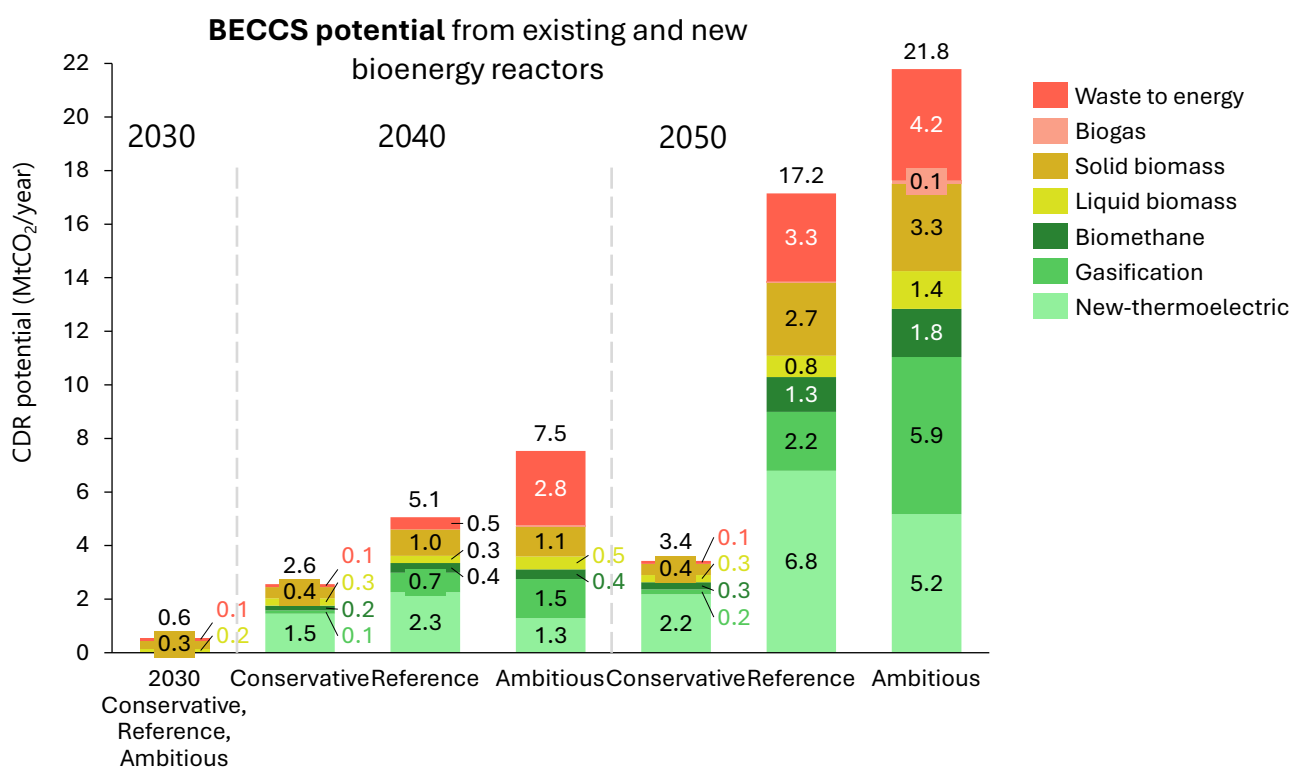


Figure 24. BECCS potential from existing biomass reactors (shades of red, yellow) and from potential mobilisation of residual biomass towards new bioenergy reactors (shades of green). BECCS deployment across the realistic scenarios is constrained by CO₂ injection capacity.

7.4.1 Main assumptions behind BECCS potential in the realistic scenarios

BECCS deployment in the realistic scenarios focuses on large-scale bioenergy plants (>10 MW), which are more likely to integrate CCS due to economies of scale. Around 60 such thermoelectric plants are already operating (section 3.5.1) and these were assigned in order of proximity to their closest CO₂ storage hub, either Ravenna, Jonio (Calabria), or Gela (Sicily), only if they were under 300 km from the relevant storage site.

Two complementary strategies underpin BECCS deployment: **1. retrofitting existing plants**, prioritised by size and proximity to storage sites; and **2. developing new bioenergy capacity with CCS**, using the ~11 Mt/year residual biomass suitable for bioenergy. Of this additional biomass, around 2.2 Mt of wet biomass was allocated to biomethane with CCS, while 8.8 Mt of dry and waste biomass was allocated to combustion and gasification (including hydrogen production). This is aligned with official scenarios that indicate that Italy will produce 5-6 bcm of biomethane by 2030¹⁸, increasing to 8-10 bcm by 2050²⁴, and an expansion of hydrogen production expected to meet up to 2% of energy demand by 2030 (8-23 TWh) and rise to 74-139 TWh demand^{18,24}. Figure 24 shows the potential CDR from BECCS from retrofitting existing biomass reactors with CCS and from potential mobilisation of residual biomass towards new bioenergy reactors, under the same assumptions and capture efficiencies described in Annex A.2.

7.4.2 Allocation of CO₂ storage

Market interest for CO₂ storage from point-source CCS, BECCS, and DACCS can potentially drive Italy to fully characterise and activate new sites from depleted hydrocarbon fields and deep saline aquifers, matching and surpassing the capacities of the currently available Ravenna CCS Hub⁸⁴. Accounting for conservative discount factors, by 2050, geological storage projects could supply highly durable CO₂ storage of up to **14.4 MtCO₂/year** in the Conservative scenario, **44 MtCO₂/year** in the Reference scenario, and **74 MtCO₂/year** in the Ambitious scenario. Italy's Ravenna roadmap - 4 MtCO₂/year by 2030, 12 MtCO₂/year by 2035, and a 16-20 MtCO₂/year plateau through 2040-2050 - roughly aligns with the Conservative scenario and forms the foundation from which the Reference and Ambitious cases extend deployment to Jonio, Gela, and selected onshore sites. Nevertheless, market interest for storage amongst industrial and CDR players will require more sites to be characterised and activated before 2040, as industrial CCS alone will require over 27 and 34 MtCO₂ storage from 2030 and 2040 respectively, as per Snam market survey¹²⁷. Figure 25 shows how geological storage CO₂ is assumed to be allocated across CCS, BECCS and DACCS in the realistic scenarios.

Geological CO₂ storage allocation by 2050

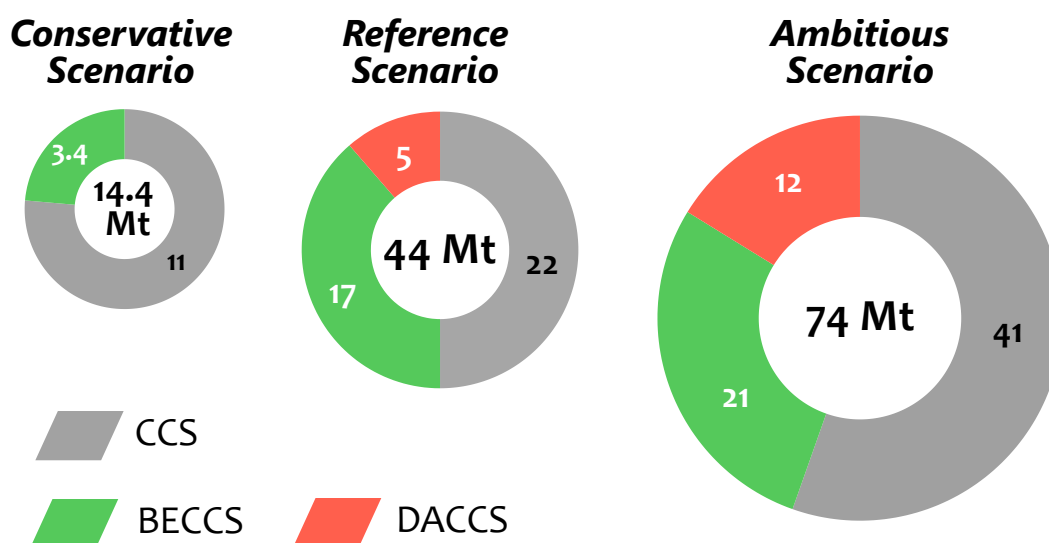


Figure 25. Allocation of geological CO₂ storage capacity in 2050 between CCS and CDR methods across the three realistic scenarios.

Geological CO₂ storage: estimating the total realistic potential

To determine how much geological storage can realistically be allocated to CCS and CDR, this study followed a multistep process. First, it derived a realistic CO₂ storage potential from the theoretical estimates presented in Chapter 3. Second, it discounted the portion of this potential required to meet projected CCS demand. Third, it allocated the remaining storage capacity across CDR methods, i.e. BECCS and DACCS.

First, the maximum available storage described in Chapter 3 was used to limit capacities in the different scenarios. Table 13 describes the potential projects, ranking them by level of difficulty depending on whether they are functional (low), proposed or studied (medium), or lacking data for

full characterisation (high). In the **Conservative scenario**, the lack of actual industry interest for CCS precludes the opening of new sites other than Ravenna. In the **Reference scenario**, the success of the Ravenna CCS hub and increasing interest from industry players lead to the opening of other studied storage sites in Jonio and Gela/Ragusa by 2040, as well as onshore Ravenna areas. In this scenario, two additional projects matching the Ravenna injection capacity are activated between 2040 and 2050 to fulfil the CCS interest from both point source CCS and CDR providers. In the **Ambitious scenario**, Italy invests heavily in CCS, including BECCS, DACCS, and point-source CCS with transport infrastructure, and fast-paced activation of additional storage in deep saline aquifers to deliver three times the Ravenna capacities.

Project difficulty	Project / Option	Max injectability (Mt/year)	Max Capacity (Mt)	Conservative Scenario	Reference Scenario	Ambitious Scenario
LOW: permitted	Ravenna CCS Hub	4 by 2030; 12 by 2035; 16-20 by 2040 onwards	515	515 Mt total 20 Mt/year 25 years	515 Mt total 20 Mt/year 25 years	
MEDIUM: plausible by 2040-2050 with timely permits	Jonio Hub (off-shore Ionian Sea)	4-5 (*)	130	Do not materialise	130 Mt total 5 Mt/year 26 years	
	Onshore Ravenna area	2-3 (*)	69		69 Mt total 3 Mt/year 23 years	
	Onshore Sicily (Gela/Ragusa)	1-1.5 (*)	35		35 Mt total 1.5 Mt/year 23 years	
HIGH: needs new exploration and/or cross-border arrangements	Residual unstudied hydrocarbon fields (HCF)	106.8 (*)	2,750	Do not materialise	1030 Mt total 40 Mt/year 25 years	
	Italian deep saline aquifers (Upper/Median/Lower Adriatic; other basins)	181.32 (*)	nearly 4.7 Gt at 2% storage efficiency		1779 Mt total 60 Mt/year 25 years	

Table 13. Potential CO₂ storage projects across all scenarios. (*) indicates an assumption of injection capacity equal to the Ravenna CCS hub.

Second, the potential injection capacities of each project were discounted using a Risk Adjustment Factor (RAF, detailed in Annex C.1) based on project difficulty, to provide a more realistic characterisation of how many projects will reach full commercial deployment compared to theoretical potentials. They were assumed to be 90% RAF for low-risk projects such as the Ravenna CCS hub; 65% for medium-risk ones; and 50% for high-risk sites that are not fully characterised. These discount factors are not precise representations of the risks for specific storage techniques or projects, but they provide a realistic buffer for the volumes estimated in each scenario. The chosen RAF values are described in Figure 26, estimated using data from ongoing or cancelled storage projects from both depleted hydrocarbon fields and deep saline aquifers around the world (Annex C.1).

In the **Conservative** scenario, the capacity of the Ravenna hub stores about **14 MtCO₂/year** in 2050 (compared to 16 in the theoretical potential). In the **Reference** scenario, in addition to the Ravenna hub, the inclusion by 2040 of medium-risk projects in onshore Ravenna, Jonio and Gela can collectively store around **44 MtCO₂/year** in 2050 (compared to 69.5 in the theoretical potential). In the **Ambitious scenario**, deep saline aquifers are activated and Italy can provide over **74 MtCO₂/year** of CO₂ storage by 2050 (compared to 129 in the theoretical potential). These values represent the total CO₂ geological storage potential; the next step is to allocate this capacity between CCS and CDR.

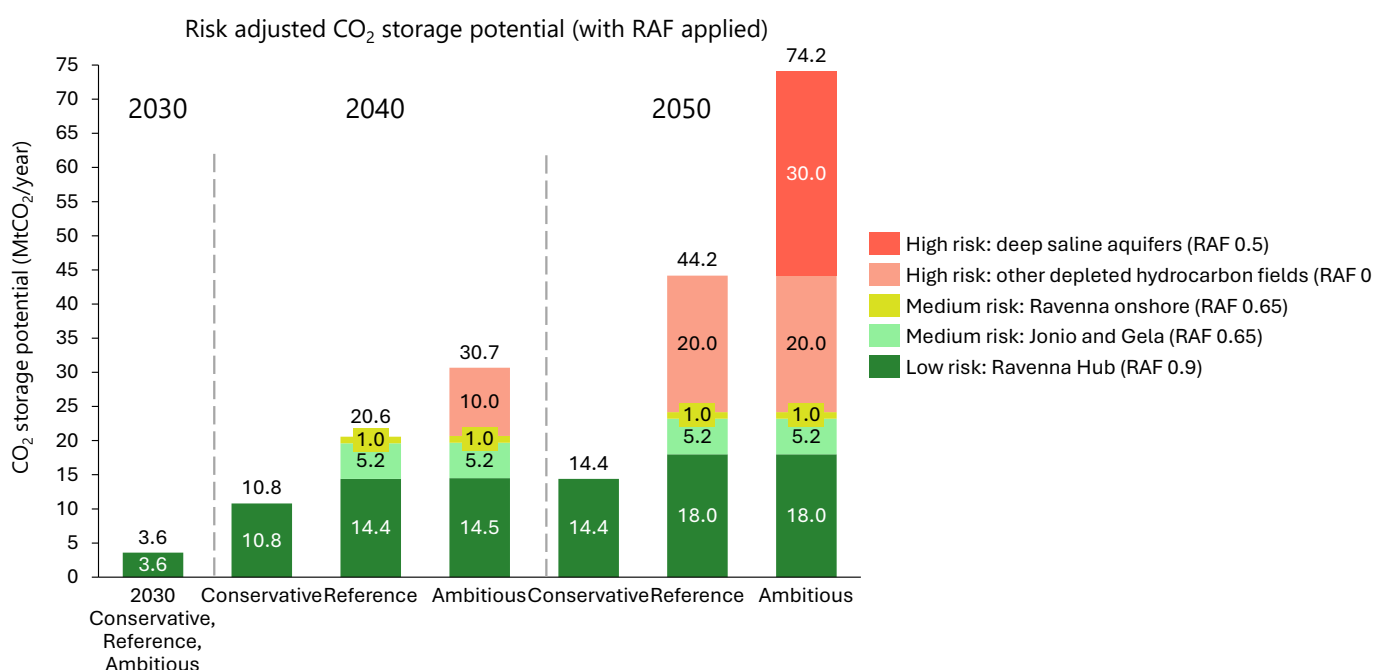


Figure 26. Risk-adjusted CO₂ storage potential (MtCO₂e/year). The risk adjustment factor (RAF) is applied on the theoretical CO₂ storage potential analysed in section 3.7.3

Geological CO₂ storage: allocating to CCS and CDR

To allocate CO₂ storage capacity to CCS and CDR in the realistic scenarios, this study started from the CCS market interest data from the Snam survey¹²⁷ (described in section 3.7) and projected them linearly to 2050, yielding an **estimated CCS demand of 41.3 Mt/year by 2050. This demand was then disaggregated by industry and region** and allocated to the main existing and potential storage hubs - Ravenna (32.2 Mt/year), Jonio (5.3 Mt/year), and Gela/Ragusa (3.8 Mt/year) - representing the theoretical distribution of point-source CCS by 2050, with Annex C.2 providing values for 2030 and 2040. **Realistic deployment is expected to be lower than this estimated theoretical demand because both storage performance and CCS project realisation are uncertain**, and RAF alone does not fully explain lower deployment outcomes. The Conservative and Reference scenarios therefore incorporate partial market uptake, delays in transport and storage infrastructure, and the likelihood that only a subset of announced industrial CCS projects will be in operation by 2050. **Realistic industrial market interest by 2050 for point-source CCS** and the allocation of the remaining CO₂ storage to CDR is therefore as follows:

- In the **Conservative scenario**, limited storage capacity lowers CCS interest. 11 MtCO₂/year of the demand indicated by the market survey is allocated to CCS. The remaining **3.4 Mt/year is allocated to CDR**.
- In the **Reference scenario**, actual market interest for industrial point-source CCS is around 22 MtCO₂/year in 2050, roughly half of the realistic storage capacity estimated above. The remaining **22 Mt/year are allocated to CDR**.
- In the **Ambitious scenario**, the acceleration of CO₂ storage development enables industry to deliver its full projected CCS contribution of 41 MtCO₂/year, **leaving 33 Mt/year for CDR**.

A key differentiating factor across scenarios is the allocation of storage capacity between CCS and CDR over time. In the **Conservative scenario**, storage is predominantly allocated to CCS between 2030 and 2040. After 2040, BECCS share rises to approximately 25% of CO₂ storage. In the **Ambitious scenarios**, improving technological and economic conditions for CDR lead to a gradual rebalancing. **The share of storage allocated to point-source CCS declines** from approximately 85% in 2030 to 65% in 2040 and 55% by 2050.

An important assumption of the proposed scenarios is that point-source CCS from industry continues to grow over time, but in the Reference and Ambitious scenario is outpaced by CDR deployment. While there is a good chance industry will gradually reduce emissions due to emerging low-carbon technologies, emissions from official estimates require increasing CCS to reach net-zero, which is therefore modelled as growing in line with expanding storage capacity.

Geological CO₂ storage: allocating to BECCS and DACCS

With the realistically available geological CO₂ storage for CDR now defined - after accounting for CCS requirements - the last step is to allocate this remaining storage capacity between the two relevant CDR pathways: BECCS and DACCS.

In this assessment, **geological storage has been prioritised for BECCS over DACCS**. This reflects Italy's substantial existing bioenergy base and the strong potential to integrate CDR into established systems. BECCS represents a viable nearterm option thanks to cobenefits such as supporting agricultural and forestry value chains, creating local jobs, and supplying lowcarbon heat or power. It is also likely to face fewer social barriers as it builds on existing bioenergy and wastetoenergy facilities making it appear less speculative and more aligned with local economic development, energy security, and hardtoabate decarbonisation needs.

After allocating storage to BECCS, **limited capacity remained for DACCS**, and only in the Reference and Ambitious scenarios. As shown previously in Figure 25, full utilisation of this residual storage would allow DACCS deployment of up to 5 MtCO₂/year in the Reference scenario and 12 MtCO₂/year in the Ambitious scenario by 2050.

To assess whether these storage-constrained deployment levels were sufficient, **the analysis also estimated DACCS needs from a demand-driven perspective**. Rather than relying solely on bottom-up assumptions about technological scale-up, this approach evaluated the volume of DACCS required to address residual hard-to-abate industrial emissions. Two complementary analytical methods were used to triangulate this estimate (see Annex C.3).

First, the assessment analysed industry interest in CO₂ capture and storage and evaluated the share of emissions that could be addressed through point-source CCS. For each industrial sector, projected CO₂ capture volumes for 2030, 2040, and 2050

(extrapolated) were derived from the Snam market survey¹²⁷. A review of case studies was then used to **determine the feasible split between emissions that could be captured at source and those that remained technically or economically unfeasible for point-source CCS**. These residual emissions were assigned to DACCS. Annex C.3 details the methodology and the resulting sectoral split.

This analysis suggested that, even if industry captured and stored 41.3 MtCO₂/year by 2050, **a portion of emissions will remain inherently hard to abate, and would therefore require removal via DACCS**. On average, around 14% of these emissions could not be addressed through point-source CCS and would therefore require removal via DACCS, corresponding to 6.07 MtCO₂/year. This

demand-driven estimate is consistent with the storage-constrained deployment levels identified above, indicating that the available geological storage would be sufficient to meet both BECCS prioritisation and residual DACCS needs in the Reference and Ambitious scenarios.

CO₂ storage through ex-situ mineralization

Ex-situ mineralization - the above-ground carbonation of alkaline solid materials in reactors - offers a geologically independent pathway for permanent CO₂ storage in Italy. As estimated in Chapter 4, the combined use of available olivine (1.72 MtCO₂/year), steel slag (0.25 MtCO₂/year), cement kiln dust (0.03 MtCO₂/year), and concrete demolition waste (0.12 MtCO₂/year), could enable up to **2.12 MtCO₂/year** of durable storage with this method. Even though in early development, Italy also has unusually strong domestic evidence for feasibility for this storage pathway: researchers have demonstrated accelerated aqueous carbonation of steel slag and CKD and have estimated a regional potential of **0.22–0.47 MtCO₂/year** in Lombardy alone¹⁰⁸.

Ex-situ mineralization is deployed in both the Reference and Ambitious scenarios, with scale determined by the extent to which Italy mobilises its industrial residues of steel slag, cement kiln dust, and concrete demolition waste. In the Reference scenario, deployment reaches 0.2 MtCO₂/year by 2050, reflecting partial utilisation of this resource base, with early uptake focused on more accessible industrial residues. As a result, ex-situ mineralization plays a supplementary role, providing modest but valuable geologically independent storage. In the Ambitious scenario, deployment scales to the estimated potential of about 0.4 MtCO₂/year by 2050, enabled by comprehensive utilisation of all

industrial residues. Olivine, which would be the major feedstock is excluded as it is already being used for enhanced rock weathering. This outcome assumes successful integration of industrial supply chains, improvements in process efficiency, and the establishment of robust MRV frameworks. Under these conditions, ex-situ mineralization becomes a useful complementary pathway, delivering durable storage while reducing reliance on constrained geological CO₂ injection capacity.

This additional storage capacity given by ex-situ mineralization is allocated to BECCS with anaerobic digestion, reflecting strong alignment in CO₂ stream characteristics, infrastructure, and regional integration. Anaerobic digestion provides a concentrated, biogenic CO₂ stream that can be readily utilised in mineralization without additional capture, improving overall system efficiency. This integration is further supported by proximity to industrial residues which are often co-located with AD facilities in agricultural and industrial clusters. Together, these factors support a cost-effective and scalable pathway, combining reliable CO₂ supply with a geologically independent storage option that complements constrained geological capacity.



7.5 A like-for-like net-zero pathway for Italy

For this study, longterm residual emissions were taken from the scenario of the Long-term Strategy (LTS), which projects **68–100 MtCO₂** per year in 2050, with a midpoint of **84 MtCO₂/year**. This range spans the LTS scenario family: the 68 Mt lower bound corresponds to the most ambitious trajectories (LTS C/Cs), where the power sector generates negative emissions (Gaeta et al., 2022), civil buildings are largely decarbonised through a 2%/year deep renovation rate, and aviation demand is contained through modal shift; the 100 Mt upper bound corresponds to LTS A, where fossil fuels with CCS continue in industry and aviation grows. The midpoint of 84 Mt is the arithmetic mean of this scenario family and aligns with the LTS B trajectory, the intermediate scenario in which gas replaces coal in steel production.

These residuals split into 27 MtCO₂ of biogenic emissions from agriculture and biogenicwaste sectors and 57 MtCO₂ of fossil emissions from industry, power, transport, and civil uses. The LTS was selected because it offers a credible route to net-zero while still leaving a substantial volume of emissions that must be neutralised through CDR. Other scenarios drawn from academia and industry can be found in Annex D.

The presented scenarios depend on coordinated CDR deployment and concrete emissionreduction commitments across all sectors. The economic, political, technological, and social design to make these scenarios a reality should comply with the like-for-like principle (Carbon Gap, 2025) which implies that removals should mirror the origin and lifespan of the emissions they address. Shortlived **biogenic emissions** can be paired with temporary, naturebased removals, while longlived **fossil emissions** (from industry, power and energy, fossil fuels, non-bio waste) require durable CDR such as BECCS, biochar, or DACCS. Complying with the like for-like principle means **both temporary and durable CDR methods must be scaled up in parallel** to match the corresponding biogenic and fossil emissions.

Italy's average residual emissions in 2050 are estimated at **84 MtCO₂/year**, with 57 MtCO₂ classified as **fossil**, and 27 MtCO₂ as **biogenic**. Figure 27 describes how the designed scenarios apply the *like-for-like* principle.

The **Reference scenario** assumes point-source CCS for 22 MtCO₂/year from industry (independent from CDR), lowering the residual fossil emissions

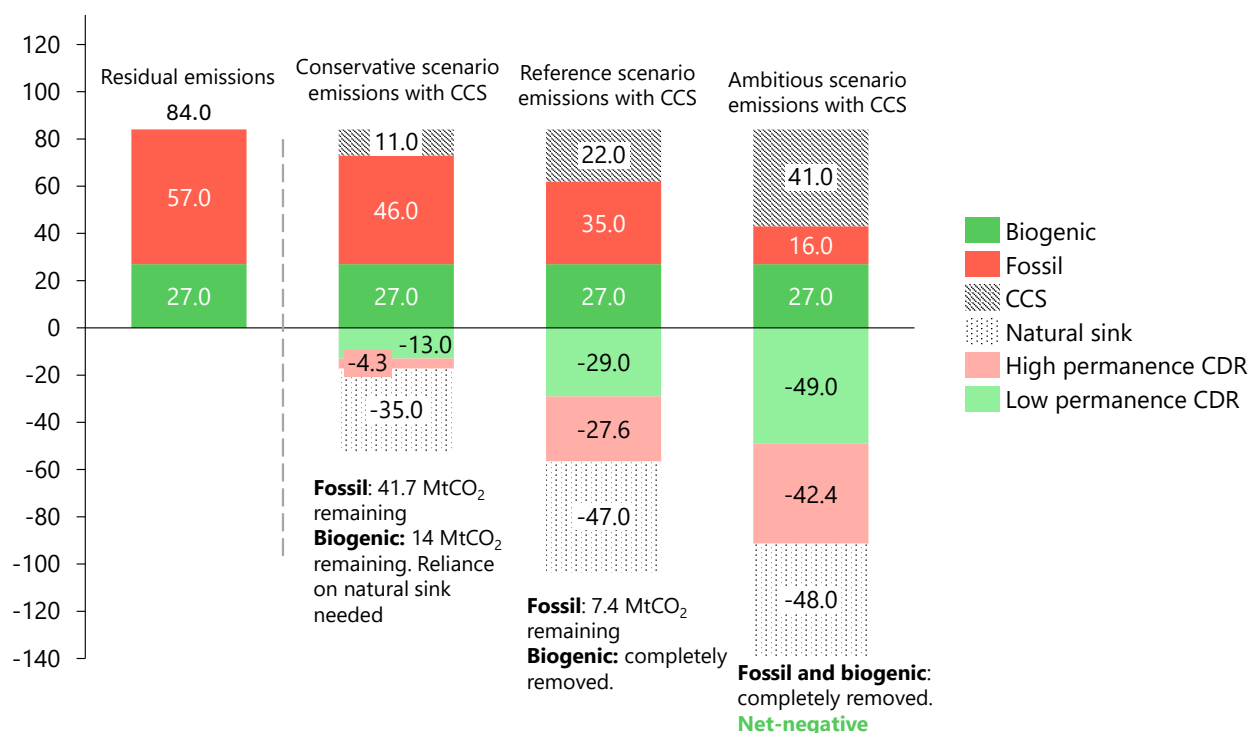


Figure 27. The like-for-like principle applied to the 2050 Conservative, Reference, and Ambitious scenarios. Biogenic emissions are completely removed by nature-based CDR methods without relying on the natural sink in the Reference and Ambitious scenarios. Fossil emissions are completely removed by highly permanent CDR methods only in the Ambitious scenario.

to 35 MtCO₂/year. These are *almost* fully removed through durable CDR methods (DACCS, BECCS, biochar OAE and ERW), by using the full remaining CO₂ storage capacity (after CCS allocation) estimated in the Reference scenario. Notably, even under the intense efforts to fulfil the **Reference scenario** CDR solutions, **7.4 MtCO₂ of fossil emissions remain**, highlighting the need for Italy to plan for scenarios that land between the Reference and the Ambitious ones described. Nature-based CDR methods, mainly bio-based products, agricultural, forest, and ecosystem management, can remove **29 MtCO₂/year**, 2 Mt more than is theoretically needed, and without relying on the expected forest sink (47 MtCO₂/year).

Assuming the emissions landscape remains constant with respect to the Reference scenario, the **Conservative scenario** not only falls short on 2030 *fit-for-55* targets, but also on net-zero by 2050. In this scenario, Italy could deploy **4.3 MtCO₂/year** of durable CDR methods and **11 MtCO₂/year** from point-source CCS by 2050, missing the like-for-like target by **41.7 MtCO₂/year**. Nature-based methods reach **13 MtCO₂/year** and require the expected **35 MtCO₂/year** from natural sinks to comply with the needed **27 MtCO₂/year** of biogenic emissions.

Conversely, in the **Ambitious scenario**, Italy exceeds *like-for-like* requirements, reducing **41 MtCO₂/year** through point source CCS, with additional durable removals of **42.4 MtCO₂/year** from engineered CDR by 2050. This is nearly double the removals needed to address the expected fossil emissions. A similar case can materialise for low-permanence nature-based methods by 2050, sequestering **97 MtCO₂/year (48 MtCO₂/year of which come from the natural sink)**, almost four times the needed capacity to remove biogenic emissions.

Collectively, the presented scenarios are in line with the *like-for-like* principle and reflect the societal appraisal for nature-based methods suggested by the citizens' panel, but also the need for clear deployment of a diversified portfolio of durable CDR alternatives. Point-source CCS paid by polluters is a critical part of the joint societal efforts to bring Italy to net-zero, and government efforts to promote an ample portfolio of methods are essential. A clear result from this analysis is that, to guarantee net-zero (even net-negative) in the future, Italy must focus its efforts to deliver the volumes and portfolio that land between the **Reference and Ambitious scenarios**.



7.6 Estimated costs of implementing the scenarios

The costs of deploying the proposed CDR portfolio vary across scenarios, reflecting differences in ambition, technology mix, and deployment timeline. Annex E presents cost ranges (€ per tCO₂) for each CDR method alongside projected removal volumes (MtCO₂) based on the realistic scenarios and their total deployment costs, drawing on average values from the current literature.

Please note that the cost estimates used in this estimation are projections for market prices of the CDR credits generated by different methods. They reflect the effort needed to support the deployment of the modelled portfolio, but the reader must understand that:

- The effort should and will be **distributed between private and public money**, through a diversity of voluntary and compliance mechanisms.

- The analysed costs do not include the necessary investments in the lead up to deployment to optimise the methods and reduce costs.

Indicative annual costs range from €0.4–1.9 billion by 2030 under the Conservative scenario, rising to €8.2–26 billion per year by 2050 under the Ambitious scenario (Table 10). To put this in perspective, the upper-bound 2050 figure represents approximately 1–1.2% of Italy's current GDP - comparable in order of magnitude to other major national energy expenditures²⁸⁹⁻²⁹⁰. Near-term costs through 2030 are modest and fall well within the range of current national infrastructure programmes. Crucially, these figures represent the upper bounds of current scenario projections and are sensitive to technology cost trajectories and deployment assumptions. The trajectory of durable CDR costs - particularly DACCS - is expected to decline substantially with technological maturation and economies of scale.²⁹¹⁻²⁹²

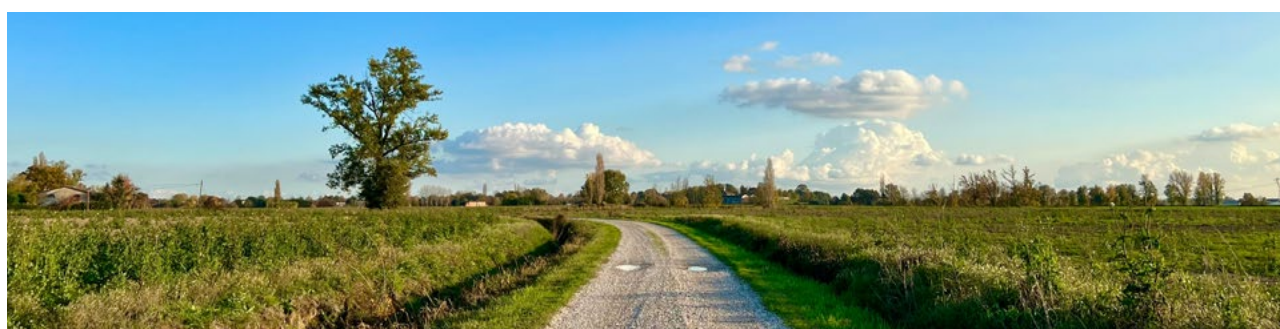
2030			2050		
Conservative	Reference	Ambitious	Conservative	Reference	Ambitious
0.4 to 1.9	0.8 to 3.0	1.1 to 3.8	0.5 to 2.8	4.0 to 15.1	8.2 to 26

Table 10. Indicative annual costs of deploying the scenarios, in € billion. See Annex E for the cost breakdown. Costs are subject to high uncertainty and will vary over time.

In the short term, expenses needed to support the deployment of modelled scenarios will differ by CDR method.

Land-based and hybrid approaches - including cropland management, agroforestry, biochar, and BECCS - are mature and ready to be scaled. They need credible and growing demand. These methods build domestic capacity, land management expertise, and supply chains that cannot be rapidly procured at a later stage, and many deliver co-benefits for biodiversity, soil health, and rural economies.

For technological CDR, and DACCS in particular, current costs remain high, and global learning curves are expected to drive significant reductions over the coming decades. **Italy's near-term priority for more novel CDR and DACCS should therefore be to support fast innovation with pilots, build regulatory frameworks, and deploy CO₂ transport and storage infrastructure** - investments that reduce lead times and position the country to scale deployment cost-effectively once the technology matures.



Conclusions

Italy stands at a crossroads. On one side lies a conservative path where CDR remains marginal, residual emissions of more than 50 MtCO₂/year persist past mid-century, and climate neutrality becomes an aspiration rather than an outcome. On the other lies a deliberate strategy that mobilises Italy's land, biomass, minerals, energy, and storage assets to deliver more than 100 MtCO₂/year of removals by 2050, closing the gap to net-zero and enabling a move toward net-negative emissions. This assessment shows that the second path is technically and socially feasible - but not automatic. It requires rapid, coordinated action from government, institutions, regions, industry, and civil society over the next decade.

1 Key conclusions on Italy's CDR potential

1.1 Italy's upper bound is high but not limitless.

Under physical and storage constraints, Italy's **theoretical CDR potential is 233 MtCO₂/year by 2050**, dominated by ecosystem management methods (116 MtCO₂/year), biomass conversion methods (78 MtCO₂/year), and synthetic methods, i.e. DACCS (33 MtCO₂/year), with a smaller contribution from geochemical methods (6 MtCO₂/year). This indicates that, on resources alone, Italy could more than counterbalance its projected residual emissions.

1.2 Realistic CDR pathways can meet or exceed Italy's residual emissions. By 2050, total carbon sinks (CDR and natural sinks) reach **53 MtCO₂/year** in the Conservative scenario, **104 MtCO₂/year** in the Reference scenario, and **139 MtCO₂/year** in the Ambitious scenario. Only the Reference and Ambitious pathways are compatible with closing the average **84 MtCO₂/year** residual-emissions gap implied by Italy's Long-Term Strategy; the Ambitious scenario further enables net-negative outcomes of between 40–70 MtCO₂/year.

1.3 Geological storage is the binding enabler.

Even with sufficient renewable electricity and waste-heat potentials, CO₂ injection capacity limits durable CDR. This assessment assumes a theoretical storage capacity of about 100 MtCO₂/year (98.5 MtCO₂/year geological plus 2.12 MtCO₂/year of mineralisation) as the long-term maximum, with realistic pathways delivering 14.4, 44, and 74 MtCO₂/year of annual geological CO₂ storage by 2050 in

the Conservative, Reference, and Ambitious scenarios, respectively. Without timely appraisal and permitting of additional sites beyond Ravenna, Italy cannot unlock BECCS and DACCS at scale.

1.4 Land and agriculture are Italy's near-term backbone for CDR.

Across scenarios, managed land and agricultural practices provide **half or more** of total CDR by 2050. Forest and ecosystem management alone have a theoretical potential of 35 MtCO₂/year, while soil-carbon, agroforestry, and cropland management together contribute around 81 MtCO₂/year in the theoretical case and 10–48 MtCO₂/year in realistic scenarios. The wide range of removals available from the LULUCF sector is heavily dependent on the adoption and maintenance of key policies such as the CAP and other nature conservation directives of the EU. Maintenance and continuous growth of CDR-promoting methods in agriculture and grassland management will play a paramount role across all scenarios with a crucial difference being the large increase in forest fires and the failure to manage them.

1.5 Biomass conversion can realistically deliver 23–30 MtCO₂/year under plausible policies.

With current and additional biomass streams, BECCS, biochar, and long-lived biobased products can sequester 23 MtCO₂/year in the Reference scenario and up to 30 MtCO₂/year in the Ambitious scenario by 2050, compared with only 5 MtCO₂/year in the Conservative scenario. The difference hinges on retrofitting existing bioenergy plants with CCS; aiding the intended biomethane and green hydrogen production with CCS with residual biomass; and using residues for durable products and biochar instead of low-value combustion. The diversity of biomass resources in Italy is already a well-utilised resource with nearly 3,000 biomass reactors, a well-established residual Hard Wood Products (HWP) industry, and a growing social awareness on the importance of circularity. BECCS is the main contributor, building on Italy's existing bioenergy facilities and expanding through new capacity across biomethane production and biomass gasification with CCS, in line with the national Long-term Strategy projected energy transition.

1.6 Synthetic and geochemical methods are small today but strategic by 2050. Under realistic constraints, DACCS contributes modestly - 5 MtCO₂/year in the Reference scenario and 12 MtCO₂/year in the Ambitious scenario - yet becomes crucial for residual industrial and process emissions that are hard to abate by other means. ERW and OAE add a further 0.5 MtCO₂/year in the Reference scenario and 1.8 MtCO₂/year in the Ambitious one, once CRCF methodologies are in place and mineral resources (basalt, olivine, limestone) are fully mobilised.

1.7 Timing matters: 2030 and 2040 are decisive waypoints. In the Ambitious scenario, total carbon sinks (CDR and natural sinks) already reaches 80 MtCO₂/year by 2030 and 116 MtCO₂/year by 2040, front-loading deployment in line with the Paris temperature goals. Delayed action pushes Italy into the conservative trajectory, where CDR stagnates near 50 MtCO₂/year, making climate neutrality unattainable without last-minute, costly and risky overshoot strategies.



2 Readiness gaps: policy, institutions, and social license

2.1 Policy architecture is fragmented and lacks a CDR backbone. CDR is referenced across the PNIEC 2024, ISPRA projections, the Long-Term Strategy, and sectoral plans, but there is no dedicated national CDR strategy, no quantitative and method-specific CDR milestones for 2030–2040, and no explicit integration of the CRCF's removal categories into domestic law. As a result, Italy risks underutilizing a theoretical CDR potential of 233 MtCO₂/year.

2.2 MRV and certification remain the weakest links. Several methods - biochar, ERW, OAE, product storage, and DACCS - depend on robust MRV aligned with the CRCF. Without bankable methodologies, Italy cannot credibly scale beyond **10–20 MtCO₂/yr** from these methods, even though combined potentials exceed **40 MtCO₂/yr** in 2050.

2.3 Social support is conditional and uneven. Citizen-panel results show strong support for nature-based methods, biochar, and mineralization, but persistent scepticism toward offshore storage and large DAC/OAE projects. Support improves when costs are borne by polluters, when local co-benefits are visible, and when communities share in revenues. Failure to address these concerns would limit CDR deployment to the conservative range, despite higher technical and economic potential.

2.4 Human and administrative capacity lag behind needs. "Green jobs" already account for about 3.1 million positions (13.4% of employment), yet over half of green-skills vacancies are hard to fill. At the same time, regional authorities struggle with permitting for wind, PV, and CCS, and lack specialized staff for CDR project evaluation and MRV. Without a skills and institutional-capacity plan aligned to a >100 MtCO₂/year CDR system, Italy risks bottlenecks even where capital and technology are available.

2.5 Territorial constraints require careful spatial planning, not avoidance. Protected areas cover 21–25% of national territory and urban/artificial surfaces around 7–8%, while wildfire-prone regions in the south regularly see tens of thousands of hectares burned each year. These constraints do not preclude CDR but require spatially explicit planning to locate DACCS and BECCS in industrial clusters and ports, deploy land-based CDR in resilient landscapes, and avoid public demotivation towards these methods.

3 Priority actions for stakeholders

To translate this assessment into a credible roadmap, stakeholders should treat the Reference and Ambitious scenarios not as distant possibilities but as planning baselines. At least half of the following actions must be launched or firmly decided before 2030 if Italy is to approach 100–150 MtCO₂/yr of removals by mid-century:

- **Build and adopt a national CDR strategy with quantitative milestones.** Parliament and government should enshrine intermediate CDR targets consistent with the Reference/Ambitious pathways—e.g. on the order of 40–60 MtCO₂/yr by 2040 and ≥100 MtCO₂/yr by 2050—clarifying the expected contributions of LULUCF, biomass conversion, geochemical methods, and DACCS.
- **Lock in CO₂ storage as a strategic asset.** MASE and relevant agencies and industries must move from a single-hub model (Ravenna, up to 20 MtCO₂/yr) to a national network capable of 45–75 MtCO₂/yr injection by 2050, fast-tracking appraisal of Ionian, Sicilian, and onshore saline formations, and aligning CO₂ pipeline planning with industrial clusters and ports.
- **Make CAP and nature-restoration spending CDR-smart.** The difference between 10 MtCO₂/yr (Conservative) and 30–48 MtCO₂/yr (Reference/Ambitious) from agriculture and ecosystem management hinges on how Italy uses CAP eco-schemes and Nature Restoration Law funding. Redirecting and simplifying these instruments to favour food-systems, soil-carbon health, agroforestry, seagrass, wetlands, and peatlands is one of the most cost-effective ways to scale removals this decade.
- **Create clear, bankable MRV frameworks for priority methods.** Italy should prioritize early CRCF-aligned methodologies for biochar, ERW, OAE, and long-lived products, so that at least 10–15 MtCO₂/yr of these removals can be certified and traded by 2040, rising toward the 30–40 MtCO₂/yr potentials identified in this study.
- **Use public procurement and standards to pull CDR into markets.** Building codes, public tenders, and infrastructure standards can make timber and biobased products, cement with captured CO₂, and low-carbon materials mainstream. Even modest requirements in public construction—say, 20–30% of new floor area in timber/hybrid structures—could unlock demand for 1–2 MtCO₂/yr of product-storage removals by 2030 and much more thereafter.

- **De-risk early BECCS and DACCS projects.** A first wave of 3–5 flagship projects by 2030—e.g. BECCS retrofits on existing bioenergy plants near industrial clusters—would prove feasibility, anchor CO₂ infrastructure, and provide real-world cost and MRV data, paving the way for the 25–35 MtCO₂/yr from biomass conversion and 5–16 MtCO₂/yr from DACCS in 2050.
- **Build social licence through co-ownership and benefit-sharing.** Regional governments and municipalities, especially in the Mezzogiorno, should explore co-ownership models, local revenue-sharing, and dedicated job programs tied to CDR projects. Aligning even a few thousand long-term jobs with CDR clusters could transform public perception from “imposed projects” to valued local industries.
- **Invest in skills, research, and coordination.** Universities, vocational institutes, and industry should coordinate to ensure that Italy’s projected 880,000+ EU-wide green jobs by 2030 translate into a skilled workforce for CDR design, operation, and MRV at home. A national CDR coordination body could bridge ministries, regions, regulators, and research institutions, preventing the siloed governance that currently slows action.

Collectively, the Carbon Removal Readiness Assessment for Italy shows that the country can credibly plan for over 100 MtCO₂/year of high-quality removals by mid-century, provided it treats CDR as a strategic pillar of its climate policy rather than a residual add-on. The physical resources, technical options, and societal awareness are already present. What is missing—and urgently needed—is an integrated political decision to move from fragmented pilots to a coherent, just, and durable CDR system that supports, rather than substitutes, rapid emissions cuts.



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Annex A. Biomass additional data

A.1 Total biomass breakdown and residual biomass for CDR

Italy has a rich biomass landscape from many sources. The main types produced by different sectors annually in Italy are described in Table A.1 below. These were extracted from diverse sources (see caption) and classified as agricultural residue, livestock manure, municipal waste, agri-food industry co-products, forest biomass, and harvested wood and energy crops residues, totalling **120.5 Mt** produced yearly. Most residual biomass is used in Italy for priority uses

such as bioenergy, compost, fertilising and hard-wood products. These priority uses and other constraints were deducted to estimate the recoverable portion available for CDR. After deducting 33.99 Mt already used for bioenergy, 43.83 Mt in bioproducts, and 14.73 Mt subject to physical or logistical constraints, 27.99 Mt/year remains potentially recoverable for CDR, equivalent to approximately 23% of total production.

Type of Biomass	Estimated Mass (Mt/ year dry)	Subtotal	Constraints, Priority uses	Bioenergy uses (MtDM/yr)	Bioproducts (MtDM/yr)	Losses from constraints	Recoverable portion for CDR
Forestry biomass							
Forest harvesting residues ^{1,2}	34.4	54.31	Operational constraints: limited access, biodiversity conservation priorities, fire mitigation protocols, and soil retention demands.	15.66	17.24	4.94	16.47
Hedgerows & agroforestry ^{1,8}	11.81						
Heavy forest residues (stumps, branches) ^{1,8}	1.1						
Sawmill residues ^{1,2,8}	7						
Agricultural residues							
Cereal straw ^{2,3,4}	15.12	36.89	30-40% of straw and pruning remain in fields for mulching. 25% is used for bioenergy ^{2,3,4}	8.58	13.15	7.88	7.28
Dedicated fibre/perfumery crops ¹	9.1						
Field crop residual wood ⁴	1.563						
Herbaceous residues (e.g. corn stalks, sunflower) ²	6.2						
Orchard & vineyard pruning ^{4, 5}	4.906						
Municipal waste							
Green urban waste ^{6,7}	1.4	15.9	Only 30% of solid biomass is recoverable due to separate collection inefficiencies and pre-treatment needs. Used oils and paper are mostly recycled ^{6,7}	5.9	8.53	0.27	1.2
Used edible oils ^{6,7}	7.1						
Paper/ cardboard ^{6,7}	3.54						
Wood waste ^{6,7}	1.34						
Sewage sludge ^{6,7}	0.32						
Organic household waste ^{6,7}	2.2						

Type of Biomass	Estimated Mass (Mt/year dry)	Subtotal	Constraints, Priority uses	Bioenergy uses (MtDM/yr)	Bioproducts (MtDM/yr)	Losses from constraints	Recoverable portion for CDR
Livestock manure							
Total livestock manure ^{3,10}	8.7	8.7	Only 30-40% of dry manure can be centrally processed, due to local reuse (fertiliser) and logistical issues ^{3,7,10}	2.54	3.11	1.31	1.74
Harvested forest wood and energy crops							
Harvested forest wood ^{1,2,8}	0.07	3.18	Most biomass is used for wood products, combustion, animal bedding and/or biogas ^{1,2,8}	0.66	1.11	0.26	1.15
Short rotation coppice (poplar and willow) ^{1,2,8}	2.76						
Energy crops (perennial grasses, miscanthus, switchgrass) ¹	0.35						
Agrifood industry co-products							
Olive pomace (sansa) ⁵	0.302	1.55	25% of residues (e.g. olive pomace) required for compost/feed/byproducts reuse ^{1,3,5,6,9}	0.65	0.69	0.07	0.15
Grape marc (pomace) ^{3,5}	0.001						
Citrus pulp (fruit/veg) ⁵	0.824						
Sugar beet residues ^{1,2}	0.001						
Potato processing residues ^{1,2}	0.424						
Meat & egg industry waste ^{1,2}	0.001						
Fish & aquaculture waste ^{1,2}	0.001						
Total	120.533			33.99	43.83	14.73	27.99

Table A.1. Categories, types of available biomass, and realistic biomass availability for CDR after constraints and priority uses. Sampling year and reference in superscripts: 1. *S2Biom-2016*²⁴¹, 2. *ENEA-04-2021*⁷⁸, 3. *Giocoli et al., 2025*²⁴², 4. *Ugolini et al., 2022*²⁴³, 5. *Ruggeri et al., 2025*⁷⁹, 6. *ISPRA-2023*²⁴⁴, 7. *ISPRA-2024*²⁴⁵, 8. *FAO Forests-2020*⁸¹, 9. *Demichelis et al., 2025*²⁴⁶, 10. *Scarlat et al., 2018*²⁴⁷.

A.2 Biomass feedstock used in existing bioenergy reactors

Active biomass reactors in Italy use **33.3 Mt** of biomass each year to generate nearly **129.32 TWh** of heat and electricity. Based on the assumptions outlined in this annex, BECCS applied to these facilities could capture around **49 MtCO₂ each year** – mostly from combustion processes (about 46.6 MtCO₂), with a smaller share (around 1.9 MtCO₂) from anaerobic digestion and fermentation. Table A.2 summarises reactors types, energy outputs, and biomass feedstocks based on GSE-2021^{82,83}.

To estimate how much biomass is required for each process, the reported energy output is converted back into fuel use. This is done by accounting for two factors: 1. the lower heating value (LHV), which measures how much final energy is contained in the fuel, and 2. the conversion efficiency, which reflects how efficiently each technology converts fuel into useful energy. For heat and transport, no efficiency adjustment is applied, as reported values (GSE-2021) already represent fuel consumption on an LHV basis. Meanwhile, for electricity generation, typical efficiencies are assumed: 25% for steam-cycle plants (solid biomass) and for incinerators and electricity production^{248,249} (biogenic municipal

solid waste), 38% for electric-only biogas CHP plants²⁵⁰, and 40% for bioliquids. Fuel properties follow standard values from the IPCC⁷: solid biomass (e.g. wood, residues): 17 GJ/t (dry basis LHV); biogenic municipal solid waste (MSW): 10 GJ/t (midpoint of reported 8–12 GJ/t range); biogas: 20 GJ/t, assuming a 60% methane composition; bioliquids (e.g. vegetable oils, biodiesel): 37 GJ/t.

The CDR removal potential from BECCS is calculated by combining the standard emission factors per unit of energy with the LHV of each biofuel and then apply a realistic 90% capture rate. For solid biomass, the IPCC⁷ default emission factor for wood-type fuels is 110 kg CO₂ per GJ, combined with a LHV of 18.5 GJ/t for wood, times 90% capture rate yields a factor of 1.83 tCO₂ per ton of dry biomass (its inverse is 0.55 tDM/tCO₂). Similarly, using the 2023 Climate Registry Default Emissions Factors²⁵¹, the emissions per GJ of energy were transformed into biomass basis. These result in conversion factors for MSW biomass (1.30 tDM/tCO₂), biogas (captured methane, 1.11 t/tCO₂), and Biomethane (1.23 t/tCO₂, 0.4t gas), which was treated like natural gas, with IPCC/IEA emissions of 56 kgCO₂/GJ.

Fuel / feedstock	Bioenergy process	Final energy used (TWh/y)	LHV (GJ/t, dry)	Conversion efficiency (%)	Estimated biomass use (Mt/y, dry)	Conversion factor (t/tCO ₂)	BECCS CDR (at 90% capture) (MtCO ₂ /y)
Electricity							
Solid biomass	Direct combustion (steam boiler and steam turbine CHP/condensing)	4.49	17	25%	3.8	0.55	6.96
Biogenic waste (biodegradable fraction of MSW)	Direct combustion (waste-to-energy with steam cycle)	3.49	10	25%	5.03	1.3	3.87
Biogas (from AD of manures, agro-residues, OFMSW, sewage, etc.)	AD/fermentation plus combustion in gas engines / turbines	2.41	20	38%	1.14	1.11	1.03
Bioliquids (vegetable oils, FAME, etc.)	Direct combustion (diesel-type engines / turbines)	4.11	37	40%	1	0.41	2.45

Fuel / feedstock	Bioenergy process	Final energy used (TWh/y)	LHV (GJ/t, dry)	Conversion efficiency (%)	Estimated biomass use (Mt/y, dry)	Conversion factor (t/tCO ₂)	BECCS CDR (at 90% capture) (MtCO ₂ /y)
Heat							
Solid biomass	Direct combustion in boilers, stoves, district heating (plus CHP heat)	83.28	17	1	17.64	0.55	32.27
Biogenic waste (biodegradable MSW)	Direct combustion with heat recovery (district heating / industrial use)	3.29	10	1	1.18	1.3	0.91
Biogas	AD/fermentation plus combustion in boilers / CHP heat	9.72	20	1	1.75	1.11	1.58
Bioliqids (heat)	Direct combustion in boilers / CHP heat	0.47	37	1	0.05	0.41	0.11
Biofuels							
Biodiesel	Direct combustion (compression-ignition engines)	16.15	37.5	1	1.55		Transport biofuels are excluded from the BECCS potential because combustion occurs in dispersed mobile sources
Bio-ETBE (renewable ethanol share only)	Fermentation-derived fuel (ethanol → ETBE), combusted in SI engines	0.31	26.8	1	0.04		
Biomethane	AD/fermentation → upgrading to biomethane → combustion in engines	1.59	50	1	0.11		
Total		129.32			33.3		49.18

Table A.2. Current biomass reactor capacities and biomass feedstock use. Biomass inputs are back-calculated from energy outputs. The BECCS potential of existing biomass reactors is calculated for each energy process. Emissions from transport fuels were not considered as CO₂ capture was assumed to be performed on stack.

A.3 Biomass allocation in the theoretical CDR potential

Table A.3 details the allocation of Italy's residual biomass available across CDR methods: up to **10.08 Mt** for biochar, **6.88 Mt** for durable biobased products, and **8.84 Mt** for BECCS with combustion and **2.21 Mt** for BECCS with anaerobic digestion. It shows how the 27.99 Mt of residual biomass identified in Table

A.1 is allocated across CDR pathways in the theoretical potential. Feedstock properties drive the allocation: wet biomass (manure, sludge) goes to anaerobic digestion; dry fibrous biomass to combustion BECCS or biochar; woody residues are distributed across all three pathways.

Type of Biomass	Estimated Mass (MtDM/year)	Recoverable portion for CDR (Mt/year)	Recovered for Biochar (Mt/year)	Recovered for bioproducts (Mt/year)	Recovered for BECCS combustion (Mt/year)	Recovered for BECCS AD (Mt/year)	BECCS conversion factor (tDM/tCO ₂)	Potential BECCS from residual biomass (MtCO ₂)
Forestry Biomass	54.31	16.48	5.68	5.1	5.7			10.44
Forest harvesting residues	11.81	1.17	0.58	0	0.59	0	0.55	1.08
Hedgerows & agroforestry	1.10	0.40	0.13	0.13	0.14			0.26
Expanded forest residues (stumps, branches)	34.40	12.39	4.13	4.13	4.13			7.56
Sawmill residues	7.00	2.52	0.84	0.84	0.84			1.54
Agricultural Residues	36.89	7.27	3.81	0.79	2.69			4.93
Cereal straw	15.12	1.92	0.96	0	0.96	0	0.55	1.76
Orchard & vineyard pruning	9.10	1.69	1.01		0.68			1.24
Field crop residual wood	1.56	0.62	0.32		0.32			0.59
Herbaceous residues (e.g. corn stalks, sunflower)	6.20	1.45	0.72		0.73			1.34
Dedicated fibre/perfumery crops	4.91	1.59	0.80	0.79	0			0
Municipal Waste	15.9	1.2	0.15	0.61	0.06	0.38		0.44
Green urban waste	1.40	0.15	0	0.07	0.00	0.08	1.12	0.07
Used edible oils	7.10	0.01		0	0.01	0	0.41	0.02
Paper/cardboard	3.54	0.25		0.25	0		0.55	0
Wood waste	1.34	0.24		0.19	0.05			0.09
Sewage sludge	0.32	0.29	0.15	0	0	0.14	1.12	0.12
Organic household waste	2.20	0.26	0	0.10		0.16		0.14

Type of Biomass	Estimated Mass (MtDM/year)	Recoverable portion for CDR (Mt/year)	Recovered for Biochar (Mt/year)	Recovered for bioproducts (Mt/year)	Recovered for BECCS combustion (Mt/year)	Recovered for BECCS AD (Mt/year)	BECCS conversion factor (tDM/tCO ₂)	Potential BECCS from residual biomass (MtCO ₂)
Livestock Manure	8.7	1.74				1.74		1.55
Total livestock manure	8.7	1.74	0	0	0	1.74	1.12	1.55
Harvested forest wood and energy crops	3.18	1.15	0.38	0.38	0.39			0.17
Harvested forest wood	2.76	0.99	0.33	0.33	0.33	0	0.55	0.60
Short rotation coppice (poplar and willow)	0.35	0.13	0.04	0.04	0.05			0.09
Energy crops (perennial grasses, miscanthus, switchgrass)	0.07	0.03	0.01	0.01	0.01			0.02
Agri-Food Industry Co-Products	1.54	0.15	0.06			0.09		0.09
Olive pomace (sansa)	0.42	0.04	0.02	0	0	0.02	1.12	0.02
Grape marc (pomace)	0.82	0.08	0.04			0.04		0.04
Citrus pulp (fruit/veg)	0.30	0.03	0			0.03		0.03
Totals	120.53	27.99	10.08	6.88	8.84	2.21		
			Total BECCS potential from residual biomass					18.15
				Of which, combustion				16.18
					And anaerobic digestion			1.97

Table A.3. Theoretical biomass allocation to CDR methods and **BECCS potential from residual biomass** (excluding BECCS theoretical potential from existing biomass reactors, which is estimated as an additional 49 MtCO₂/year).

Annex B. Summary of detailed assumptions of the realistic CDR scenarios

CDR method	Conservative	Reference	Ambitious
Afforestation, reforestation	Delayed payments and permitting result in the afforestation of only 6 kha.	From 2030 onwards, afforestation/reforestation efforts are supported by a responsible allocation of SR funds (80% used) which enables monitored afforestation on 10% of the projected forest area (0.14 Mha).	Enhanced and optimally distributed funding from SRA ²²⁰ and SRD ²¹⁹ measures (increased by 300%), guarantee that half of the projected growth (0.7Mha) and conversion of forest land is monitored and certified.
Certified forest management	Delayed payments and permitting limit forest certification to only the current 75 kha of applied projects.	The use of already planned CAP funding (SRA27-31 ²²⁰) supports the certification of newly established forests, in addition to the existing 1.2 Mha already under certification.	
Agroforestry	Agroforestry is conservatively increased to match half of the Reference scenario's capacity.	Increased funding from measures such as SRD05 and SRA28, increasing by 100 kha every 10 years.	Expansion and sustained maintenance of 400 kha of agroforestry.
Agricultural practices (soil carbon sequestration: cropland and pasture management))	Clear decline in the effectiveness of the CAP, with farmers slowly abandoning certain CDR-promoting practices. CAP ES 2, 4, and 5 show a regression of 70%, 60%, and 50% in 2030, 2040, and 2050 respectively.	Enhancement and maintenance of CAP and pillar II incentives for soil carbon sequestration (e.g. ES4 reaching up to 60% land coverage). In parallel, a 50% increase in pollinator strips and hedgerows expands coverage to 40% of available land surroundings. Plant cover for orchards is expanded through ES2, increasing by 0.25 Mha every 10 years to reach 1.5 Mha coverage (40% of total orchards area). Expansion of conservation and rotational grazing is tripled - especially in constrained mountain areas - compared to the 200 kha supported under SRB01-03 ²²¹ , which in 2024 reported used only 10% of its available budget.	ES2 and ES4 under the CAP are further expanded to cover up to 5 Mha of arable land (around 70%) with soil carbon sequestration practices, and 2.6 Mha of orchards (70%) with permanent plant cover. Grasslands reach 2 Mha (55%) under conservation and rotational grazing practices.
Peatland and wetland restoration	No clear action is taken to restore peatlands, except the rewetting of the Po-Valley Ramsar site (1,500 ha).	From 2040, 50 kha of the already lost Posidonia oceanica is restored, alongside 74 kha of endangered wetlands and 75 kha of peatlands, thanks to the support funds. In this scenario there is a 3x increase to cover constrained mountain areas under this method. of EU funds (e.g. LIFE, EMFAF 2021-27 and Interreg projects), as well as prompt national action according to the new EU Nature Restoration Law.	
Coastal revegetation	50% of already lost Posidonia is restored through already funded projects.		

CDR method	Conservative	Reference	Ambitious
Durable bio-based products	Deployment is assumed to remain constrained by a limited range of products eligible for storage credits, uneven regional uptake, and the continued preference for conventional materials (e.g. mineral/steel solutions) where cost outweighs embodied carbon. As a result, the supporting ecosystem (e.g. design capacity, certification, and end-of-life logistics) develops gradually, leaving part of the eligible biomass underutilised. The use of residual biomass increases slowly, reaching 0.7 Mt by 2030, 1.7 Mt by 2040, and 3.5 Mt by 2050.	Supported by product-storage certification under the CRCF, a mature and bankable market for durable bio-based products expands to use nearly 4 Mt of available fibres and wood residues by 2050 (1.5 Mt by 2030 and 3 Mt by 2040). These are primarily used in timber construction and cellulose-based insulation.	A well-developed and scalable supply chain enables the widespread use of bio-based products, maximising carbon storage in buildings while making efficient use of biomass and staying within sustainability limits. Standardisation, performance guarantees, and improved design for moisture and fire risks increase confidence among insurers and lenders, while streamlined permitting accelerates deployment. As a result, up to 80% of the available 6.6 Mt of wood, paper, and fibre residues is utilised.
Biochar	Biochar reaches just 10% of its 10 Mt residue potential (1 Mt) per year, due to limited long-term evidence on benefits, low public support, and the absence of clear incentives and user-friendly MRV systems. A conservative conversion factor of 0.8 tons of CO ₂ sequestered per ton of biomass ²²² was applied.	A strengthened CAP focused on soil restoration and sustainable food systems enables Italy's biochar market to grow in line with global trends. This allows for the mobilisation of around 60% of the ~10 Mt of biomass suitable for pyrolysis and gasification. As a result, biomass use for biochar increases progressively to 2 Mt by 2030, 4.5 Mt by 2040, and 6 Mt by 2050. Through pyrolysis, roughly one-third of the biomass is converted into stable biochar, with the remainder released as gases and bio-oil, resulting in about 2.1 Mt of biochar by 2050. A conservative conversion factor of 0.8 tons of CO ₂ sequestered per ton of biomass ²²² was applied.	Targeted incentives (similar to those under the CAP) support soil restoration through biochar, reinforced by the CRCF which unlocks institutional demand beyond voluntary markets. Biochar markets grow rapidly, exceeding a 14% CAGR by 2030, driven by increased agricultural demand to restore degraded soils and improve productivity. Biomass use scales from 3 Mt by 2030 to 6 Mt by 2040 and over 8 Mt by 2050, with a production of 2.8 Mt of biochar. A conservative conversion factor of 0.8 tons of CO ₂ sequestered per ton of biomass ²²² was applied.
BECCS (overall)	Only 3.4 MtCO ₂ /year of CO ₂ storage capacity is allocated to BECCS after accounting for the capacity prioritised for point-source CCS (11 MtCO ₂ /year).	17 MtCO ₂ /year of CO ₂ storage capacity is allocated to BECCS after accounting for the capacity prioritised for point-source CCS (22 MtCO ₂ /year).	22 MtCO ₂ /year of CO ₂ storage capacity is allocated to BECCS after accounting for the capacity prioritised for point-source CCS (41 MtCO ₂ /year).

CDR method	Conservative	Reference	Ambitious
BECCS (combustion)	Only a small number of existing combustion-based biomass plants near the Ravenna CCS Hub install CCS, increasing from 3 out of 40 reactors by 2030 to just 5 by 2040 and 2050. The scale up of BECCS (combustion and gasification) is further constrained by weak policy support for new gasification plants that could use residual biomass. As a result, only 10-15% of residual solid and waste biomass is directed to these BECCS pathways, while the majority is directed to conventional bioenergy reactors without CCS. Limited deployment of BECCS gasification yields just 0.4 TWh of hydrogen, implying a continued reliance on electrolysis to meet future hydrogen demand.	By 2030, only 3 out of the 40 existing reactors above 10 MW near Ravenna install CCS, while by 2040 these rise to 8 reactors storing CO₂ in Ravenna, one in Jonio, and one in Gela. By 2050, around 50% of eligible plants are equipped with CCS (20 near Ravenna, 7 near Jonio, and 3 near Gela). In parallel, the residual biomass suitable for thermochemical conversion (8.84 Mt) is mobilised for new BECCS (combustion and gasification) plants. Of this, 70% is allocated to new thermoelectric plants, and 30% is allocated to gasification (for hydrogen production). Deployment reaches 20% by 2040 and 60% by 2050, generating up to 5.1 TWh of potential flexible energy in the form of hydrogen.	By 2030, 3 out of the 40 existing reactors above 10 MW near Ravenna install CCS, while by 2040 these rise to 10 reactors storing CO₂ in Ravenna, 2 in Jonio, and 3 in Gela. By 2050, these numbers scale to 30 reactors for Ravenna, 12 for Jonio, and 3 maintained for Gela, covering 75% of the available reactors above 10 MW, all within a 300 km range from a storage hub. Gasification accounts for the majority of residual biomass use, with 60% allocated to gasification and 40% to new thermoelectric plants, all equipped with CCS. Biomass mobilisation increases from 20% by 2040 to 80% by 2050, generating over 14 TWh of hydrogen.
BECCS (anaerobic digestion)	Only a small number of existing biomethane plants are equipped with CCS, gradually processing 10–15% of available wet residual biomass by 2040–2050. This results in modest removals and biomethane production of around 0.1 bcm.	New biomethane plants with CCS scale up slowly, using 20% of available biomass by 2040, increasing to 60% by 2050. They produce 0.4 bcm of biomethane.	New biomethane plants with CCS process around 0.4 Mt of wet biomass by 2040, increasing to 2.21 Mt (~100%) by 2050. This results in 0.75 bcm of biomethane produced by 2050, representing around 7–9% of national demand.
ERW	ERW remains in pilot and demonstration mode as progress on CRCF methodologies and domestic permitting lags, while conservative baseline deductions and high grinding and transport emissions constrain creditability, allowing bankable projects to grow only gradually - from about 5% of available material use in 2030 to roughly 10% by 2050. ERW is assumed to be deployed with basalt and olivine.	Higher methodological certainty from CRCF methodologies enables progressively larger ERW deployment: 20% of available raw materials by 2030, 45% by 2040, and 65% by 2050. Early pilots scale into commercial projects by 2030, and adoption accelerates as national policies formally recognise ERW and decarbonisation pressure in mining, steel, and construction increase demand for these credits. With CRCF-aligned rules in place - covering quantification, additionality, longterm storage, and sustainability (QU.A.L.I.TY criteria²²⁴) - Italy can issue accredited credits at scale, supporting accelerated deployment well before 2040.	Rapid delivery of CRCF methodologies, progress in MRV systems, and national policies that prioritise CDR enable Italy to mobilise 30% of available minerals by 2030, 70% by 2040, and close to 100% by 2050. By 2030, early pilots mature into full commercial deployment, and markets for crophealth and soilamendment products using these minerals consolidate, supported by CRCF credit incentives in a pattern similar to biochar. This combination allows ERW to scale much faster than in the other pathways.

CDR method	Conservative	Reference	Ambitious
OAE	Not deployed primarily due to lack of social acceptance.	Not deployed primarily due to lack of social acceptance.	OAE deployment begins in 2040, using 0.87 Mt of limestone. By 2050, limestone use rises to 1.74 Mt. Dolomite is not used, as its technological readiness remains lower than that of limestone and because limestone is available in substantially larger, more accessible quantities.
DACCS	Not deployed as there is no CO ₂ storage available after CCS and BECCS prioritisation.	Once geological CO ₂ storage is allocated to point-source CCS (22 Mt) and BECCS (17 Mt), the remaining geological CO ₂ (5 Mt) is allocated to DACCS in 2050. This DACCS portfolio requires 4.4 TWh of electric energy, and 1.7 TWh of medium/high temperature waste heat. DAC units are co-located near industrial clusters and ports with access to existing CO ₂ transport infrastructure, powered by low-carbon electricity from the national grid and low-temperature waste heat from industrial processes, allowing the remaining geological storage capacity to be accessed without competing with point-source CCS pipelines.	Once geological CO ₂ storage is allocated to point-source CCS (41 Mt) and BECCS (21 Mt), the remaining geological CO ₂ (12 Mt) is allocated to DACCS in 2050. This DACCS portfolio requires 10 TWh of electric energy, and 12 TWh of medium/high temperature waste heat. DAC units are co-located near industrial clusters and ports with access to existing CO ₂ transport infrastructure, powered by low-carbon electricity from the national grid and low-temperature waste heat from industrial processes, allowing the remaining geological storage capacity to be accessed without competing with point-source CCS pipelines.
Ex situ mineralization	Not deployed as it remains at pilot, early-demonstration stage (TRL 5–7 for industrial waste feedstocks), with high energy requirements (2.7–3.7 MWh/tCO ₂), unresolved MRV frameworks under the CRCF, and significant logistical barriers associated with processing large volumes of heterogeneous solid waste.	Deployed with partial utilisation of its resource base, with early uptake focused on more accessible industrial residues due to higher processing and energy requirements. Expansion is further constrained by unresolved MRV frameworks under the CRCF and logistical challenges associated with handling and transporting large volumes of heterogeneous waste streams.	Enabled by comprehensive utilisation of industrial residues - steel slag, cement kiln dust, and concrete demolition waste. This outcome assumes successful integration of industrial supply chains, improvements in process efficiency, and the establishment of robust MRV frameworks.

Annex C. Geological CO₂ storage additional notes

This annex provides supporting detail for the CO₂ storage allocation methodology described in section 7.4.2. It presents the risk adjustment factor (RAF) applied to storage scenarios; the projected CCS demand by low and medium-risk storage sites; and the demand-driven DACCS estimation.

C.1 Risk Adjustment Factors for CO₂ storage scenarios

Developing realistic scenarios for CO₂ storage deployment requires recognising that **nameplate injection capacity is rarely achieved in practice**, even at well-run sites. Subsurface uncertainty, evolving regulatory requirements, and operational constraints routinely separate design assumptions from longterm performance. Experience across active projects (e.g. Sleipner, Northern Lights, Quest, and Decatur, Snøhvit, In Salah, and Gorgon) indicates that injectivity and pressure behaviour can diverge sharply from preinjection models. Geological heterogeneity, compartmentalisation, caprock strain, wellbore issues, and brine or solids migration frequently reduce usable injectivity.

Incorporating a **Risk Adjustment Factor (RAF)** into national or corporate CO₂ storage scenarios is therefore essential to avoid overestimation and ensure that planning aligns with operational realities as new subsurface data can reduce achievable injection rates at any stage. Because storage performance varies by geology and project design, different storage types warrant different RAFs. Using differentiated RAFs ensures that 2030–2050 projections reflect realistic, pressure-limited performance rather than theoretical nameplate capacity, strengthening the credibility of climate-strategy planning.

- **Lowrisk projects** - such as depleted fields with proven injectivity or wellcharacterised saline formations - tend to perform close to design capacity and justify RAFs near **0.9**.
- **Medium-risk projects**, where heterogeneity or pressure uncertainty is present but manageable, align with RAFs around **0.65** ^{258, 259}.
- **Hig-hrisk projects**, marked by strong compartmentalisation, uplift or fracture risk, salt precipitation, or frequent well interventions, merit RAFs near **0.50**, as illustrated by underperformance at In Salah^{260,261} and Gorgon^{262,263}.

Ravenna CCS⁸⁴ (Phase 1) illustrates a low risk case: its nameplate capacity of 0.025 MtCO₂/year and observed injection rate of 0.0225 MtCO₂/year, correspond to a RAF of 0.9, reflecting typical firstyear downtime for commissioning, monitoring, and rampup, while high reservoir quality and reuse of a proven gas field further reduce geological risk.

C.2 Projected CO₂ storage demand from industrial CCS by storage site (2030–2050)

Table C.2 presents the projected theoretical CO₂ storage **demand** from point-source CCS and its allocation across Italy's main low- and medium-risk storage hubs. Based on CCS market interest data from the Snam survey¹²⁷, demand was projected to 2050 and spatially allocated to Ravenna, Jonio, and Gela/Ragusa. The values shown for 2030, 2040, and 2050 reflect the evolution of this demand over time and its distribution across key storage sites, providing the basis for allocation of CO₂ geological storage to CCS and CDR described in section 7.4.2.

Low and medium-risk storage site	Theoretical CO ₂ storage demand from CCS and its allocation across storage sites		
	2030	2040	2050
Ravenna	21	26.6	32.2
Jonio	3.7	4.5	5.3
Gela/Ragusa	2.7	3.3	3.8
Total	27.4	34.4	41.3

Table C.2. Estimated theoretical demand for CO₂ storage from point-source industrial CCS. Values for 2050 were linearly projected based on the Snam market survey¹²⁷.

C.3 Sector-level CCS and DACCS demand estimates

To estimate the necessary contribution of DAC technologies to fully remove industry-specific emissions by 2030, 2040, and 2050, **this study estimated the proportion of emissions that can be removed via point-source CCS based on industry-specific examples.**

Table C.3 summarises the projected total emissions that each industry aims to remove according to the Snam survey¹²⁷ (linearly projected to 2050 from 2030 and 2040 data), the proportion that can be abated by CCS, and the residual amounts that would require DACCS for permanent removal.

Sector	2030			2040			2050			Split rationale
	Total	DAC	Point-source CCS	Total	DAC	Point-source CCS	Total	DAC	Point-source CCS	
Cement (10% DAC; 90% CCS)	1.9	0.19	1.71	4.79	0.48	4.31	7.68	0.77	6.91	Process carbon dioxide from calcination is unavoidable; kiln flue gas is concentrated and technically well-matched to point-source capture. Use direct air capture only for residuals and retrofit gaps (Heidelberg Materials ²⁶⁴).
Lime (10% DAC; 90% CCS)	0.82	0.08	0.74	0.68	0.07	0.61	0.54	0.05	0.49	Same calcination chemistry as cement (limestone decarbonation); sector roadmap explicitly frames capture as essential to reach neutrality/negativity.
Waste to energy (0% DAC; 100% CCS)	4.35	0	4.35	4.45	0	4.45	4.55	0	4.55	High share of biogenic carbon; proven full-chain capture at scale with around 90% capture rates - this is cheaper and more direct than air capture (Hafslund Oslo Celsio ²⁷²).
Power generation (18% DAC; 82% CCS)	9.79	1.73	8.06	11.97	2.11	9.86	14.15	2.5	11.65	Gas-fired power with post-combustion capture favours point-source CCS due to concentrated flue gas; residual and distributed sources use DAC (NTZ ²⁷³).
Chemicals (7% DAC; 93% CCS)	1.9	0.14	1.76	2.39	0.17	2.22	2.88	0.21	2.67	High-purity process streams (especially hydrogen/ammonia) make point-source capture the lowest-cost option; electrification and new routes reduce the rest (Yara International ²⁷¹).
Refining (6% DAC; 94% CCS)	2.72	0.17	2.55	3.08	0.19	2.89	3.44	0.22	3.23	Complex sites with several large, amenable sources (hydrogen units, fluid catalytic cracking heaters). Hubs like Rotterdam's Porthos aggregate refinery and hydrogen plant capture; direct air capture only for site-wide residuals (Porthos ²⁷⁰).

Sector	2030			2040			2050			Split rationale
	Total	DAC	Point-source CCS	Total	DAC	Point-source CCS	Total	DAC	Point-source CCS	
Other (100% DAC; 0% CCS)	0.27	0.27	0	0.31	0.31	0	0.35	0.35	0	Unspecified sectors are conservatively associated to DACCS due to lack of data.
Steel (20% DAC; 80% CCS)	3.26	0.65	2.61	4.1	0.82	3.28	4.94	0.99	3.95	Main pathway is hydrogen direct-reduced iron with electric arc furnaces and higher scrap; capture remains site-specific (blast-furnace retrofits) and limited (Axens ²⁶⁶).
Glass (56% DAC; 44% CCS)	0.54	0.3	0.24	0.68	0.38	0.3	0.82	0.46	0.36	Decarbonisation led by electric/hybrid/hydrogen furnaces and cullet (recycling). Many furnaces are small and dispersed; capture is technically challenging at scale - use direct air capture for residuals (NSG Group ²⁶⁷).
Paper (8% DAC; 92% CCS)	1.09	0.09	1	1.03	0.09	0.94	0.97	0.08	0.89	Large mills have biogenic carbon dioxide streams (recovery boilers, lime kilns); bioenergy with capture gives durable removals at lower cost than direct air capture (Svante ²⁶⁹).
Ceramics (56% DAC; 44% CCS)	0.54	0.3	0.24	0.68	0.38	0.3	0.82	0.46	0.36	The sector is SME-heavy with numerous small kilns; retrofitting capture is usually uneconomic. Priority is fuel switch, electrification, efficiency; buy removals or co-locate modular direct air capture (CerameUnie ²⁶⁸).
Totals	27.18	3.92	23.26	34.16	4.99	29.17	41.14	6.07	35.07	

Table C.3. Industry-specific use of point-source CCS and DACCS to address emissions.

Annex D. Background scenarios, additional notes

This annex provides three layers of context for the residual emissions estimates used in Chapter 7. Section D.1 describes the official and academic energy scenarios for Italy's 2050 energy system, providing the basis for electricity surplus estimates in Chapter 3.1 and the availability of this resource used for theoretical and realistic CDR potentials. The cross-scenario comparison in Table D.1 positions the LTS against academic work. Tables D.2 and D.3 present the official emissions trajectories and sectoral decomposition that underpin the 68–100 MtCO₂/year residual range used throughout Chapter 7.

D.1 Overview of Italy's energy scenarios

The latest PNIEC 2024 set out a 2050 playbook to reach net-zero, while ISPRA 414 showed that current measures fall short and that significant post 2030 policy tightening will be required to reach carbon neutrality.

Italy's [PNIEC-2024](#)¹⁸, the official energy and climate strategy, targets **490 TWh** of electricity production by 2050 (81% RES, 7% non-RES, 12% import/export balance), against a projected consumption of 475 TWh, leaving a small surplus of **15 TWh** (grid losses not included) potentially available for CDR. This baseline (BL) strategy envisions a system with >80% renewable energy, complemented by potential contributions from nuclear, CCS, and hydrogen, and emphasises technological neutrality, cost-efficiency, security, and gradual electrification across sectors. A decarbonisation scenario aligned with the LTS (described below) offers an even more optimistic production capacity.

The [Terna-Snam 2024](#)²¹ scenarios support PNIEC planning, and outline a more conservative pathway, with electricity consumption reaching 415 TWh by 2040 and **475 TWh** by 2050 (Global Ambition Scenario). Production is estimated at 498 TWh (84 % RES, 7% non-RES, and 9% import/export balance), leaving a surplus of **23 TWh** for CDR. The focus is on grid flexibility and reliability, with moderate electrification in transport and heating. While feasible and aligned with EU Fit-for-55, these scenarios lag behind more ambitious IPCC pathways.

The LTS-based model, summarised by [Gaeta et al. \(2022\)](#)²⁴ emphasises sector coupling and system flexibility, projecting 672 TWh of production and 620 TWh of consumption in the Decarbonization Scenario by 2050. This implies a **52 TWh surplus for CDR**. Built on PNIEC evolution and multi-stakeholder input from ministries, industries and academia, it balances ambition with national realism.

More transformative scenarios ([Carbon-Free Europe](#)²⁶ and [Heat Roadmap EU](#)²⁵), envision a deeply electrified energy system based primarily on renewables, with fossil fuel consumption either eliminated or paired with CCS. The CFE Core Pathway foresees **900 TWh** of production by 2050 (832.5 TWh consumption), enabled by a vast expansion of renewable capacity (456 GW), while the HRE4 scenario estimates **1205 TWh** of electricity production by 2050 (900 TWh consumption), driven by the electrification of heating, cooling, and transport, alongside large-scale deployment of district heating and energy efficiency, despite estimating a massive electricity production mainly derived from condensing power plants. Both the CFE-CORE and HRE4 models yield large surpluses, with **78.5 TWh** and **305 TWh** of projected surplus electricity by 2050, but reflect EU-wide ambition rather than Italy-specific constraints that the LTS model provides.

D.2 Scenarios from industry and academia

Italy's biggest energy consortium, **Terna/Snam**, has provided independent studies focused on energy transition, but also includes CDR as part of their projections. Under current measures (WM), gross GHG emissions reach 314 MtCO₂e in 2030 and stagnate above 200 MtCO₂e through 2040, relying almost entirely on LULUCF (~28–36 MtCO₂/year) with minimal CCS (4 MtCO₂/year by 2030, rising to 16–40 MtCO₂/year by 2040 depending on the scenario). With additional measures (WAM), emissions fall to 291 MtCO₂e by 2030, and the more ambitious Decarbonisation and Global Ambition scenarios (DE-IT, GA-IT) push gross emissions down to 185–192 MtCO₂e by 2040, with combined CCS and LULUCF removals of 70–76 MtCO₂/year. For 2050, Terna-Snam's extrapolated Neutrality scenario — aligned with Italy's LTS, PNIEC and ISPRA 414 — targets approximately 80 MtCO₂e of gross residuals compensated by 40 MtCO₂/year of CCS/BECCS/DACCS and 35–40 MtCO₂/year of LULUCF sinks to achieve net zero. Their [Documento di Descrizioni degli Scenari 2024](#)²¹ describes the following scenarios:

- **2030 with two variants:** PNIEC Policy (aligned to Italy's PNIEC 2024) and PNIEC Slow (slower transition). All scenarios already use CCS from 2030;
- **2040 with two policy pathways:** DE-IT (Distributed Energy Italia) with electrification-heavy pathways and GA-IT (Global Ambition Italia) = more H₂ and more CCS (incl. in power), plus PNIEC Slow;
- **2050 with a target of carbon neutrality:** the report references Italy's Long-Term Strategy (2021), indicating a need for up to 40 MtCO₂/year of CCS by mid-century, depending on natural sinks (it doesn't model 2050).

Independently, a recent publication from **Markkanen-2024**²⁵² and colleagues modelled a roadmap at the EU level to reach net-zero through three scenarios within a broader EU-level framework across three scenarios and their storage-constrained ("lim") variants. In 2030, all six scenarios produce similar gross emissions (219–224 MtCO₂e), with CDR dominated by soil carbon sequestration, afforestation, and nascent BECCS (4–9 MtCO₂/year of net removals). By 2040, the scenarios diverge sharply: the technology-led TEC pathway reaches 155 MtCO₂e gross with up to 120 MtCO₂/year of removals — heavily weighted towards DACCS (48–98 Mt) and BECCS (29–31 Mt) — while the environment-focused ENV and security-focused SEC pathways land at 75–116 MtCO₂e gross with 54–86 MtCO₂/year removals. By 2050, all scenarios project net-negative outcomes (–46 to –63 MtCO₂/year), driven by DACCS (72–163 Mt), BECCS (21–40 Mt), and enhanced weathering, though these are grounded in EU-wide assumptions and likely overestimate what is achievable at the Italian national level alone. The assumptions for these results are the following:

- In the **TEC** scenario the authors assume a technology-led pathway in which societal and economic growth is achieved with relatively low constraints on resource use or environmental protection. This leads to continued reliance on fossil fuels, high energy demand, moderate efficiency gains, and comparatively weak climate policy.
- In the **ENV** scenario the focus shifts to environmental protection: stronger regulation, greater energy-efficiency improvements, a more rapid deployment of low-carbon technologies, and more moderate economic growth, such that emissions decline more quickly and environmental impacts are more constrained.
- Finally, the **SEC** scenario emphasises security of supply (energy security) and resilience, so that policy prioritises stable energy access, domestic production, diversification of supply, and moderate mitigation ambition. This results in a different mix of technologies and emissions trajectories than the purely environment-driven case, balancing security concerns with climate outcomes.

D.3 Official emissions scenarios

Italy faces a **reduction challenge of roughly 300 MtCO₂ between 2023 and 2050**, with the LTS still about 100 MtCO₂ lower than the ISPRA WAM pathway. Many factors were modelled to reach this ambitious goal, yet all grounded in EU market, technological, and legislative trends (as described by [Gaeta 2022](#))²⁴. The LTS closes this gap by accelerating decarbonisation across all major sectors. It drives the power system to near zero emissions through full decarbonisation and a coal phase out, while industry cuts its remaining footprint through a mix of CCS and low carbon fuels. Transport and other energy uses shift toward electrification, efficiency, and renewable or green fuels, reducing long term fossil demand. Agriculture continues to emit but balances this through stronger land based carbon sinks, supported by improved land management and fire prevention to secure the LULUCF sector's contribution. CCS becomes a structural pillar of the transition, delivering at least 20 MtCO₂ per year and potentially up to 55 MtCO₂ far more by 2050.

The **ISPRA-WM (With current Measures)** reflects a system running on today's policy settings alone. It projects the country forward using only measures already in force, such as existing efficiency standards and renewable energy support. In this "business as usual" world, no new interventions are introduced to stimulate removals, and residual emissions remain high -around 200–230 MtCO₂ per year by 2050.

The **ISPRA-WAM (With Additional Measures)** scenario moves a step further by incorporating the additional measures introduced through the PNIEC 2024 revision and aligned with the EU Fit for 55 package. It assumes stronger action across ESR sectors and a reinforced LULUCF target for 2030 (35.8 MtCO₂). These enhancements bend the curve more decisively, lowering residual emissions to roughly 175 MtCO₂ per year by mid century. Figure D.3.1 illustrates Italy's emissions trajectories as per official scenarios from ISPRA, PNIEC and the LTS.

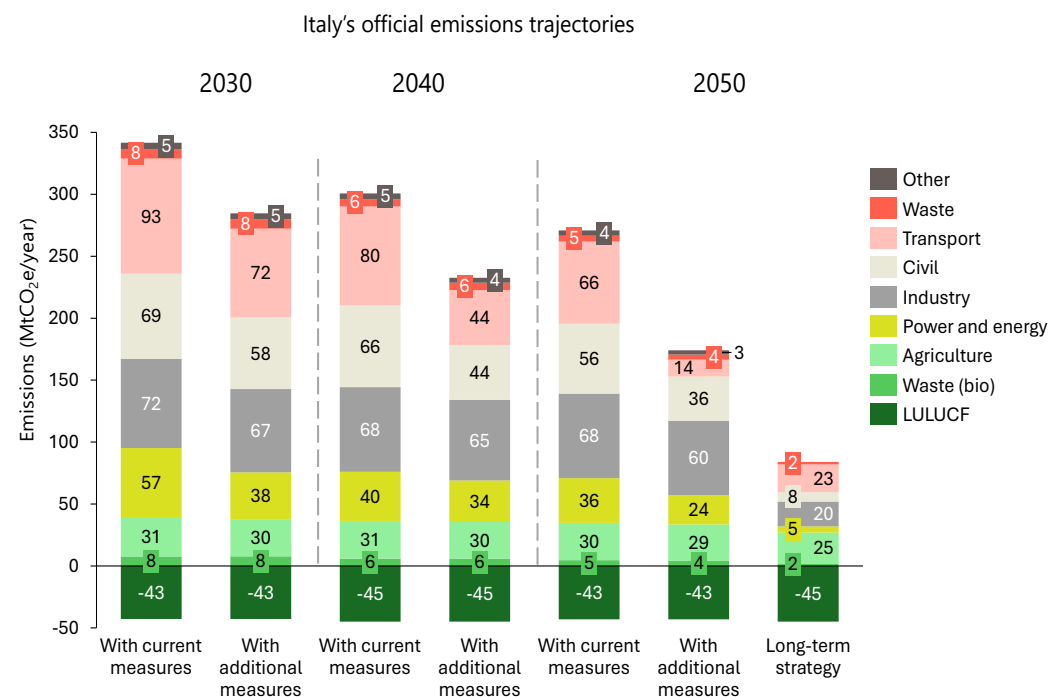


Figure D.3.1. Official national emission trajectories according to the ISPRA-WM (with current measures), ISPRA-WAM (with additional measures), and the LTS (long-term strategy) scenarios.

Table D.3.2 compares the evolution of these scenarios. Both ISPRA WM and WAM scenarios lack several of the transformative actions central to the LTS. The LTS scenario has been extended here to encompass a family of scenarios drawn from subsequent work by Gaeta *et alii*. In this expanded framing, net-zero pathways accommodate residual emissions in the range of 68–100 MtCO₂/year by 2050, broadening the original LTS range of 65–85 MtCO₂/year by 2050¹. This range spans from LTS Scenario A - which assumes continued fossil fuel use with CCS in industry and power, alongside aviation growth - to LTS Scenario C, which assumes hydrogen deployment in the steel sector, 100% renewable electricity, modal shift in transport, and reductions in aviation emissions.²⁴

Year	Scenario	Total GHG excl. LULUCF (MtCO ₂ e)	Net removals (LULUCF + engineered) (MtCO ₂ e)	Main CDR Portfolio	Notes
2023	Historic (ISPRA 2025)	384.7	53.6 (LULUCF only)	afforestation/reforestation, carbon farming, some bioenergy, no BECCS.	Latest inventory year (observed).
2030	ISPRA-WM	370–380	35 (LULUCF only)	Forest management, carbon farming, and small-scale biogas.	Current measures are insufficient for ESR and Fit-for-55 targets.
	ISPRA-WAM	295–310	35–40 (LULUCF only)	afforestation/reforestation, BECCS (pilot), carbon farming.	Fit-for-55 compliant only if fully implemented.
2040	ISPRA-WM	280–300	40–45 (LULUCF)	afforestation/reforestation, limited carbon farming /BECCS.	Fails on neutrality trajectory.
	ISPRA-WAM	150–200	50–60 (LULUCF + early engineered)	afforestation/reforestation, BECCS, hydrogen tech in energy mix, carbon farming, biochar.	Electrification and hydrogen scale-up. Nuclear considered.
2050	ISPRA-WM	200–230	45–50 (LULUCF)	afforestation/reforestation, minor BECCS.	Fails to reach net-zero.
	ISPRA-WAM	175	45–50 (LULUCF)	afforestation/reforestation, minor BECCS/CCS.	Fails to reach net-zero.
2050	LTS	68–100 (gross residuals)	75–105 (40–50 LULUCF and 35–55 engineered)	Mix: afforestation/reforestation, BECCS, biochar, DAC (pilot), carbon farming, and energy mix reconfiguration.	Net-zero balance, consistent with neutrality target.

Table D.3.2. Official CO₂ emission pathways by the main Italian planning documents. For this study, the Long-term strategy family of scenarios was extended based on the work by Gaeta *et al.* to estimate residual emissions by 2050.

Table D.3.3 describes how each main sector will reduce its emissions according to the official sources of the LTS scenario family expansion. Sector residuals represent the range across the four LTS decarbonisation scenarios (LTS A, B, C, Cs) modelled by Gaeta et al. (2022)²⁴ using the TIMES-RSE model. Lower bounds correspond to LTS C/Cs; upper bounds to LTS A.

Sector	1990 baseline (approx. MtCO ₂ e)	2050 WAM (MtCO ₂ e)	Reductions vs 1990 (%) to reach LTS scenario	Reductions vs 1990 (Mt) to reach LTS scenario	2050 Residual un-der LTS (pre-CDR) (MtCO ₂ e)	Actions to reduce emissions
Power & energy industries	137	24	95–100	130–135	0–10	95%-100% of energy from RES; coal phase-out; flexible demand; minimal gas with CCS; repower bio units for BECCS. The power sector has the potential to achieve net-negative.
Industry (combustion + IPPU)	91	60	70–85	65–75	20	Electrification & efficiency; green H ₂ for high-T heat; clinker substitution; CCS on cement/lime/chemicals; circularity. Unavoidable residual emissions from solvents and F-gases.
Civil (residential + services)	78	35	80–90	60–68	5–10	Heat pumps; deep retrofits (2% per year); district heating; smart controls; phase-down fossil boilers.
Transport (road, aviation, shipping)	100	14	70–85	70–85	15–30	EVs dominate LDVs; rail & intermodal freight; e-fuels/H ₂ for aviation & maritime; modal shift & logistics.
Agriculture (non-CO₂)	38	29	35	18	25	Enteric methane inhibitors; improved manure management; nitrification inhibitors; precision fertilization; efficient and digitalized water management
Waste	19	10	70–85	14–16	3–5	CH ₄ capture; organics diversion; CCS on major incinerators; circular economy.
Cross-sector engineered	—	—	-	—	—	Long-term contracted removals sited near storage hubs; powered by RES; robust MRV (CRCF).
Totals	463	172	-	—	68–100	

Table D3.3. Sector-specific roadmap to net-zero according to the LTS-derived scenarios (Gaeta et al.).²⁴ Official scenarios generally take 1990 as baseline for emissions reductions.

Annex E. Breakdown of cost estimates for deploying the scenarios

Reported costs reflect **levelised removal costs (€/tCO₂)** derived from published literature and should be interpreted as indicative rather than definitive. Levelised removal costs refer to the average cost of removing one tonne of CO₂ over the full lifetime of a CDR project, accounting for all major expenses spread across all tonnes removed. They incorporate capital expenditure, operations and maintenance, feedstock and energy supply, CO₂ transport to the storage or application site, and baseline monitoring, reporting, and verification (MRV).

These estimates carry **substantial uncertainty**. Cost ranges vary widely across studies, underlying assumptions differ, and many CDR pathways remain at first-of-kind or early deployment scale, where learning effects have not yet materialised. **As technologies mature, costs are expected to decline**, while factors such as biomass availability may impact price. Broader system effects - including supply chain constraints, labour markets, and regional infrastructure buildout - also influence long-term cost trajectories. CDR deployment is additionally associated with significant job creation and regional development potential, particularly in the Reference and Ambitious scenarios. Tables E.1 present the cost ranges for each scenario in 2030 and 2050 and expand on the results summarised in section 7.6.

	Unit cost (€/tCO ₂ removed)	Conservative Scenario				Reference Scenario				Ambitious Scenario			
		2030		2050		2030		2050		2030		2050	
		CDR potential	Cost M€	CDR potential	Cost M€	CDR potential	Cost M€	CDR potential	Cost M€	CDR potential	Cost M€	CDR potential	Cost M€
Afforestation and reforestation ²¹⁸	25-100	0.11	2.5-10	0.1	2.5-10	2.3	57-230	2.3	57-230	5.82-5.10	145-580	11.7	293-11700
Improved forest management ²¹⁸	0 - 50	1.66	0-83	1.66	0-83	1.86	0-93	1.86	0-93	2.01	0-101	2.47	0-123
Agroforestry ²¹⁸	20-90	4.83	97-435	4.83	97-435	5.19	104-467	5.93	119-533	6.30	126-567	6.30	126-567
Cropland management ²¹⁸	36-123	7.04	254-866	5.06	182-622	10.79	388-1327	14.36	517-1766	11.38	410-1400	18.57	669-2284
Pasture management ²¹⁸	36-123	0.4	20-69	0.56	14-49	1.60	58-197	2.40	86-295	3.8	86-295	4.76	288-984
Peatland and wetland restoration ²¹⁸	8-110	0	0	0	0	0	0	0.16	2.4-33	0	15-206.8	0.14	30-413
Seagrass bed regeneration ²¹⁸	18 - 92	0	0	0.15	3-14	0	0	0.3	6-28	0	0	0.30	6-30
Biochar ²¹⁸	100-223	0.83	83-184	0.83	83-184	1.65	165 - 369	4.96	496-1106	2.48	248-553	21.41	666-1485

	Unit cost (€/tCO ₂ removed)	Conservative Scenario				Reference Scenario				Ambitious Scenario			
		2030		2050		2030		2050		2030		2050	
		CDR potential	Cost M€	CDR potential	Cost M€	CDR potential	Cost M€	CDR potential	Cost M€	CDR potential	Cost M€	CDR potential	Cost M€
Biobased products ²⁸⁴	37 - 138	0.19	7.2-26.7	0.96	36-133	0.39	14-53	1.16	43-160	0.58	21-80	1.54	57-213
BECCS (combustion) ²¹⁸	27-360	0.55	15-198	3.43	93-1234	0.56	15-200	16.9	458-6091	0.56	15-200	21.43	579-7715
BECCS AD with ex-situ mineralisation ²⁸⁵⁻²⁸⁸	120-450	0	0	0	0	0	0	0.2	24-90	0	0	0.4	48-180
ERW ²¹⁸	54-400	0.04	2 to 16	0.08	4-32	0.16	9-85	0.53	29-210	0.24	13-97	0.81	44-324
Mineral OAE ²⁷⁴	60.6-103.9	0	0	0	0	0	0	0	0	0	0	1	61-104
DACCS ²¹⁸	450-900	0	0	0	0	0	0	5.0	2250- 4500	0	0	8	7200- 14400
Total costs		480-1888M€		513-2797M€		810-2999M€		4085-15140 M€		1064-3830 M€		8237-22009 M€	

Table E.1. Breakdown of cost estimates for deploying the realistic scenarios. CDR potential amounts are in MtCO₂.

Annex F. Current incentives for land-based CDR and agricultural efficiency promotion

The widely distributed forest areas and agricultural lands will be paramount in the deployment of land-based CDR methods, guarded by current and future policies described in Table F.1 which presents a summary of the main actions relevant to CDR methods and their expected coverage based on the 2024 CAP Performance Report⁴⁷.

Incentive	Description	Budget 2024 (EUR)	Current coverage	% of 2024 budget used	Expected coverage / trajectory	Future expansion notes	Associated CDR method
ES1 – AMR & animal welfare	Antimicrobial reduction and animal-welfare actions (Levels 1–2)	€335,892,932 (gross spend)	5.67 M LU (live-stock units)	n/a (not disclosed by APR per-scheme)	Stable; result indicator R.43 ≈60% of LU supported in 2024	2025 rule tweaks for small farms to raise uptake	Conservation & rotational grazing (where pasture-based)
ES2 – Grass cover in woody crops	Grassing/cover in orchards, vineyards and olives (incl. NVZ/Natura 2000)	€100,828,996 (gross spend)	1,057,988 ha (aggregate)	n/a	Contributes to R.19/R.21/R.23; on track vs. 2024 milestones	Strong and steady demand; supports Natura 2000 management (R.33)	Grass cover
ES3 – Heritage olive groves	Maintenance of high-landscape-value olive groves	€145.8 M (gross spend, total)	578,983 ha	n/a	Stable; contributes to R.33 (> 10% of N2000 SAT managed)	High uptake sustained	Olive landscape preservation (avoid burning pruning; natural pest control; water management)
ES4 – Extensive forage rotations	Low-input forage systems with crop rotation	€154 M (gross spend)	3,127,692 ha	n/a	Key driver of R.14/R.19 (soil carbon/protection); 2024 over-performance	Unit amounts rebalanced in Oct 2024 to meet demand	Cover/intermediate crops; direct seeding; minimum till
ES5 – Pollinators on arable/woody	Flower strips & landscape features for pollinators (arable and woody)	€28,179,564 (gross spend)	62,252 ha (+ ~3,200 ha on woody)	n/a	Supports R.24 and R.33; growth expected in 2025	From 1 Jan 2025, includes 4% non-productive areas (ex-GAEC 8)	Pollinator strips / hedges

Incentive	Description	Budget 2024 (EUR)	Current coverage	% of 2024 budget used	Expected coverage / trajectory	Future expansion notes	Associated CDR method
SRC01 – Natura 2000 (compensation)	Compensation for costs/ income loss inside Natura 2000	n/a	316 beneficiaries; 8,436 ha (measure). R.33: 10.29% of N2000 SAT under improved management	56.78%	Maintains >10% of N2000 SAT under improved management with ES/SRA support	Easier access via ES5 (from 2025) + additional SRA09 calls	*Could be Wetland restoration & conservation (site-dependent)
SRA01 – Integrated production	Area-based agri-environment commitments (reduced inputs, IPM)	≈€85 M paid (AF2024)	n/a	72.52% (SRA group)	Growing with 2025 calls	Additional regional calls open	Organic & regenerative practices (closest analogue)
SRA29 – Organic farming	Adoption/maintenance of organic practices	≈€200 M paid; €2.1 bn under call (~97% of envelope)	≈0.83–0.94 Mha	72.52% (SRA group)	2025 milestone feasible (oversubscribed pipeline)	Multi-year commitments already in 2025–27 pipeline	Organic farming
SRA30 – Animal welfare (RD)	Animal-welfare commitments under RD (distinct from ES1)	>€57 M paid	n/a	72.52% (SRA group)	Incremental rise in 2025	Aligns with insurance and ES4 uptake	Conservation & rotational grazing (where pasture-based)
SRA08 – Permanent grassland management	Management commitments on permanent meadows and pastures (e.g., grazing/mowing regimes, hay meadow management).	n/a	195.08 kha	72.52% (SRA group)	Stable to increasing with regional sub-actions and 2025 calls.	Focus on pasture/meadow regimes; complements rotational grazing under ES4.	Conservation and rotational grazing
SRD15 – Productive forestry investments	Productive/value-chain forest investments	€1,805,198 paid (AF2024)	(admin: 23 beneficiaries / 21.8 ops)	≈8% (SRD group)	Catch-up expected in 2025	Underpins R.30 once 2025 payments start	Certified forest management

Incentive	Description	Budget 2024 (EUR)	Current coverage	% of 2024 budget used	Expected coverage / trajectory	Future expansion notes	Associated CDR method
SRF01-04 – Risk management	Subsidised insurance & mutual funds	n/a	~66,579 farms (R.5); 60,171 SRF01 policies	70.63% (SRF group)	Higher coverage in 2025 as the National Mutual Fund (SRF04) pays out	2024 EAFRD booking delays shift to 2025	Enabling; no direct CDR method
SRB01-03 – ANC/LFA	Compensatory allowances in areas with natural constraints	€185 M paid (SRB01)	2,096,376 ha; 104,712 beneficiaries (total ANC)	n/a	High and steady maintenance in mountain/constraint areas	Complements eco-scheme uptake on marginal lands	Conservation & rotational grazing (where grass-based systems prevail)
HY02 – Beekeeping	Apiculture programmes (training, health, equipment)	≈€5.2 M (EU share, annual)	≈798,957 hives (cumulative)	≈88%	2025 milestone already achieved	Stable lines; synergies with ES5	Pollinator strips / hedges (ecosystem synergy)
Sectoral – Wine (incl. Green harvest)	OCM wine measures (investments, crisis tools, green harvest)	€212.17 M paid (AF2024)	Green harvest: 8,702 ha; 2,110 beneficiaries	≈73%	Strong execution maintained	Wine accounted for >50% of sectoral spend in 2024	Grass cover (typical CDR lever in vineyards)
Sectoral – Fruit & Vegetables (POs)	Producer-organisation programmes (incl. environmental actions)	€247 M POs approved; €122.5 M paid (AF2024)	85 POs approved (2024); 29 paid (AF2024)	≈40% (advances vs. approved POs)	Large pipeline into 2025	Contributes to R.19/R.21/R.24	Pollinator strips / hedges (frequent PO action)
Sectoral – Olive & Table Olives (POs)	Olive-sector OPs (quality, environment, training)	≈€47 M/year (EU+nat+private)	45 OPs; >€27 M advances; €33.1 M gross paid (AF2024)	≈57% (advances vs. annual)	Stable	Constant role within sectoral spend	Olive landscape preservation
Sectoral – Potatoes (POs)	Potato producer-organisation programmes	€6 M/year; €3.226 M paid (AF2024)	16 OPs in 2024; 19 OPs planned for 2025	≈53.8%	Growing (new OPs)	Niche line expanding	Cover/intermediate crops; direct seeding; minimum till
SRA27/SRA31 – Forestry management (non-productive)	Non-productive forest management/enhancement	€0 paid (AF2024)	—	0%	2025 milestone expected to be exceeded (tenders/areas already requested)	Delivery timeline returned to accelerate in 2025	Certified forest management

Table F.1. Estimated budget and land coverage by CAP and SR (Rural Development) incentives (CAP Eco-schemes)¹⁴²



ABOUT

Carbon Gap

Carbon Gap was established to be Europe's first philanthropically funded environmental advocacy organisation, focusing exclusively on CDR. The mission is to ensure that Europe becomes a leader in developing and deploying CDR solutions at scale in a safe and equitable manner to preserve a stable climate. Carbon Gap is coordinating the delivery of the project that has produced this report.

www.carbongap.org

B3 Carbon

B3 Carbon is a consulting company founded by Beatriz Beccari Barreto focused on decarbonisation. The mission is to promote decarbonisation in different parts of the world, ensuring the climate goals established by different treaties and countries are met in a measurable and equitable manner. B3 carbon is the author of the report.

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