CARBON REMOVAL
READINESS ASSESSMENT

Il potenziale italiano di rimozione del carbonio atmosferico

Report

Aprile 2026

Una collaborazione tra

carbon gap

B3 carbon

Introduzione ai Carbon Removal Readiness Assessments

Molti governi hanno preso l'impegno di raggiungere l'obiettivo delle zero emissioni nette (*net-zero*), riconoscendo la necessità di ridurre drasticamente le proprie emissioni e compensare quelle residue per limitare il cambiamento climatico. L'Intergovernmental Panel on Climate Change (IPCC) prevede la rimozione di centinaia di miliardi di tonnellate di diossido di carbonio (CO_2) atmosferico per stabilizzare il riscaldamento globale e mantenere l'aumento delle temperature medie ben al di sotto dei 2°C rispetto al periodo preindustriale. Tuttavia, pochi Paesi dispongono attualmente di un piano solido per sviluppare e implementare soluzioni di rimozione del diossido di carbonio dall'atmosfera (*Carbon Dioxide Removal - CDR*) su scala sufficiente a compensare le emissioni residue per raggiungere l'obiettivo delle zero emissioni nette. Generalmente, le quantità necessarie di rimozione della CO_2 dall'atmosfera sono stimate a livello globale e non sono adeguate a informare in modo efficace la pianificazione e la definizione delle politiche nazionali sulla rimozione del carbonio.

Le analisi sul potenziale di rimozione del carbonio (*Carbon Removal Readiness Assessments - CRRA*) mirano a colmare questa lacuna e a supportare i politici e funzionari pubblici nell complementare le attuali strategie nazionali climatiche con obiettivi specifici, ambiziosi e, allo stesso tempo, realistici di rimozione del carbonio. Le analisi CRRA stimano in che misura i Paesi possano realisticamente implementare la rimozione della CO_2 utilizzando un approccio che parte dal basso (*bottom-up*), cioè dal territorio e dagli attori locali, per poi risalire verso i livelli più alti di decisione e pianificazione attraverso la creazione di roadmap nazionali che aiutino i decisori politici e altri attori rilevanti a comprendere le opportunità offerte dalle soluzioni di rimozione della CO_2 e le azioni necessarie per realizzarle.

Ringraziamenti

Questo report è stato redatto da B3 Carbon con il supporto di Carbon Gap, utilizzando la metodologia e i materiali dei *Carbon Removal Readiness Assessment* sviluppati da Carbon Gap. Desideriamo esprimere la nostra sincera gratitudine a tutte le persone che sono state intervistate durante la preparazione di questo report sul potenziale del CDR in Italia. I loro contributi hanno permesso di affinare la metodologia e di arricchire i principali risultati ottenuti. Desideriamo ringraziare anche i ricercatori il cui lavoro è fondamentale per stimare la disponibilità delle varie risorse. Un ringraziamento speciale va inoltre a tutti i revisori che, con i loro preziosi contributi hanno contribuito a perfezionare e migliorare il report, tra cui la Prof.ssa Sabina Bigi (Università di Roma, La Sapienza), la Prof.ssa Giulia Costa (Università di Roma Tor Vergata) e il Prof. Giacomo Antonioni (Università di Bologna).

Disclaimer

Il presente report presenta una stima quantificata del potenziale dell'Italia per l'implementazione dei metodi di rimozione della CO2. Poiché la maggior parte dei metodi valutati in questo report si trova ancora nelle prime fasi di sviluppo, l'analisi è soggetta a un'incertezza significativa. Alcuni metodi potrebbero non rivelarsi praticabili, mentre altri esclusi dal presente report potrebbero svilupparsi più rapidamente del previsto. Il CRRA valuta la fattibilità tecnica e fisica dell'implementazione della rimozione del carbonio a livello nazionale e non sostituisce gli studi di fattibilità a livello di progetto o le valutazioni tecnico-economiche.

B3 Carbon e Carbon Gap non si assumono alcuna responsabilità per l'uso del presente report e dei suoi contenuti, comprese eventuali azioni o decisioni intraprese a seguito di tale uso.

Riassunto esecutivo

L'Italia e l'Europa stanno già sperimentando gli impatti di un clima che si sta riscaldando rapidamente. Dopo la COP30 di Belém, dove i governi hanno riaffermato l'obiettivo di mantenere il riscaldamento globale a non più di 1,5 °C rispetto ai livelli preindustriali pur riconoscendo l'elevata probabilità di un superamento temporaneo, l'urgenza è ancora più evidente. L'estate 2024 è stata la più letale mai registrata in Europa, con circa 62.775 decessi legati al caldo, di cui oltre 19.000 in Italia. L'accelerazione del riscaldamento delle temperature nel Mediterraneo insieme ad una popolazione sempre più vulnerabile in rapido invecchiamento, rende la traiettoria climatica italiana una priorità strategica: riduzione delle emissioni, rafforzamento dell'adattamento e sviluppo del potenziale di rimozione del carbonio diventano elementi imprescindibili per la resilienza del Paese.

Il crescente rischio climatico si inserisce in un periodo di incertezza strategica per l'Italia. La politica climatica nazionale è in evoluzione, tra il dibattito sul ritmo delle riduzioni delle emissioni, l'attuazione del Piano Nazionale di Adattamento ai Cambiamenti Climatici e lo sviluppo dei primi quadri normativi per la cattura, l'utilizzo e lo stoccaggio del carbonio (CCUS). I recenti segnali provenienti dal governo mostrano una combinazione di cautela e apertura sul fronte climatico, creando un contesto complesso per la pianificazione di lungo periodo e rendendo ancora più urgente definire un percorso coerente per la rimozione della CO_2 atmosferica.

L'Italia entra ora in un decennio decisivo per la rimozione della CO_2. Nonostante il calo delle emissioni, le politiche attuali lasciano il Paese su una traiettoria che supera di quasi il 60% il percorso lineare verso le emissioni nette zero al 2050, anche considerando gli assorbimenti naturali esistenti. Nel 2023, le emissioni lorde di gas serra (escludendo i contributi del settore LULUCF - uso del suolo, cambiamento di uso del suolo e foreste) hanno raggiunto quasi 385 $MtCO_2e$ annui. Persino gli scenari ufficiali di lungo periodo più ottimistici prevedono ancora **68–100 megatonnellate (Mt) di emissioni di CO_2 equivalente** residue nel 2050, che dovranno essere neutralizzate attraverso una combinazione di rimozione tecnologica della CO_2 e assorbimenti naturali nei suoli e nelle foreste[1]. Questo intervallo riflette successive elaborazioni modellistiche basate sulla Strategia a lungo termine (LTS), che spaziano da scenari con emissioni quasi nulle nel settore elettrico e trasporti completamente elettrificati, a traiettorie più conservative con uso continuato di combustibili fossili nell'industria pesante e nell'aviazione.

L' analisi del *Carbon Removal Readiness Assessment* per l'Italia valuta la capacità del Paese di affrontare la sfida della rimozione della CO_2, che deve procedere in parallelo a una riduzione significativa delle emissioni. Questo report distingue tra **il potenziale teorico di rimozione di CO_2**, ovvero ciò che potrebbe essere realizzato in Italia in uno scenario di massimo potenziale basato sulle risorse disponibili, e il **potenziale realistico**, che considera anche vincoli politici, economici e sociali. Insieme, questi potenziali delineano sia l'ampiezza delle opzioni disponibili sia il livello di intervento necessario affinché l'Italia integri soluzioni di rimozione di CO_2 credibili nella sua strategia di emissioni nette zero al 2050.

L'analisi si articola in sei fasi principali:

1. Identificazione e selezione dei metodi di rimozione del carbonio rilevanti per il contesto italiano;
2. Mappatura delle risorse disponibili per ciascuna soluzioni, tra cui elettricità da fonti rinnovabili, calore di scarto, biomassa, suolo, acqua e capacità di stoccaggio geologico;
3. Stima del **potenziale teorico massimo di rimozione di CO_2** al 2050;
4. Analisi del quadro normativo, economico e politico nazionale;
5. Valutazione degli atteggiamenti della società italiana verso i metodi di rimozione della CO_2, basata su interviste a stakeholder e su un panel di cittadini;
6. Stima del **potenziale realistico di rimozione di CO_2** per il 2030, il 2040 e il 2050 in tre scenari (di riferimento, conservativo e ambizioso).

Principali risultati sul potenziale di rimozione di CO_2 in Italia

Il report analizza un ampio ventaglio di metodi di rimozione della CO_2 – dagli approcci basati sugli ecosistemi alla conversione della biomassa, fino ai metodi geochimici e sintetici – valutandone i rispettivi potenziali teorici e realistici sulla base delle risorse disponibili nel Paese (ad esempio, elettricità da rinnovabili, calore residuo, biomassa, terra, acqua, minerali e stoccaggio geologico). Questa valutazione completa porta a un **potenziale massimo teorico** di **circa 233 megatonnellate (Mt) di CO_2 rimossa all'anno entro il 2050**, ipotizzando che tutte le risorse naturali disponibili, al netto di usi prioritari, siano interamente dedicate a soluzioni di rimozione di CO2. Un livello di mobilitazione di tale portata non sarebbe raggiungibile in condizioni reali, ma fornisce un valore di riferimento utile per comprendere la capacità tecnico-fisica dell'Italia di rimuovere il carbonio. Il potenziale teorico è dominato dai metodi basati sulla gestione degli ecosistemi (oltre 116 $MtCO_2$/anno escludendo gli assorbimenti naturali), seguiti dai metodi di conversione della biomassa (78 $MtCO_2$/anno), dai metodi sintetici (cioè DACCS - la cattura diretta di CO2 dall'aria) con 33 $MtCO_2$/anno e dagli approcci geochimici (6 $MtCO_2$/anno). Il potenziale della DACCS risulta limitato dalla disponibilità di stoccaggio geologico; in assenza di questo vincolo, il contributo teorico della DACCS potrebbe aggiungere fino a 148 $MtCO_2$ annuali.

Applicando ipotesi più realistiche e prudenti sull'utilizzo delle risorse e integrando i vincoli politici, economici e sociali (inclusi i risultati delle osservazioni emerse dalle interviste agli stakeholder e dal panel di cittadini), il report sviluppa **tre scenari di potenziale realistico per la rimozione del carbonio** per il 2030, il 2040 e il 2050: conservativo, di riferimento e ambizioso. Tutti gli scenari sono ancorati alla Strategia a Lungo Termine dell'Italia, che prevede emissioni residue medie pari a 84 $MtCO_2$/anno al 2050 (la media dell'intervallo compreso tra 68 e 100 $MtCO_2$/anno) da compensare attraverso una combinazione di metodi tecnologici e basati sulla natura, con il supporto degli assorbimenti naturali.

Nello **scenario conservativo**, la lentezza dei processi di autorizzazione, gli scarsi incentivi finanziari e la bassa accettazione sociale limitano fortemente lo sviluppo di soluzioni di rimozione del carbonio. La capacità di rimozione raggiunge solo **18 Mt CO_2 all'anno** entro il 2050, che, sommati a assorbimenti naturali di circa 35 $MtCO_2$/anno, portano a una capacità totale di **53 $MtCO_2$/anno:** troppo poco per conseguire le emissioni nette zero entro il 2050. Questo scenario riflette un'opinione pubblica scettica verso progetti industriali, grandi impianti di cattura diretta dall'aria (DAC) e iniziative di rimozione basate sul mare. Il sostegno è concentrato su interventi locali visibili e basati

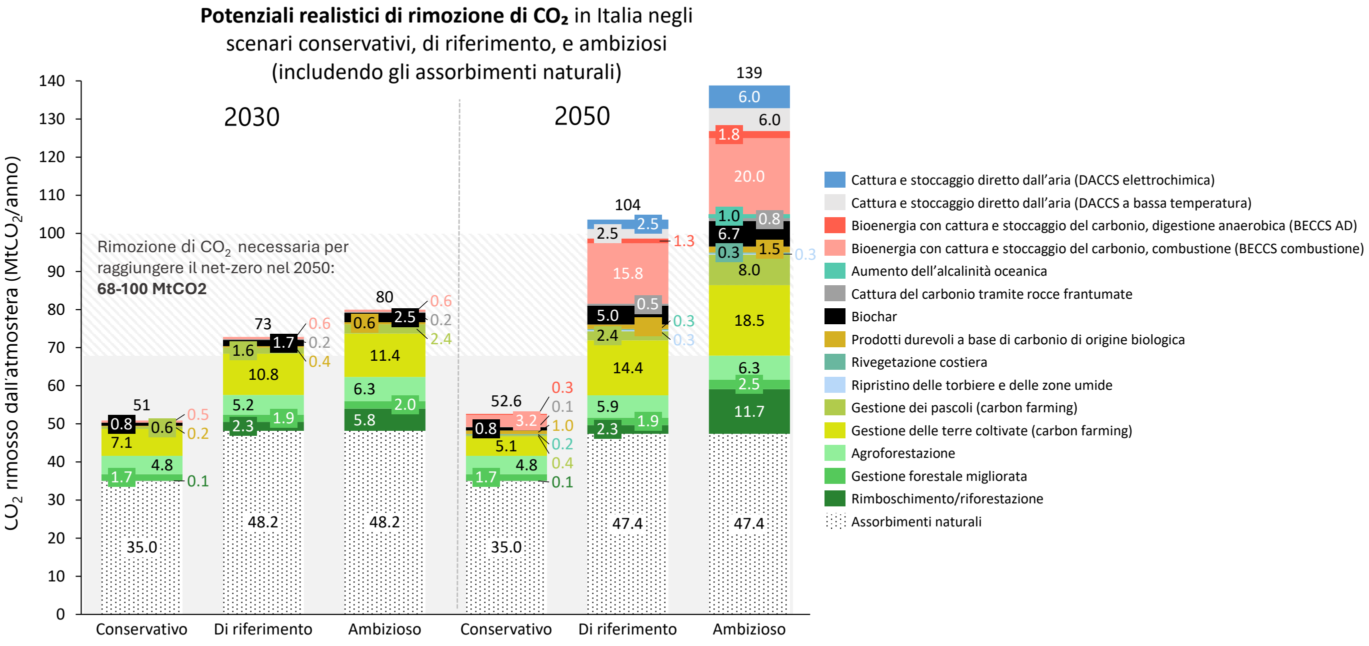


Figura 1. Tre scenari realistici - conservativo, di riferimento e ambizioso - che mostrano il possibile sviluppo di soluzioni di rimozione della CO_2 in Italia entro il 2030 e 2050.

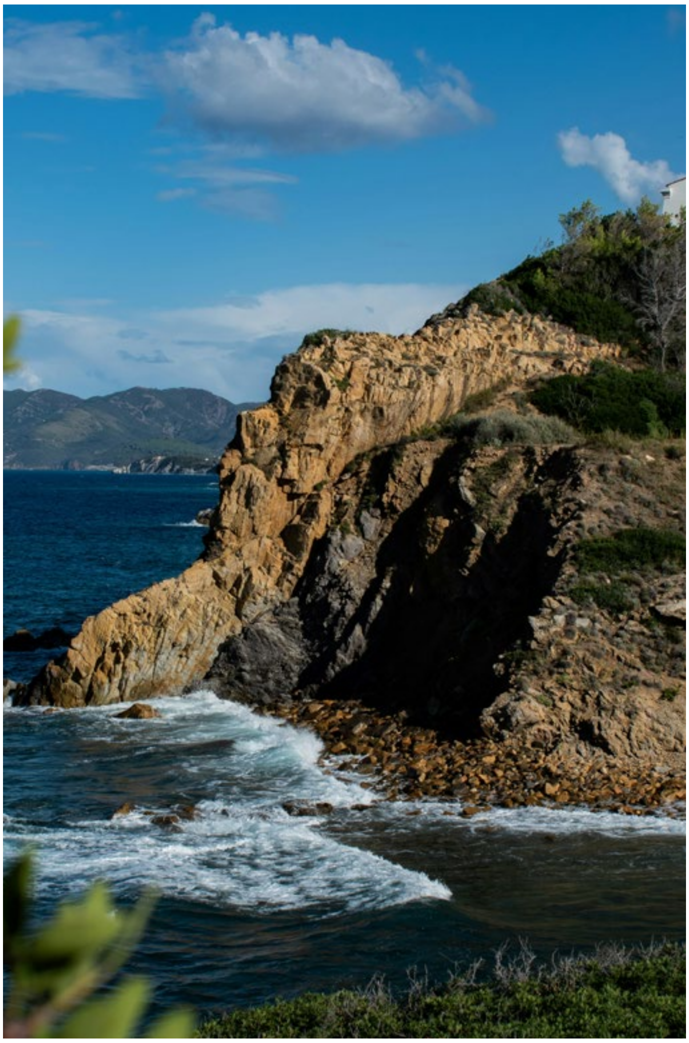
sulla natura, mentre le infrastrutture di soluzioni di rimozione di CO_2 con stoccaggio permanente – necessarie per controbilanciare le emissioni da combustibili fossili - rimangono sottosviluppate.

Lo scenario di riferimento ipotizza un'attuazione coerente dei regolamenti europei e nazionali (ad esempio PNIEC 2024, LTS, CRCF) e miglioramenti graduali nella pianificazione, nel finanziamento, e nei sistemi di monitoraggio, rendicontazione e verifica (MRV) delle rimozioni. In questo contesto, l'Italia raggiunge entro il 2050 una capacità di rimozione di CO_2 di più di **56 $MtCO_2$ all'anno** che, combinata con assorbimenti naturali superiori a 47 $MtCO_2$/anno, porta a una capacità totale di circa **104 $MtCO_2$ all'anno**. Il portafoglio di soluzioni risulta più diversificato rispetto allo scenario conservativo e comprende il carbonio del suolo agricolo, pratiche di gestione del territorio e metodi di conversione basati sulla biomassa, (ad esempio la bioenergia con cattura e stoccaggio di CO_2 - BECCS), il biochar, e i prodotti durevoli a base di carbonio di origine biologica, mentre metodi geochimici come la cattura di carbonio tramite rocce frantumate (ERW) e metodi sintetici (DACCS) contribuiscono solo in misura ridotta. Lo scenario di riferimento ipotizza una capacità di stoccaggio geologico di CO_2 pari a 44 $MtCO_2$/anno, di cui metà $MtCO_2$ è riservata alla rimozione del carbonio atmosferico (piuttosto che alla CCS – la cattura della CO_2 alla fonte, cioè dai punti di emissione industriali). In questo scenario, l'accettazione pubblica cresce grazie a un coinvolgimento efficace nei progetti e a una governance più solida a livello nazionale ed europeo. Il consenso dell'opinione pubblica viene ottenuto quando le soluzioni di rimozione di CO_2 sono implementate in contesti in cui possono essere attentamente monitorate, verificate e controllate, come ad esempio in distretti industriali, ambienti ben regolamentati e quadri normativi basati sul principio "chi inquina paga". In tali condizioni, i progetti di rimozione di CO_2 possono dimostrare benefici locali reali e svilupparsi come parte di un portfolio equilibrato di soluzioni.

Nello **scenario ambizioso**, l'Italia sfrutta pienamente il proprio potenziale di stoccaggio di CO_2 e le altre risorse disponibili. La capacità di rimozione raggiunge più di **91 $MtCO_2$ all'anno** che, sommati ad assorbimenti naturali superiori a 47 $MtCO_2$, portano a una capacità totale di circa **139 $MtCO_2$ all'anno entro il 2050.** Ciò presuppone che, dei 74 $MtCO_2$/anno di stoccaggio geologico disponibili, 43 $MtCO_2$/anno siano destinati alla rimozione del carbonio atmosferico. Ulteriori ipotesi includono la piena mobilitazione di biomassa e risorse minerali idonee, insieme a un'ampia adozione delle pratiche di *carbon farming*.

Gli scenari realistici presentati in questo report non devono essere interpretati come previsioni, ma come percorsi illustrativi. Sebbene tutti e tre gli scenari realistici dovrebbero essere realizzabili, la quantità effettiva di rimozione di CO_2 atmosferica raggiunta in Italia entro il 2030 e il 2050 dipenderà da investimenti consistenti, scelte politiche strategiche, dall'evoluzione dei mercati di crediti carbonio e dall'accettazione socioeconomica delle diverse soluzioni.

Il calcolatore CARE (*Coordinated Allocation of Removal Efforts*) di Carbon Gap è uno strumento che ripartisce il fabbisogno globale di rimozione del carbonio, in linea con l'Accordo di Parigi, in contributi indicativi per ciascun Paese sulla base di diversi principi di equità. Secondo CARE, e a seconda degli scenari considerati che riflettono i negoziati dentro e fuori l'UE, **l'Italia dovrebbe puntare a una capacità di rimozione di CO_2 atmosferica compresa tra le 195 e quasi 250 $MtCO_2$ all'anno entro in 2050.** Diventa quindi essenziale capire quale quota di questo fabbisogno possa essere effettivamente realizzata a livello nazionale.



Conclusioni principali

1. **La rimozione di CO_2 è essenziale per raggiungere gli obiettivi climatici nazionali ed europei.** Negli scenari di riferimento e ambizioso i volumi combinati di rimozione di CO_2 e gli assorbimenti naturali previsti al 2050 potrebbero essere sufficienti a compensare le emissioni residue indicate nella Strategia a Lungo Termine e raggiungere le emissioni nette zero. Il risultato dipenderà dalle decisioni prese tra il 2025 e il 2035. Saranno cruciali: lo sviluppo della capacità di stoccaggio, la progettazione del sistema energetico, l'attuazione della Politica Agricola Comune (PAC) dell'UE, il rafforzamento dei quadri MRV e di certificazione, e il modo in cui le soluzioni di rimozione del carbonio vengono comunicate e regolamentate. La domanda non è più se integrare la rimozione di CO_2 nella strategia nazionale per il Net-Zero, ma quanto rapidamente e equamente costruire gli organismi istituzionali e le infrastrutture che la renderanno possibile.

2. **La maggior parte dei metodi di rimozione del carbonio è possibile in Italia.** Un portafoglio diversificato di soluzioni riduce i rischi, distribuisce la pressione sulle risorse e fornisce maggiore flessibilità ai mercati e alla governance. Tuttavia, un portafoglio diversificato richiede un forte coordinamento tra governo, regioni e industria per garantire che ogni metodo possa svilupparsi al massimo del suo potenziale.

3. **Oltre alla disponibilità di risorse, saranno la geografia sociale e il panorama istituzionale a determinare se l'Italia riuscirà a raggiungere l'obiettivo delle zero emissioni nette (*net-zero*).** Gli stakeholder del mondo accademico, delle amministrazioni pubbliche, della società civile e delle imprese concordano su un punto: le soluzioni di rimozione della CO_2 devono integrare, non sostituire, la mitigazione. Sottolineano inoltre la necessità di un MRV rigoroso, di un forte allineamento con l'UE e di finanziamenti basati sul principio di "chi inquina paga". Tuttavia, la frammentazione istituzionale, la scarsa fiducia nelle istituzioni nazionali e le lacune nelle competenze rallentano l'implementazione. I partecipanti al panel dei cittadini, una volta informati, hanno espresso sostegno per i metodi basati sulla natura, la mineralizzazione e il biochar, ma sono rimasti scettici verso grandi hub DAC e metodi di rimozione basati sul mare, a meno che non siano garantite salvaguardie ecologiche e una distribuzione equa dei benefici.

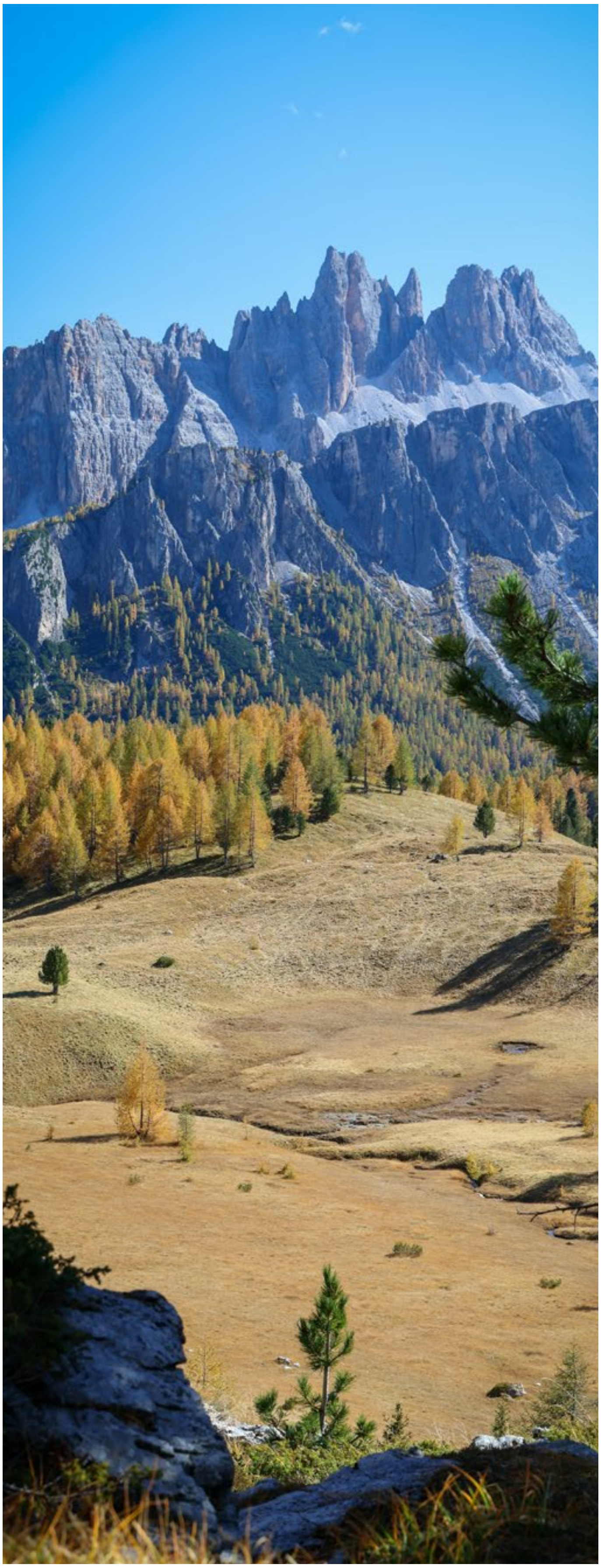
4. **Il territorio e l'agricoltura rappresentano la colonna portante a breve termine dell'Italia per la rimozione del carbonio.** In tutti gli scenari, la gestione del territorio e le pratiche agricole forniscono almeno metà della rimozione totale di carbonio entro il 2050. La gestione delle foreste e degli ecosistemi da sola ha un potenziale teorico di 35 MtCO_2/anno, mentre la gestione del carbonio nel suolo, nei pascoli e l'agroforestazione contribuiscono insieme a circa 81 MtCO_2/anno nel potenziale teorico e 12–48 MtCO_2/anno nel potenziale realistico, a seconda dell'attuazione della PAC e della gestione del rischio incendi.

5. **La capacità di stoccaggio geologico è il principale fattore limitante per le soluzioni di rimozione permanente.** Anche con abbondante disponibilità di elettricità da rinnovabili e calore di scarto, la capacità di iniezione di CO_2 limita la scalabilità di metodi come BECCS e DACCS. L'analisi stima un tetto teorico di stoccaggio geologico di 129.5 MtCO_2/anno a lungo termine, mentre gli scenari realistici di tipo conservativo, riferimento e ambizioso prevedono rispettivamente uno stoccaggio annuo di 14.4, 44 e 74 MtCO_2 entro il 2050. Si stima che una parte significativa di questa capacità di stoccaggio geologico sarà destinata alla CCS industriale, basandosi su recenti studi di mercato. Oltre all'hub di Ravenna, l'Italia dispone di altri siti potenzialmente idonei allo stoccaggio di CO_2. Tuttavia, sarà necessaria un'azione tempestiva per svilupparli in tempo per sbloccare BECCS e DACCS su larga scala.

6. **Metodi permanenti geochimici, sintetici e di conversione della biomassa operano oggi su scala ridotta, ma sono strategici per raggiungere le emissioni nette zero.** Seguendo il principio "like-for-like" (ovvero rimozioni abbinate a emissioni di stesso tipo e permanenza), metodi quali ERW (cattura della CO_2 tramite rocce frantumate), OAE (aumento dell'alcalinità marina), DACCS (cattura diretta di CO_2 dall'aria con stoccaggio) e BECCS (bioenergia con cattura e stoccaggio di CO_2) sono essenziali per controbilanciare le emissioni fossili residue difficili da abbattere, stimate in circa 57 MtCO_2 nel 2050. Secondo l'analisi "like-for-like" di questo report, solo lo scenario mbizioso sarebbe in grado di controbilanciare tutte le emissioni biogeniche e fossili residue previste nel 2050.

7 **L'Italia dovrebbe definire una strategia nazionale di rimozione del carbonio con obiettivi e percorsi chiari** per identificare i contributi attesi di ciascun gruppo di metodi: uso del suolo e silvicoltura (LULUCF), conversione della biomassa, metodi geochimici e DACCS, assicurando che ogni settore abbia un ruolo ben definito. Integrare la rimozione della CO_2 nei quadri delle politiche climatiche e allinearla agli obiettivi europei contribuirebbe a garantire maggiore prevedibilità ad industria, investitori e autorità regionali, facilitando nuovi flussi di finanziamento. È inoltre fondamentale rafforzare la fiducia dei cittadini mostrando come le soluzioni di rimozione del carbonio integrino – e non sostituiscano - le riduzioni delle emissioni nel percorso verso le emissioni nette zero.

8 **L'Italia si trova davanti a una scelta cruciale: continuare su un percorso che espone il Paese a rischi economici, energetici e climatici crescenti, oppure costruire una strategia che aumenti sicurezza, competitività e resilienza, rafforzando il territorio, l'industria e la capacità di gestire le emissioni residue**. Da un lato c'è un percorso conservativo in cui la rimozione del carbonio rimane marginale, le emissioni residue superano i 50 $MtCO_2$/anno e persistono oltre la metà del secolo e le emissioni nette zero diventano un'obiettivo sempre più lontano. L'alternativa è una strategia ben calibrata e sistemica che mobilita territorio, biomassa, minerali e residui industriali, energia e capacità di stoccaggio per raggiungere oltre 100 $MtCO_2$/anno di rimozioni di CO_2 entro il 2050, colmando il divario verso le emissioni nette zero. L'analisi inclusa in questo report mostra che questo secondo percorso è tecnicamente e socialmente fattibile, ma non automatico. Richiede un'azione rapida e coordinata da parte di governo, istituzioni, regioni, industria, settore agricolo e società civile nel prossimo decennio.



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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	**km^2**	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	**m^3**	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
CO_2	Carbon dioxide	**Mt**	Million tonnes
CO_2e	Carbon dioxide equivalent	**$MtCO_2$**	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 (CO_2) from the atmosphere to offset residual emissions[3] (IPCC, 2022). With a 70% likelihood that the 1.5°C threshold will be temporarily exceeded between 2025 and 2029[4], 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 CO_2 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 industry[5] (IPCC, 2018). CDR methods range from biological and nature-based solutions to technological processes that physically and chemically separate CO_2 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 thereafter[6], 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 IPCC[7] 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 CO_2 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 CO_2 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.

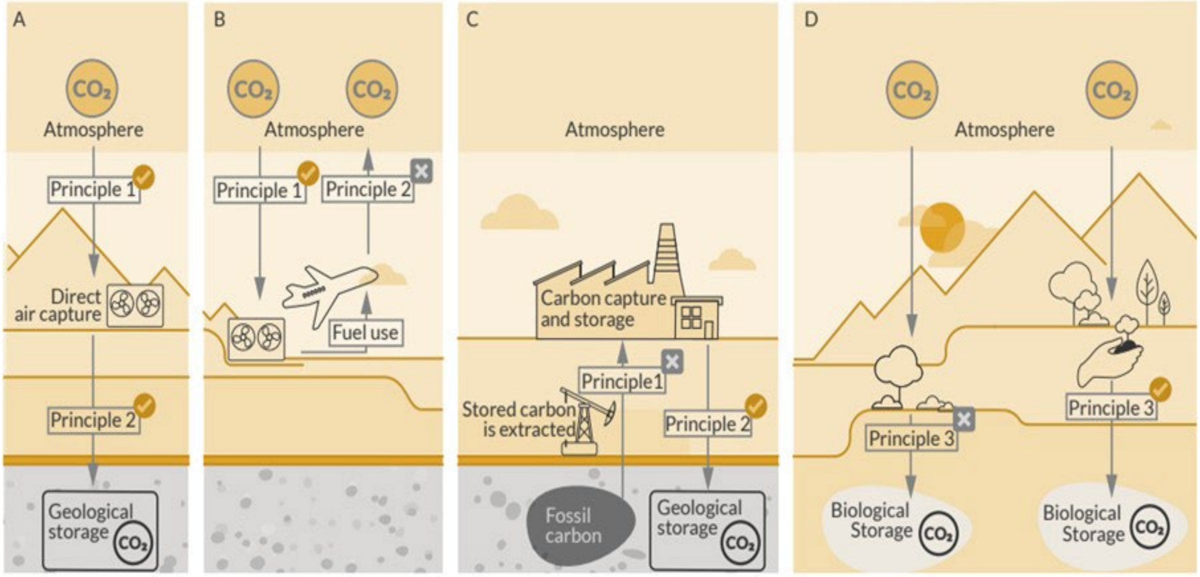
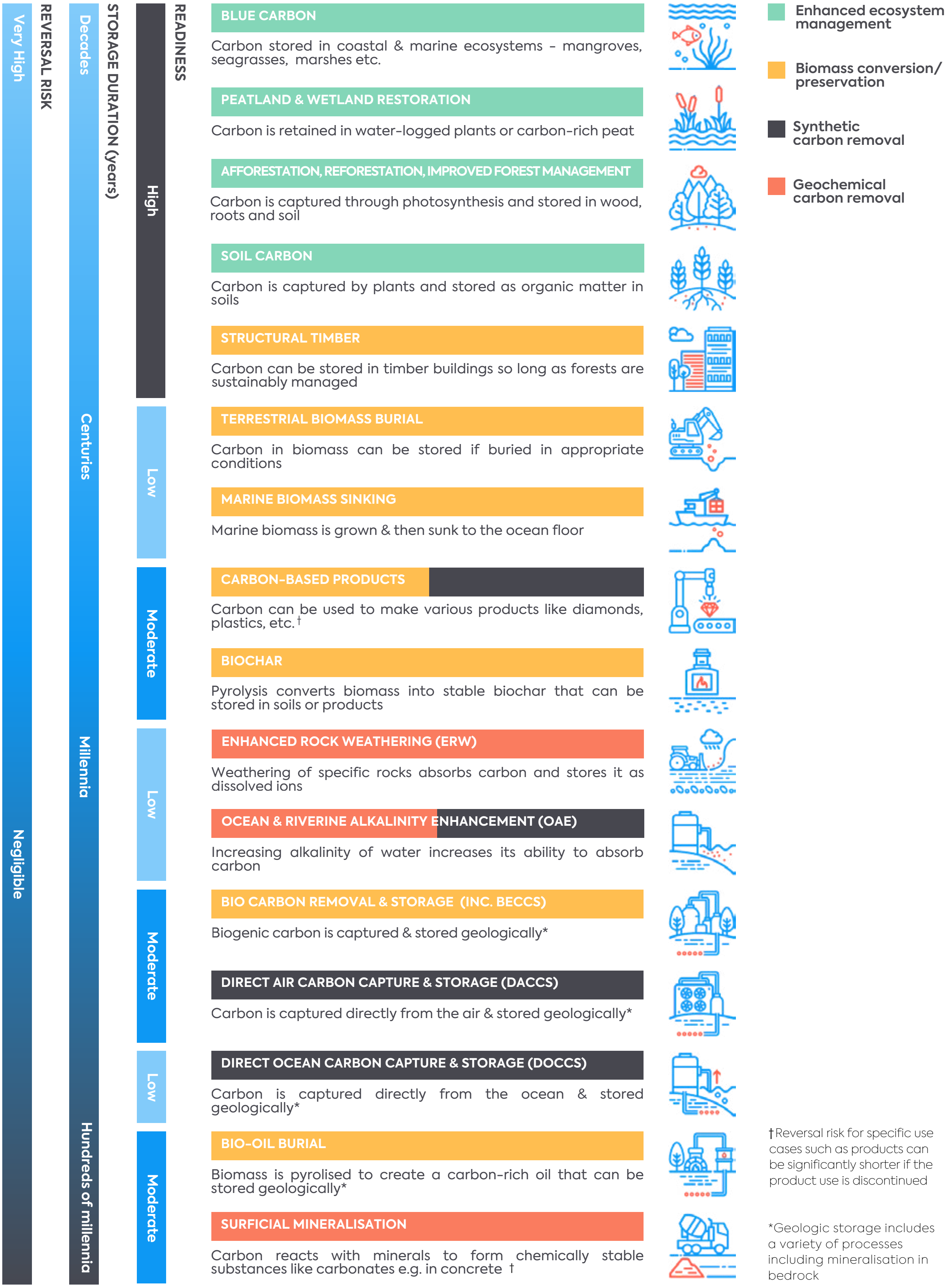


Figure 2. Differences between CDR, CCU, CCS, and natural carbon sink processes. Image A illustrates direct air capture (DAC) with permanent geological storage, a configuration that satisfies all three core principles of carbon dioxide removal. In contrast, Image B depicts DAC, in which captured CO_2 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 CO_2, 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]



BLUE CARBON
Carbon stored in coastal & marine ecosystems – mangroves, seagrasses, marshes etc.

PEATLAND & WETLAND RESTORATION
Carbon is retained in water-logged plants or carbon-rich peat

AFFORESTATION, REFORESTATION, IMPROVED FOREST MANAGEMENT
Carbon is captured through photosynthesis and stored in wood, roots and soil

SOIL CARBON
Carbon is captured by plants and stored as organic matter in soils

STRUCTURAL TIMBER
Carbon can be stored in timber buildings so long as forests are sustainably managed

TERRESTRIAL BIOMASS BURIAL
Carbon in biomass can be stored if buried in appropriate conditions

MARINE BIOMASS SINKING
Marine biomass is grown & then sunk to the ocean floor

CARBON-BASED PRODUCTS
Carbon can be used to make various products like diamonds, plastics, etc.†

BIOCHAR
Pyrolysis converts biomass into stable biochar that can be stored in soils or products

ENHANCED ROCK WEATHERING (ERW)
Weathering of specific rocks absorbs carbon and stores it as dissolved ions

OCEAN & RIVERINE ALKALINITY ENHANCEMENT (OAE)
Increasing alkalinity of water increases its ability to absorb carbon

BIO CARBON REMOVAL & STORAGE (INC. BECCS)
Biogenic carbon is captured & stored geologically*

DIRECT AIR CARBON CAPTURE & STORAGE (DACCS)
Carbon is captured directly from the air & stored geologically*

DIRECT OCEAN CARBON CAPTURE & STORAGE (DOCCS)
Carbon is captured directly from the ocean & stored geologically*

BIO-OIL BURIAL
Biomass is pyrolised to create a carbon-rich oil that can be stored geologically*

SURFICIAL MINERALISATION
Carbon reacts with minerals to form chemically stable substances like carbonates e.g. in concrete †

- 🟩 **Enhanced ecosystem management**
- 🟨 **Biomass conversion/ preservation**
- ⬛ **Synthetic carbon removal**
- 🟥 **Geochemical carbon removal**

†Reversal risk for specific use cases such as products can be significantly shorter if the product use is discontinued

*Geologic storage includes a variety of processes including mineralisation in bedrock

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 CO_2 through photosynthesis, storing it in their biomass - leaves, stems, roots, and other organic tissues. To prevent CO_2 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 CO_2 capture and geological storage. It prevents the release of CO_2 from biomass combustion or processing, thereby enabling net-negative emissions.
    - e. **BECCS with combustion** captures CO_2 from burning a wide range of solid biomass - including mixed feedstocks such as forestry residues and waste - in power or industrial plants, with CO_2 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 CO_2 from mixed gas streams at the end of the process. Gasification can be used to produce hydrogen or fuels, with CO_2 captured during the process.
    - f. **BECCS with anaerobic digestion/ fermentation** captures CO_2 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 CO_2 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 o**f 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 CO_2 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 CO_2 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 CO_2 and water, causing partial dissolution. The reaction converts atmospheric CO_2 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 CO_2, 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 CO_2 uptake.
    b. Electrochemical OAE uses electricity to modify seawater chemistry, increasing its alkalinity, and therefore its capacity to absorb and retain CO_2.
3. Ocean fertilisation adds nutrients to ocean regions to stimulate phytoplankton growth and CO_2 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 CO_2 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 CO_2 directly from ambient air - usually using solid sorbents or liquid solvents. Once captured, the CO_2 is released through the application of heat, pressure, or chemical reactions, yielding a purified CO_2 stream. This concentrated CO_2 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 CO_2.
    c. **Moisture-swing DACCS** employs sorbents that adsorb CO_2 in dry conditions and release it when exposed to moisture.
    d. **Mineral looping DACCS** captures CO_2 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 CO_2.
    f. **High-temperature DACCS** (higher than 300 °C) techniques, such as calcium looping operate at elevated temperatures, enabling rapid CO_2 capture.
2. **Direct ocean carbon capture and storage (DOCCS)** targets CO_2 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 CO_2 from solution, enabling its capture and permanent storage.

2.1.5 CO_2 storage geochemical pathways

Besides the methods presented above, carbon mineralisation is a storage pathway rather than a CDR method per se. However, it uses CO_2 captured from other sources to be stored using a (geo) chemical approach.

1. **In-situ mineralisation** refers to CO_2 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 CO_2 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 use[13]. 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 source[14]. 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].

Enhanced ecosystem management methods	**Biomass conversion methods**	**Geochemical methods**	**Synthetic methods**
● Afforestation ● Reforestation ● Improved forest management ● Agroforestry ● Peatland restoration ● Soil carbon sequestration ● Coastal revegetation	● Durable bio-based products ● Biochar ● Bioenergy with carbon capture and storage (BECCS)	● Enhanced rock weathering ● Ocean alkalinity enhancement ● Carbon mineralisation	● Electrochemical direct air carbon capture and storage (DACCS) ● Mineral looping DACCS ● Low-temperature DACCS
Excluded methods			
● None	● Terrestrial biomass burial ● Marine biomass sinking ● Bio-oil storage	● Ocean fertilisation	● Moisture swing DACCS ● High-temperature DACCS ● Direct ocean carbon capture and storage

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 CO_2 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-CO_2-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 CRRA 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 CO_2 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.

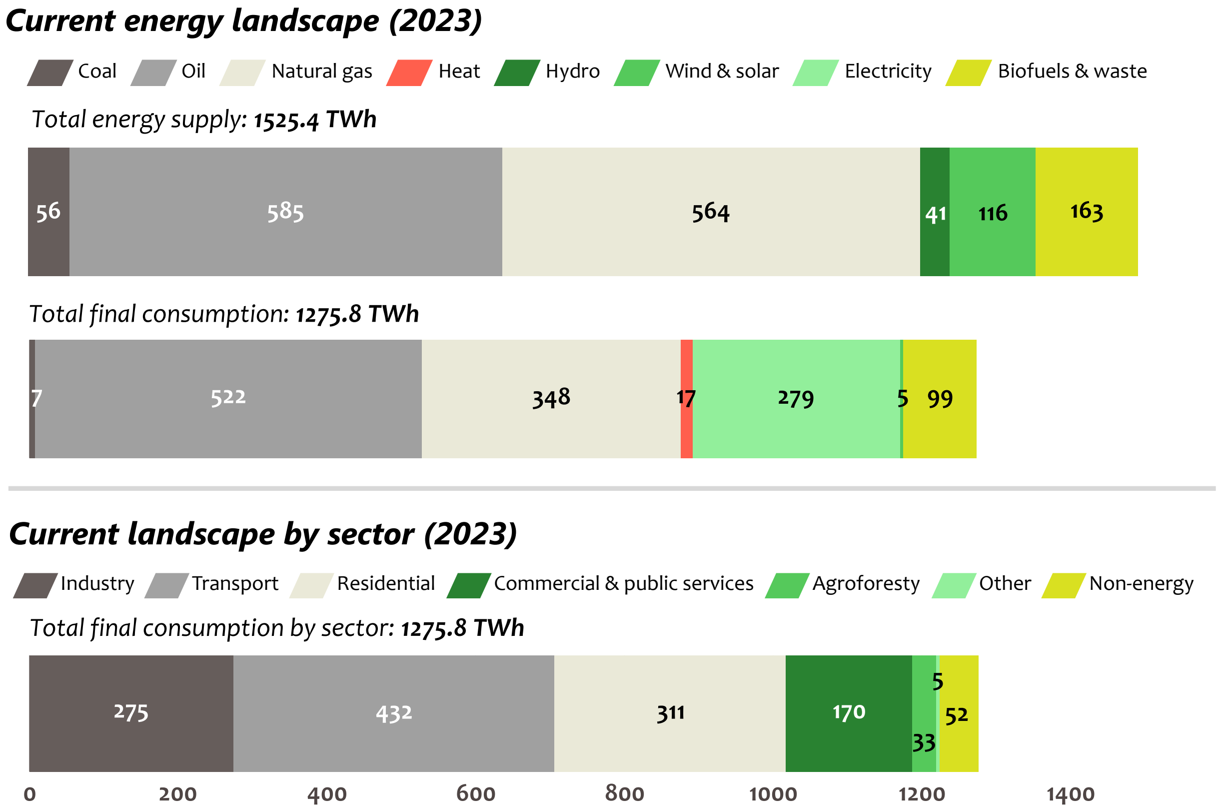


Figure 5. Summary of Italy's current energy landscape (adapted from IEA-2023).16 Final energy consumption corresponds to energy consumed after grid losses and exports.

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 generation[22]. Official projections from PNIEC-2024[18] and ISPRA-414[23] 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 risks[17]. 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 realised[19]. 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.

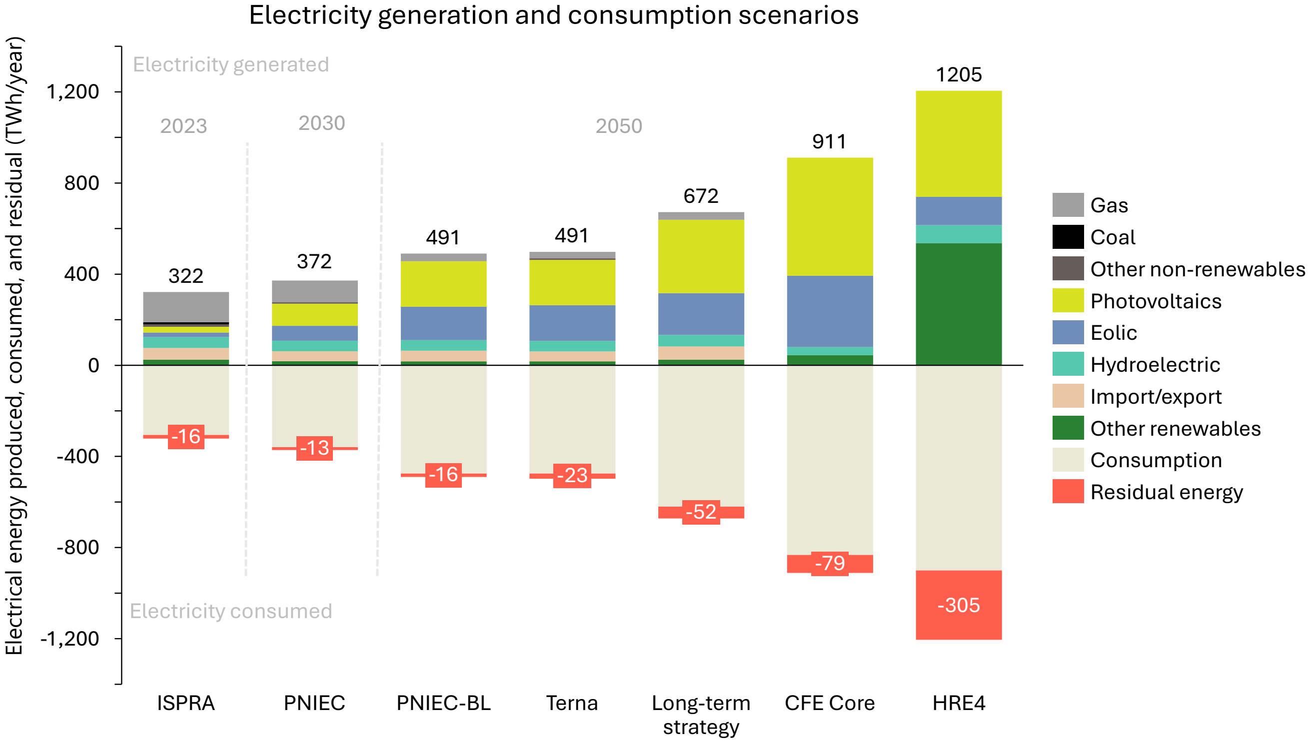


Figure 6. Estimated maximum electricity production and consumption scenarios (see Annex D for details).

Under the most ambitious scenario (HRE4-2018[25]), 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. 2022[24]) 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%) (HRE4-2018[25], IEA-2023[16], PNIEC-2024[18]). 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 consumption[16]. 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 solution[30], 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 2024[21]), 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-energy[32]. 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].

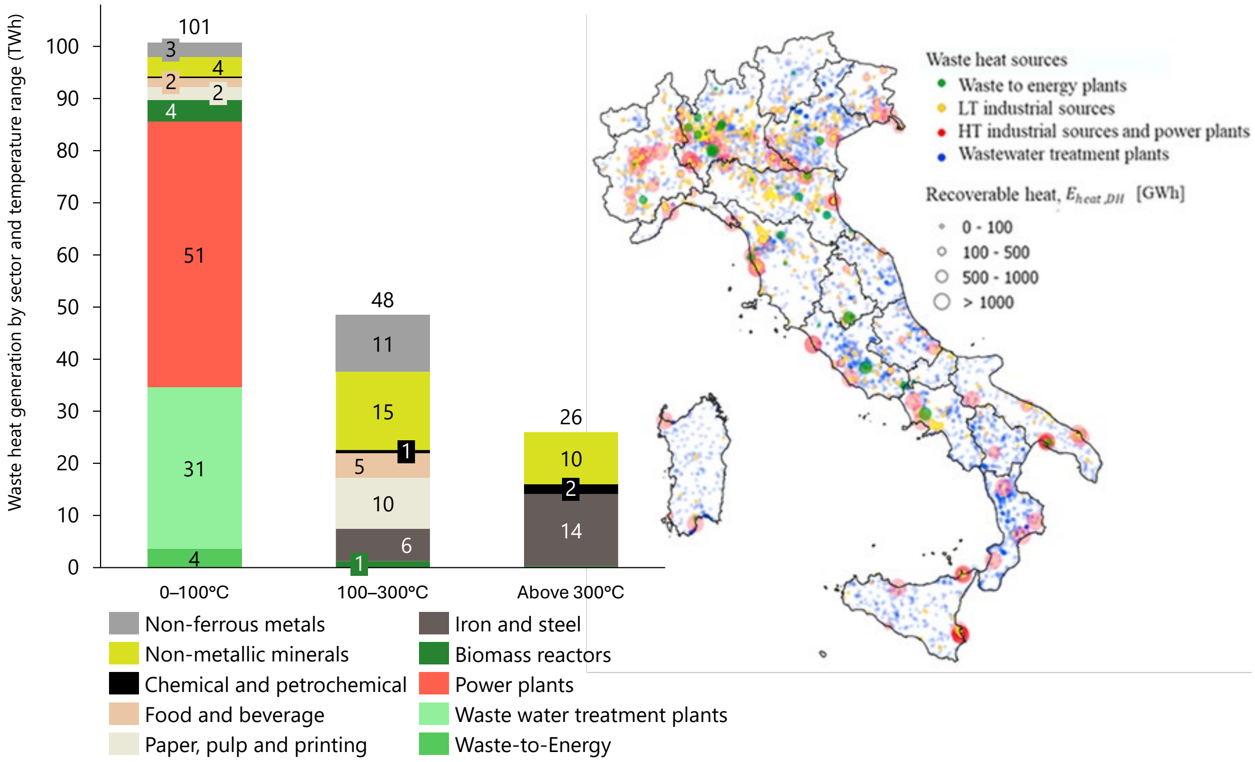


Figure 7. (Left) Waste heat generation by sector and temperature range as per 2015 (Papapetrou et al 2018[31]). (Right) Geographic distribution of low temperature (LT) and high temperature (HT) waste heat sources recoverable for district heating (Adapted from Denaire et al 2021[32]).

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 2018[31]; 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 heat[34].
- **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 TWh[32]), 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.

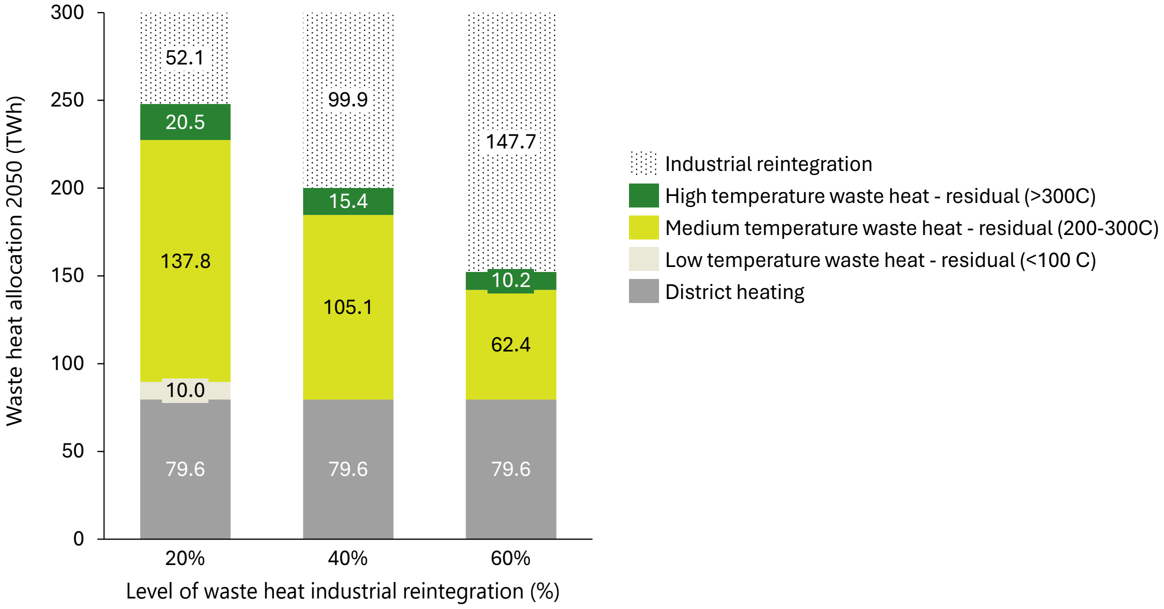


Figure 8. Waste heat allocation scenarios under three waste heat industrial integration scenarios. Industrial reintegration waste heat is captured and reintegrated into local industrial processes and therefore unavailable for CDR.

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 water[37].

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 (FAO[42]).
- **Rainwater harvesting.** Policies such as the DL 39/2023[41] 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 (FAO[42] & ISTAT-2024[36]).

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 regions[37]. 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-2023[228]). 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%) (ISPRA[23]). 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 FSC[277]. 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-414[23], PNIEC-2024[18]), 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 areas[23].

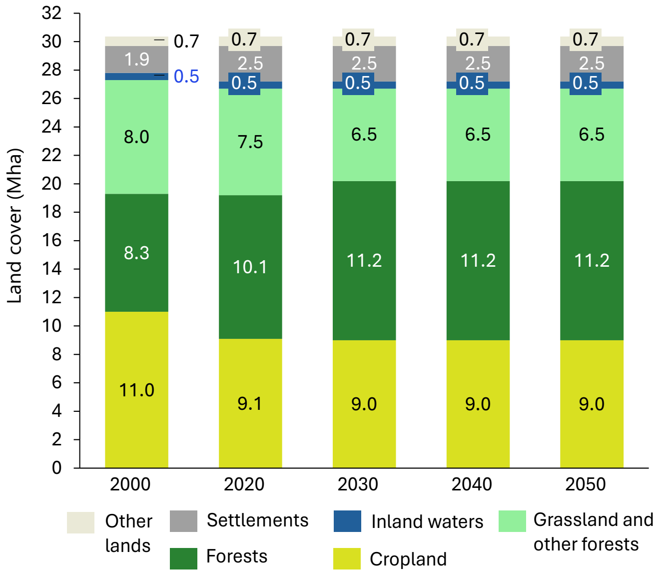


Figure 9. Past and projected land distribution. "Other lands" correspond to land that is sparsely vegetated, abandoned crop/grassland, or under natural succession. Urbanised and other constructed lands cover nearly 2.5 Mha, and inland waters 0.5 Mha (adapted from ISPRA-414[23])

Box 2 – Forest expansion without a clear afforestation strategy

The current (2025) forest sink is estimated at 46.1 $MtCO_2e$, and LULUCF scenarios estimate that, under key forest protection and certification policies (see Annex F), this could grow to **47.4-49.4 $MtCO_2e$[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-2021[1]), **the LULUCF sector is expected to account for at least 50% of the country's total CDR, contributing over 45 $MtCO_2e$ 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 soilorganiccarbon 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 $MtCO_2$ removals in 2023, Italy's LULUCF sector is projected to provide steady **39-45 $MtCO_2e$** removed per year through 2055[23]. 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**.

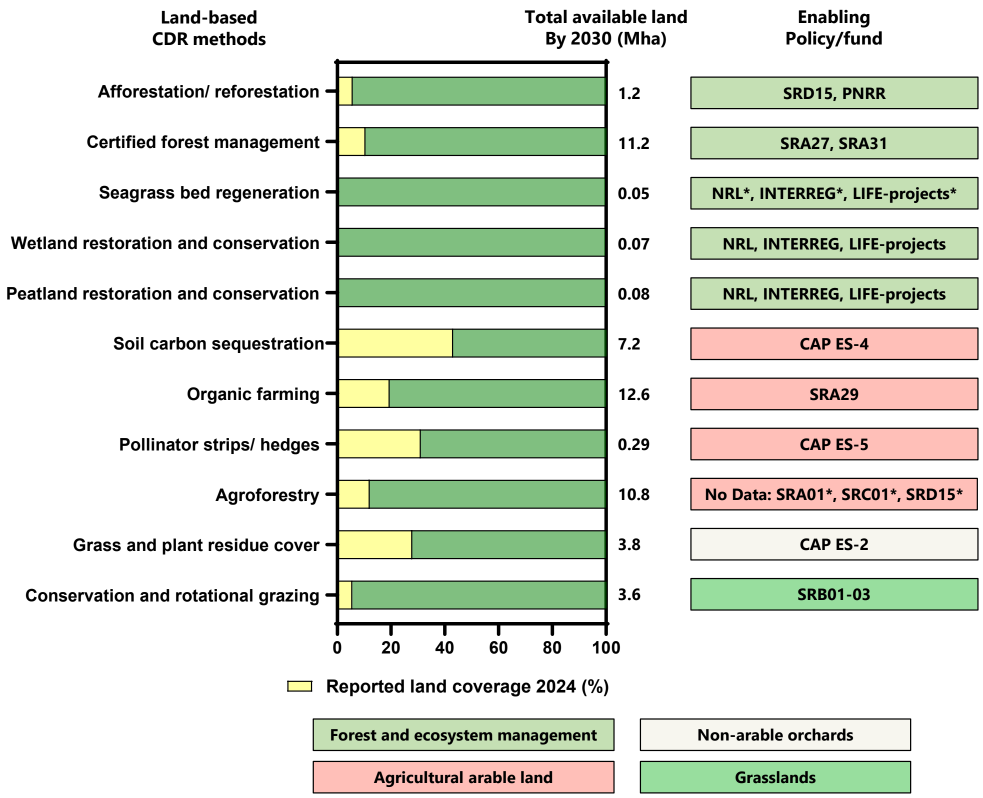


*Figure 10. Current coverage of CDR-promoting practices associated with land use, land use change and forestry, and the available incentives. * Indicates potential funds yet unused.*

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 area[52] 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 level[53].

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 2022[54]) 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 tCO_2/ha/year, depending on the basin's depth, temperature, and plant density.[56] Studies in the Mediterranean basin suggest that the total effective CO_2 burial in sediments ranges from 1-5 tCO_2/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 CO_2 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 ktCO_2 removed per year** to the current 1.04 Mt CO_2 sink. Biomass from *Posidonia* naturally accumulates on beaches (around 10-53% of total production) and could offer further CDR potential[60] by valorising it to an equivalent of **10.23 ktCO_2/year** - additional to the CDR volumes achieved through seagrass restoration.

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 ktCO_2** 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**.

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

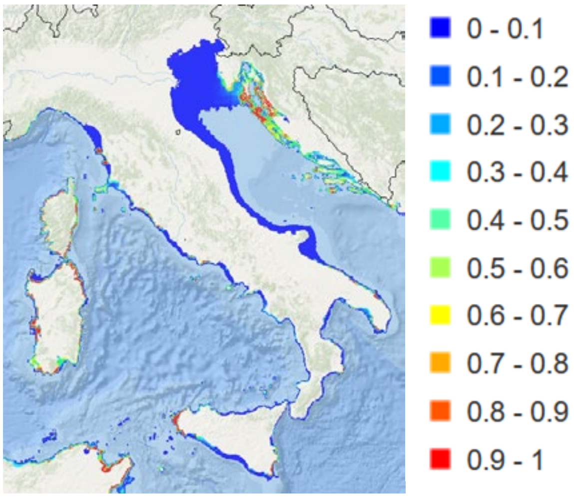


Figure 11. Distribution of Posidonia Oceanica (data retrieved in 2019 from the EU Maritime Affairs)[61].

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 CO_2 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 north[278]), 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.

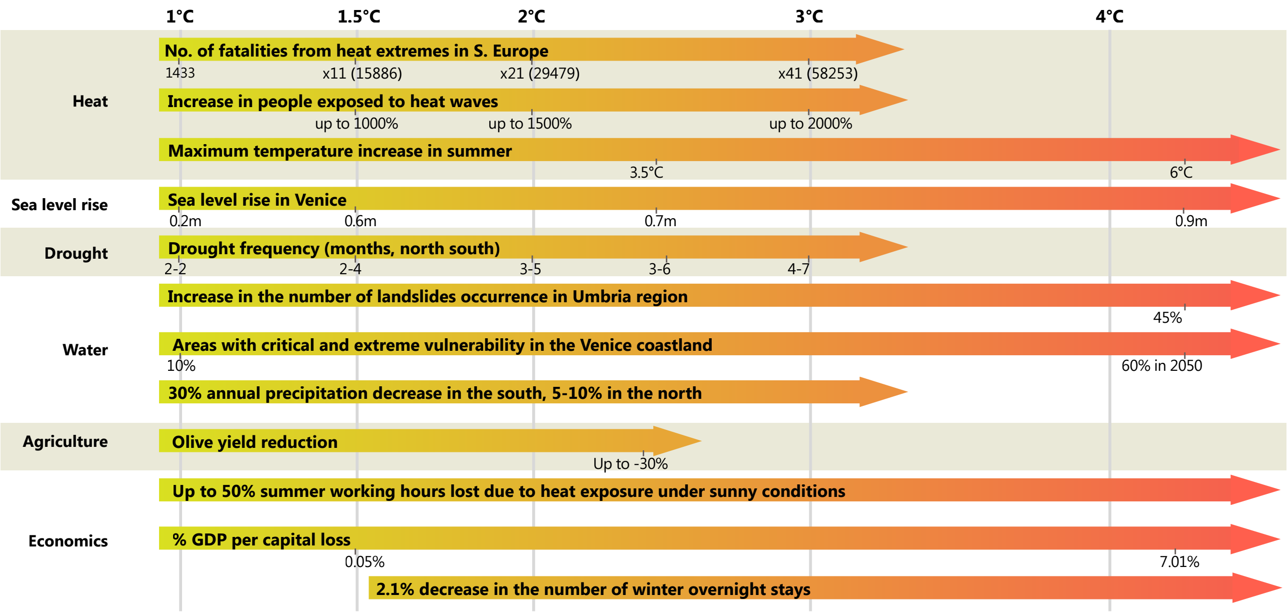


Figure 12. Projected impacts of climate change on population, sea level, weather, resources, agriculture, and economy (adapted from climate-analytics, 2021[72]).

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 fertiliser[76]. Annex A.1 describes these constraints as well as the priority uses of the main types of biomass.

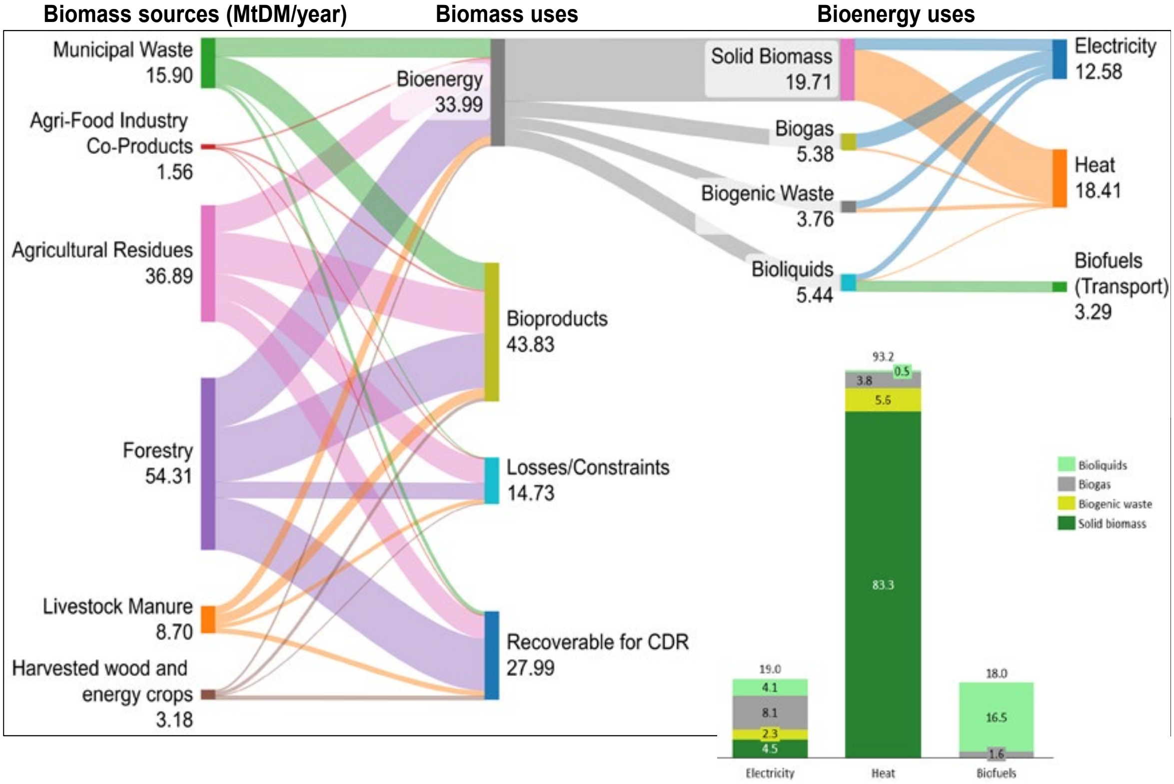


*Figure 13. (Left) Summary of biomass sources and quantities (Mt dry basis per year) and their main uses, as detailed in Table A.1. (Right) Bioenergy **produced** from existing biomass plants to generate electricity, heating, and biofuels.*

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 readiness[86].

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 annually[87], corresponding to roughly **1.9 ktCO$_2$e/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 MtCO$_2$ by 2030 and scale up to 80 MtCO$_2$ by 2040. Italy's share is estimated at **46 ktCO$_2$ by 2030** and **1.6 MtCO$_2$ 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 MtCO$_2$** per year. Most of this potential (46.6 MtCO$_2$) comes from combustion processes, with a smaller contribution 1.9 MtCO$_2$) 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 GSE[83] reactor atlas, alongside Figure 14 (right) showing the potential CO_2 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 Hub[84] (see section 3.7 on CO_2 storage). Focusing on these larger and better-located facilities, **the realistic BECCS potential of existing reactors** decreases to **13 $MtCO_2e$/year**.

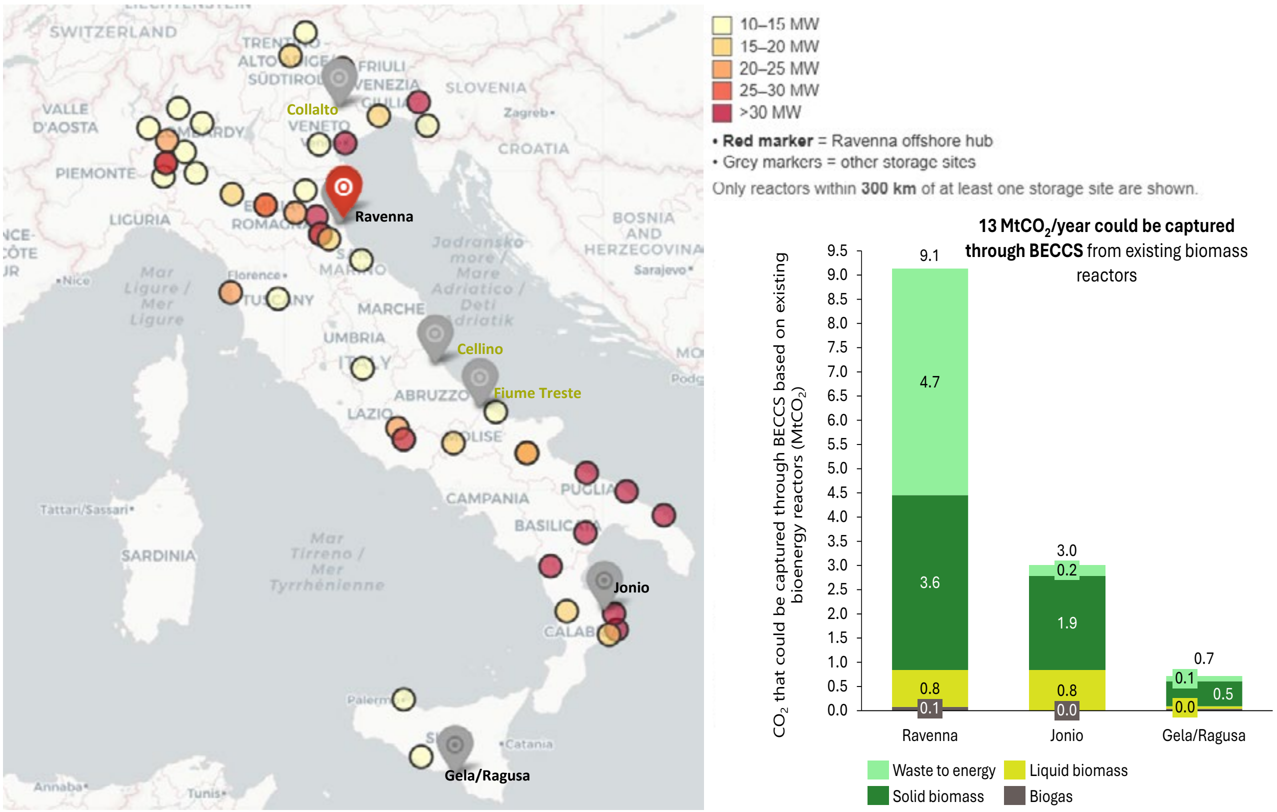


Figure 14. (Left) Location of bioenergy reactors above 10 MW and within 300 km of an existing (Ravenna hub in red) or potential CO_2 storage hub. Circle fills represent the bioenergy capacity range. Other potential CO_2 storage sites (Jonio and Gela/Ragusa) are depicted in grey. Data from GSE[83] reactor atlas. (Right) Potential of CO_2 removed per year through BECCS from existing reactors above 10 MW divided by type of reactor most feasible CO_2 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 CO_2 into dissolved ions like bicarbonate that can store carbon over long timescales, providing permanent CO_2 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 CO_2 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** (ISTAT[91] 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 amendments[93] 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 CDR[94]. 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 practices[92]. 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 products[95]. The newly licensed 20-year *Dosseni* concession in Trentino is the only officially documented new extraction site[96].

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 Italy[97]. 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 characterised[99].

3.6.2 Basalt

Italy produced approximately **9.02 Mt** of basalt in 2022 (ISTAT[91] 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 applications[100]. 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.

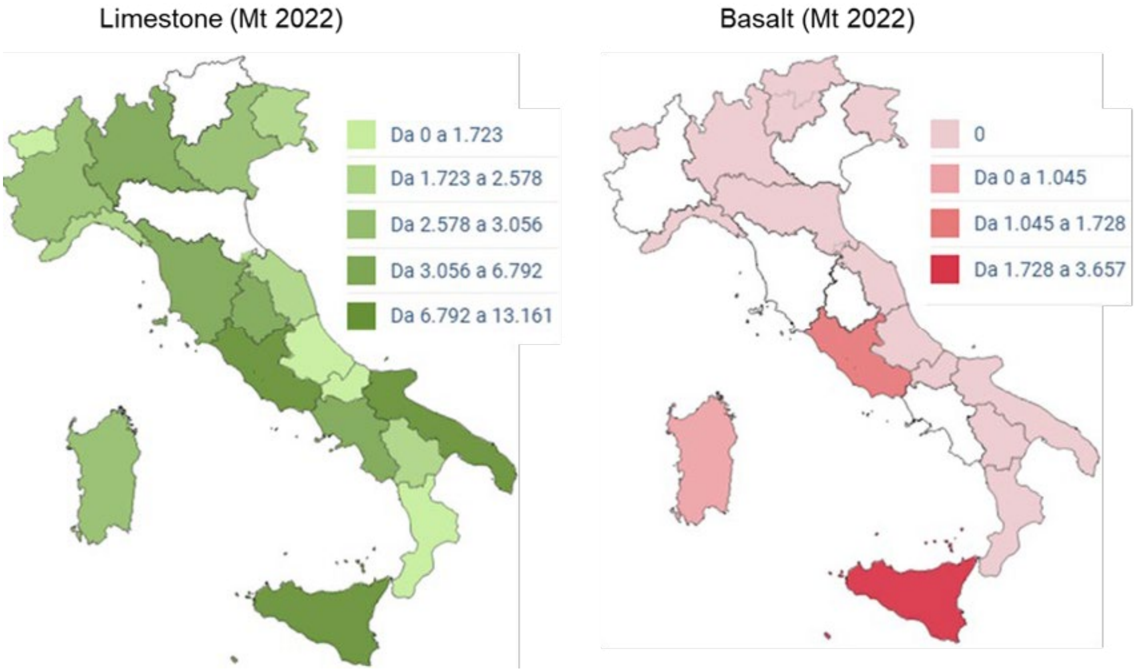


Figure 15. Geographic distribution of limestone and basalt production (ISTAT[91]).

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 CO_2 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 m^3 (1.8-2.5 Mt) before 2030[103], 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 used[106].

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 recycled[107]. 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 tCO_2 per ton of material[108,109].

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*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.

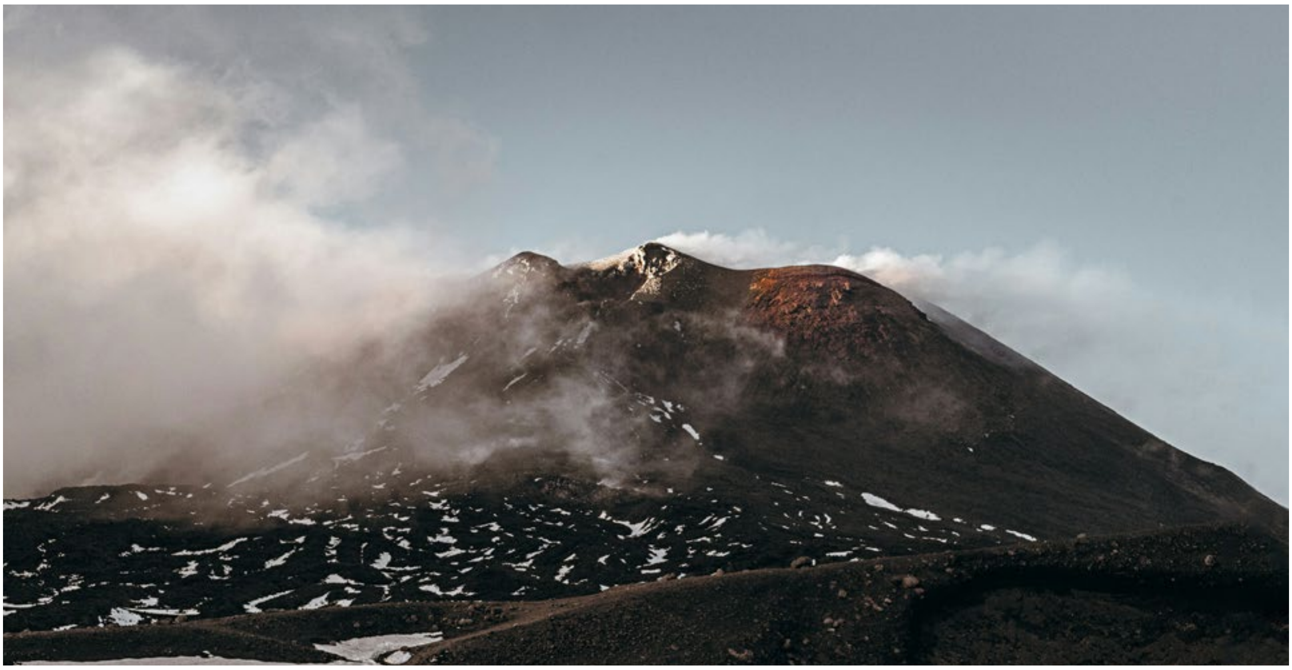
The unrecovered **11.7 Mt** of CDW could therefore be used for storage with *ex-situ* mineralisation. Given its high heterogeneity and contamination, a conservative assumption is that only ~30% can be upgraded into suitable concrete-rich feedstock (e.g. recycled concrete aggregate and fines) - equivalent to ~**3.5 Mt/year potentially available for ex-situ mineralisation.** CO_2 uptake varies with composition and processing quality, but for concrete-rich CDW typical values range from 10–57 kg CO_2 per tonne, corresponding to 0.010–0.057 tCO_2 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 2024[110]. 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 processes[111].

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 storage[80].

European steel production is projected to grow by 27% by 2030[112], a trend likely to extend to Italy despite recent global overcapacity concerns[113]. 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 targets[113]. Under these assumptions, approximately **1.27 Mt of steel slag could be available annually for CO_2 storage through *ex-situ* mineralisation by 2030.**



3.7 Geological CO_2 storage

CO_2 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 CO_2 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 CO_2 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 CO_2 storage ranges from 4-20 $GtCO_2$[123]. Within this range, deep saline aquifers account for an estimated 2.95–11.8 $GtCO_2$ (assuming a storage efficiency of 1–4%)[124], although more recent studies suggest a narrower estimate of around 4.67 $GtCO_2$[123]. Additional storage potential is estimated at 1.81–3.42 $GtCO_2$ in oil and gas fields, and approximately 71 $MtCO_2$ in coal seams. Combining these components yields a total cumulative storage capacity of roughly **6.55–8.16 $GtCO_2$, based on the more recent and conservative estimates** across different geological formations[123].

Geological CO_2 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 CO_2 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 CO_2 transport networks and storage.** These provisions are intended to facilitate the emergence of CO_2 infrastructure and hub development, including conditions that can enable third-party access where applicable.

3.7.2 The Ravenna CCS Project and market interest

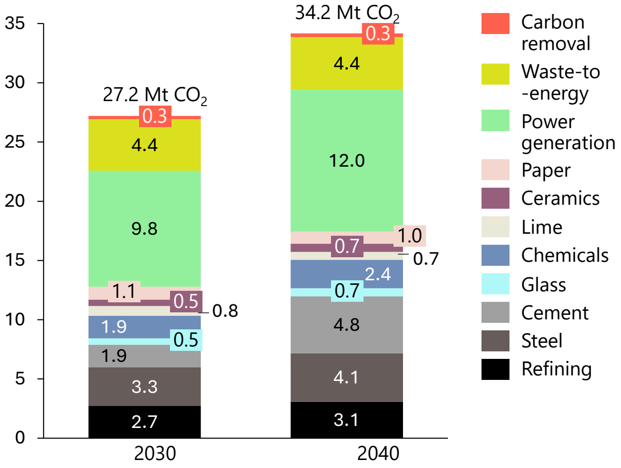
The **Ravenna CCS** Project[84], commissioned by Eni S.p.A. and Snam, represents the only large-scale working geological CO_2 storage initiative in Italy, and one of the few in the EU with potential capacities surpassing a million tons per year[126]. This site can hold cumulatively over 515 $MtCO_2$, and it has been operating a pilot injecting 25 $ktCO_2$/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 CO_2 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 CO_2 to Ravenna. The survey[127] indicates **potential demand of more than 34 $MtCO_2$ 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 CO_2 between 2027-2040, and more than 700 Mt between 2027-2050[127]. The PNIEC-202418 also reports a cross-sector interest in deploying CCS of more than 30 $MtCO_2$ 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 CO_2 from waste-to-energy facilities (in yellow), which can be considered CDR when captured and stored. Assuming a 50–60% biogenic share in the CO_2 from waste to energy (ESWET-2023)[128], this implies that CDR-related demand could represent around 9–11% of the CO_2 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 CO_2 captured are expected to increase while the amounts from waste to energy remain constant.

Market interest for industrial point-source CCS



CO_2 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. CO_2 storage capacities will need to be significantly increased to satisfy market demand, meet Italy's Long-Term Strategy[1] ambition to reduce hard-to-abate emissions from all sectors by 2050, and provide sufficient injection capacity for other CDR methods requiring geologic CO_2 storage.

Figure 16. (Top) Active CO_2 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 CO_2 storage sites

In addition to Ravenna CCS, other CO_2 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. CO_2 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 MtCO$_2$**, with an annual injection potential of **23-29.5 MtCO$_2$/year.** This represents only a small portion of the total storage capacity of oil and gas fields reported in the literature (3.42 GtCO$_2$)[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 CO_2 storage which have an estimated cumulative capacity of **4.7 GtCO$_2$**[123] within a wide storage range of 2.95-11.8 GtCO$_2$.

If all proposed depleted hydrocarbon fields and deep saline aquifers were to become operational CO_2 storage hubs, and assuming they could each achieve injection rates comparable to the Ravenna Hub (20 MtCO$_2$/year), **Italy could theoretically reach a combined injection capacity of more than 317 MtCO$_2$/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 CO_2 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 MtCO$_2$/year) and three (60 MtCO$_2$/year) Ravenna projects. Figure 17 displays the theoretical (i.e. maximalist) annual injection capacity of Italy's potential CO_2 storage sites, assuming full injectability of low and medium risk projects; plus utilisation of 40% of unstudied hydrocarbon fields (40 MtCO$_2$/year), and 30% of deep saline aquifers (60 MtCO$_2$/year). In Chapter 7, this CO_2 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 CO_2 injection capacity of nearly **129.5 $MtCO_2$/year**. After subtracting the 31 $MtCO^2$/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 beup to **98.5 $MtCO_2$/year** for CDR by 2050.

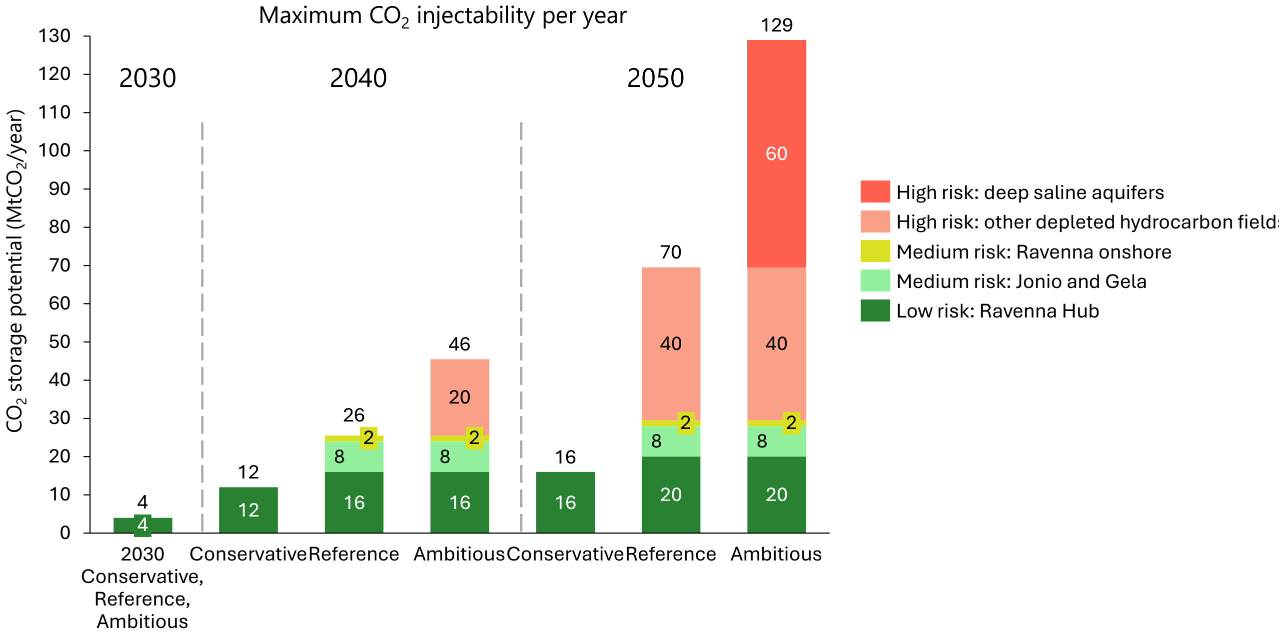


Figure 17. Theoretical injection capacity ($MtCO_2$/year) of Italy's existing and potential CO_2 storage sites.

Box 5 – Abandoned mines potentially suitable for in-situ CO_2 mineralisation

Abandoned mines represent a largely underused asset for CDR, as their extensive underground voids can be repurposed for in-situ CO_2 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 activities[116].

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 (Acquaresi, San Giovanni in Sardinia[117] with more than 79.5 Mm^3 cumulative underground voids), the Tuscan[118] pyrite mines (Gavorrano, Niccioleta with over 6.5 Mm^3 of reported excavations), and the Tassullo/San Romedio dolostone mine in Trentino[119] (with 0.6 Mm^3 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 Mm^3 of documented voids, with potential to store up to 256.3 Mt of magnesium carbonate (**128 $MtCO_2e$**) or 242.5 Mt of calcium carbonate (**107 $MtCO_2e$**). Evidence from international pilots supports this approach. In Japan (Mikasa City), CO_2-bearing slurries injected into closed underground mines mineralised in situ while improving rock stability, and broader reviews confirm the geological feasibility of mine-based mineralisation[120].

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 utilities[122].

3.8 CO_2 transport infrastructure

To date, the scale of required CO_2 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 $MtCO_2$/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 expected to export 0.2 $MtCO_2$/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 CO_2 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].

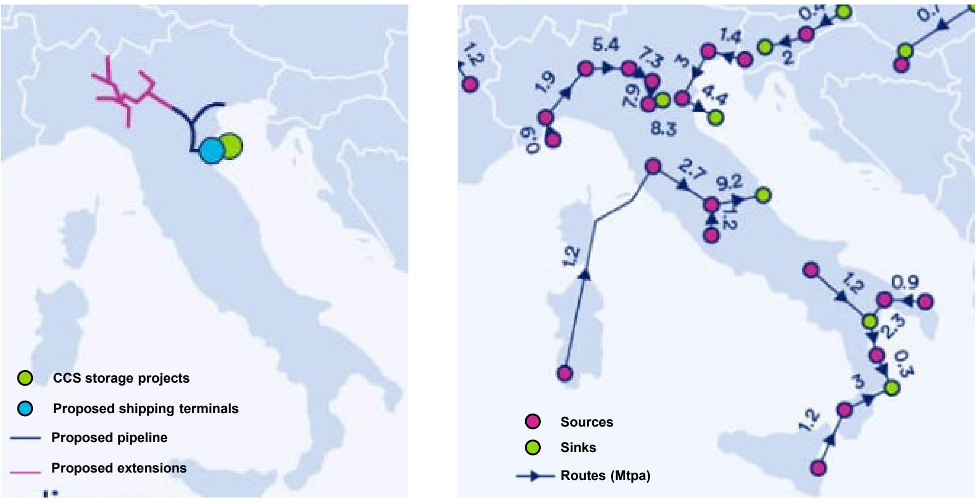


Figure 18. Proposed (left) and potential (right) CO_2 transport and storage projects and routes (adapted from: CATF[133]).

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 ERW[18]. Groundwater protection zones are strictly excluded for CO_2 injection wells and CO_2 pipelines (D.Lgs 152/2006 art. 94[136]). Legal frameworks further restrict CCS activities in the realistic scenarios: CO_2 storage is currently permitted only in authorised offshore sites such as the Ravenna CCS Hub[138] (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 tCO_2 stored, and the designation of CO_2 pipelines as public-utility infrastructure under national expropriation law. Frequent wildfires (45.8 kha burned in 2024[139]) 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 CO_2 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 CO_2 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. CO_2 storage capacity emerged as the primary limiting factor, even when assuming that by 2050 Italy could rely on a combined 98.5 $MtCO_2$ 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 $MtCO_2$/year by 2050.

Unless specified otherwise, the theoretical CDR potential (in $MtCO_2$/year) of each method was computed by multiplying the total amount of a resource allocated to a method by a conversion factor ($MtCO_2$/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 $MtCO_2$** 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 $MtCO_2$/year), mostly from agroforestry, cropland management and afforestation and reforestation. **Biomass conversion methods follow** with a total of nearly 78 $MtCO_2$ removed per year, with BECCS being the main contributor followed by biochar. **DACCS has considerable potential** (~33 $MtCO_2$/year), despite being limited by CO_2 injection capacity. **Geochemical methods** contribute with ~6 $MtCO_2$/year, of which ocean alkalinity enhancement represents the majority. Ex-situ mineralisation methods were also considered and were added as storage capacity (~2.12 $MtCO_2$/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 $MtCO_2$ 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** (IPCC[7]). **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 $MtCO_2$/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 $ktCO_2e$/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 $MtCO_2$/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 MtCO$_2$/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 MtCO$_2$/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 (MtCO$_2$/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 MtCO$_2$/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 CO_2 storage capacity,** which limits both BECCS and DACCS. Based on the estimated capacities in Chapter 3 (129.5 $MtCO_2$/year), around 31 Mt/year are expected to be used by industrial point-source CCS, while BECCS would require nearly 68 $MtCO_2$/year. The residual annual injection capacity for geological CO_2 storage (nearly 3330 Mt) plus the CO_2 storage potential of ex-situ mineralisation (2.12 $MtCO_2$/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 CO_2 storage limits the scale of deployment

In addition to geological CO_2 storage, additional CO_2 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 $MtCO_2$/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 $MtCO_2$/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 CO_2 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 $MtCO_2$/year** by 2050, compared with 239 $MtCO_2$/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 $MtCO_2$/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 MtCO$_2$e**, 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 tCO$_2$e per person and 240 gCO$_2$e per EUR of GDP, compared with the EU-27 averages of 8 tCO$_2$e/person and 247 gCO$_2$e/EUR[143]. According to ISPRA[23], 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 CCS[1]. Current planning focuses on achieving and maintaining neutrality by 2050, without quantified milestones for a net-negative trajectory thereafter.

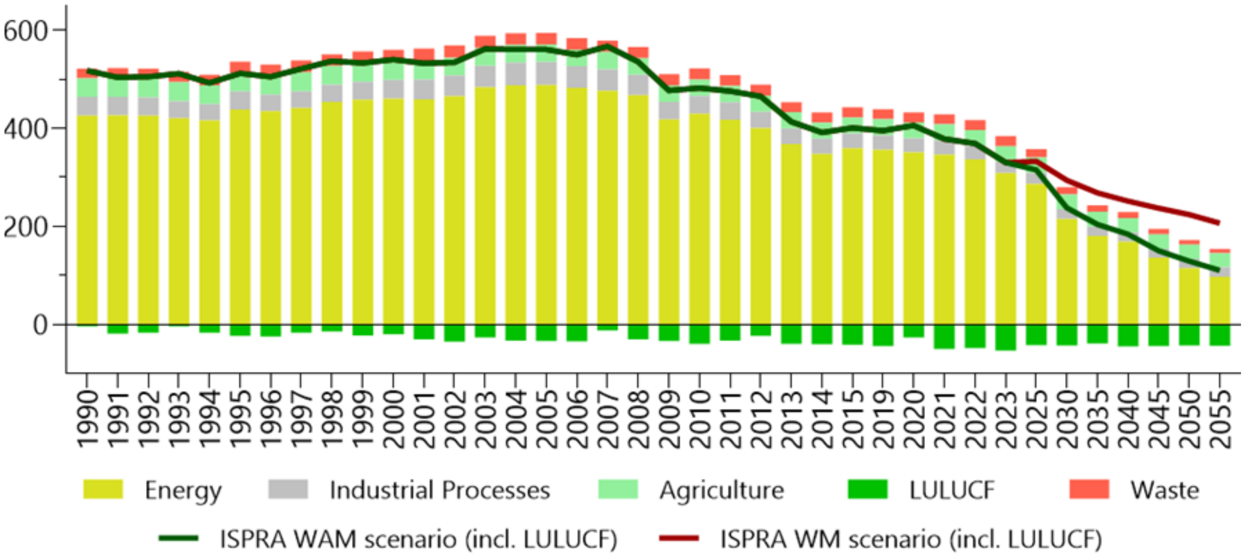


Figure 19. Italy's historical GHG emissions and 2055 projections. The green line shows the ISPRA "with additional measures" (WAM) scenario (including LULUCF), while the red line represents the "with current measures" (WM) scenario (incl. LULUCF).

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[*] 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 CO$_2$e) and –48.1% by 2050 (271.42 Mt CO$_2$e) 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 $MtCO_2e$ in net removals from this sector by 2030[147]. 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 them[148]. 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 reporting[149].

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 lever[18] 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 $MtCO_2e$ net removals by 2030**[144], which it currently exceeds: the latest inventory data shows net removals of about –53.6 $MtCO_2e$ 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 CO_2 captured through CCS and CCUS is estimated at 20–40 $MtCO_2$ per year by 2050[18], constrained by CO_2 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 CO_2 transport and storage.** The Mediterranean CCS Plan[150] and related Projects of Common Interest, notably the CALLISTO Mediterranean CO_2 Network[130], which integrates the Ravenna CCS hub as an open-access storage site for CO_2 captured in Italy and France, and the Prinos CO_2[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% reduction[151]. 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 target[144], 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 "AdriatiCO_2" project[155], connected to the Ravenna CCUS Hub; the CUSTARD project (also referred to as "CAPTURESTE" by Herambiente[156]); as well as INDIGO[157] and Re-Tyre CO_2[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 CO_2 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 CO_2 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 CO_2 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 CO_2 for offshore geological storage, a key step toward shared regional storage hubs in the Mediterranean[167].

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/EU[168] 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 alternatives[171].

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 CO_2 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 $MtCO_2$ 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 gap[173]. 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 CO_2 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	***Weaknesses***
• 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)	• No national climate law or climate neutrality objective at the national leve • 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	***Threats***
• Development of CfDs for CO_2 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 CO_2 export infrastructure with Greece, opening cross-border transport and storage options	• 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, 2023[174]; Meyer-Ohlendorf & Spasova, 2022)[175].

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

CO_2 management includes industrial and energy companies engaged in the capture, transport, utilisation, and permanent storage of CO_2 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 AzzeroCO_2, Carbon Credits Consulting, Carbonsink, to platforms like CO_2 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 MtCO_2 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 CO_2 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 CO_2 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 CO_2 Network and the Prinos CO_2 Storage project – both designated as Projects of Common Interest by the EU – further signals a shift toward regional integration of CO_2 transport infrastructure, strengthening Italy's strategic role in the emerging European CDR ecosystem[176].

Box 7. Ravenna CCS: Italy's first industrial-scale CO_2 storage facility

The Ravenna CCS Phase 1 project is Italy's first industrial-scale CO_2 capture and storage facility and commenced operations in August–September 2024. The project captures emissions from Eni's Casalborsetti gas treatment centre, with a capacity of about 25,000 tonnes of CO_2 per year and a capture efficiency above 90% (peaking at 96%). The captured CO_2 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 MtCO_2 per year by 2030, with potential to expand to 16 Mt annually depending on market demand. With an **estimated storage capacity exceeding 500 MtCO_2** in Adriatic reservoirs, Ravenna CCS is positioned to become a Southern European hub for decarbonisation. Ravenna's expansion is incorporated into the CALLISTO Mediterranean CO_2 Network, which is supported by the EU. This network envisions the permanent storage of captured CO_2 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 CO_2 project in northern Greece, developed by Energean, will convert the depleted Prinos oil field into a permanent CO_2 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 CO_2 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 CO_2 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 CO_2 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 $MtCO_2e$ (2023) correspond to a carbon-intensity ratio of 0.155 t CO_2 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 CO_2 / k € GDP) (2023)	0.168
GDP per capita (k €)	38.3
HDI	0.915
CO_2 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: ISTAT[178]; UNDP[180.]

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 policy[183].

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 seats[184].

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 targets[186]. 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 concern[187]. 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 benefit[191]

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 dependence[199].

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 workers[202]. 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 geo-biology 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 1976[18]. Alkaline construction and demolition wastes - such as **recycled concrete aggregates and fines - can absorb CO_2 through mineralisation and CO_2-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-up[204].

Wastewater residues

Italy's wastewater sector generates about 3.2 Mt of sludge annually and over 450,000 t of defecation gypsum[80]. 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 streams[205].

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 residues[206]. Evidence shows that ultramafic mine tailings and steel slags can permanently store CO_2 via accelerated mineral carbonation, sometimes producing carbonated materials suitable for construction uses[207]**.** European CCS hubs in industrial port areas such as Porthos[208] and Northern Lights[209], demonstrate how refineries and other heavy industries can share transport and offshore storage infrastructure – an approach Italy could adapt[210]. However, investment remains constrained by heterogeneous site conditions, long-term liability concerns and the lack of a dedicated framework for mineral CO_2 storage and CO_2 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 workers[212]. 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, 2025[280]). 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 identity[215]. 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 Ferla[282] 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-MtCO_2/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 CO_2 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
Afforestation / reforestation	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.
Soil carbon sequestration	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.
Peatland & coastal wetlands	Acknowledged for biodiversity but remains niche				Strong co-benefits but geographically limited and with high upfront costs.
Durable biobased products	Potential in wood products/biomaterials	Cautious	Considered supplementary	Supportive only within robust circular systems	Useful for markets/circularity; integrity depends on product lifespan.
Biochar	Soil improver but faces market cost and supply issues				Promising yet constrained by biomass supply, MRV/permanence uncertainty, and low policy visibility.
BECCS	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.
Biomass sinking & burial	Not relevant for Italy	More research required	Not a short-term priority	Too experimental	Experimental; uncertainty around permanence and ecological impacts.
Enhanced rock weathering	Operational bottleneck		Emphasis on logistics and processing capacity	Environmental concerns	Soil co-benefits; limited by grinding, logistics, acceptance.
Ocean alkalinity enhancement	Too uncertain		Uncertain but strong potential recognised	High-risk/under-researched	Scientifically promising but constrained by ecological, MRV, and regulatory uncertainty.
Carbon mineralisation (in/ ex-situ)	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.
DACCS	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.
DOCCS	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 selfassessed 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 highemitting 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 414/2025[23;] the PNIEC-2024[18], 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 MtCO$_2$ 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 MtCO$_2$/year), and strengthened removals. **Under this pathway, residual emissions fall to 68–100 MtCO$_2$** 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 MtCO$_2$eq 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 MtCO$_2$ of CCS, **none provide a clear CDR roadmap**. They also rely heavily on LULUCF, expected to deliver at least 40 MtCO$_2$ 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 $MtCO_2$ per year** by 2050, which, together with a natural sink of around 35 $MtCO_2$/year (as per LTS), results in a total carbonremoval capacity of **52.6 $MtCO_2$ annually** - insufficient for achieving net-zero emissions by 2050. The CDR potentials in this scenario is shown in Figure 21.

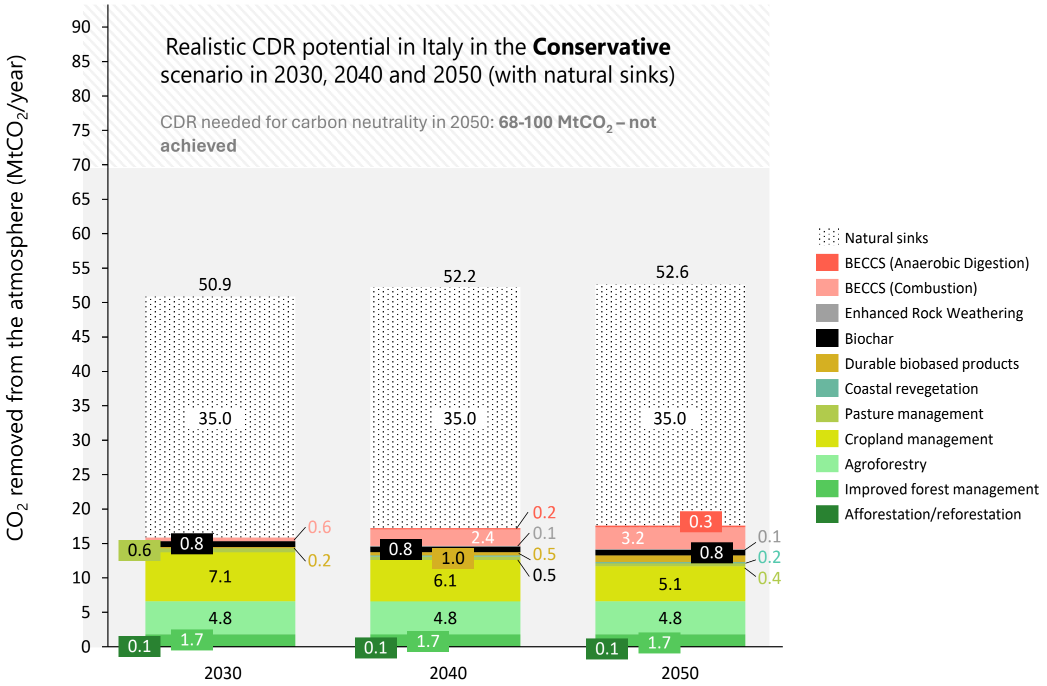


Figure 21. The Conservative scenario across 2030, 2040 and 2050

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 $MtCO_2$/year, due to a tendency to delay payments and permitting while **coastal revegetation** and **peatland restoration** account for a minimal removal of 0.15 $MtCO_2$/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 $MtCO_2$/year in total by 2050. **Durable biobased products** (1 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2$/year** by 2050 due to limited policy support and restricted CO_2 storage capacity, largely confined to the Ravenna hub and prioritised for point-source CCS (11 $MtCO_2$/year), leaving only 3.4 $MtCO_2$/year of storage available for BECCS. Few existing bioenergy plants add CCS, which remove only around 0.8 $MtCO_2$/year by 2050 through BECCS with combustion. BECCS with combustion and gasification sequesters just over 2.3 $MtCO_2$/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 $MtCO_2$/year, with only a small number of existing biomethane plants equipped with CCS.

Enhanced rock weathering contributes only 0.1 $MtCO_2$/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 MtCO_2 per year** by 2050 which, together with a natural sink exceeding 47 MtCO_2 per year, results in a total carbon removal capacity of roughly **104 MtCO_2** 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.

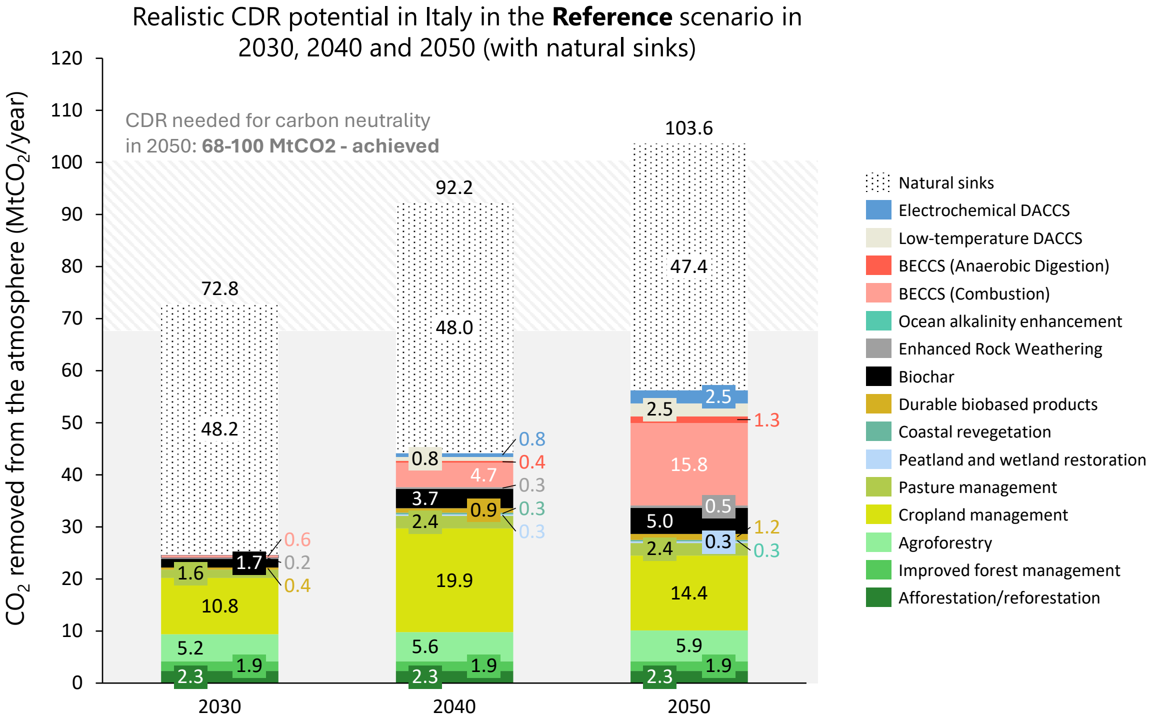


Figure 22. The Reference scenario across 2030, 2040 and 2050.

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 CO_2 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 MtCO_2/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 MtCO_2/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 MtCO_2/year, while **wetland** and **peatland restoration** contribute with 0.14 MtCO_2/year and 0.16 MtCO_2/year respectively, thanks to policy and funding support.

In this scenario **biomass conversion methods** also play an important role collectively delivering 23 $MtCO_2$/year. **Biochar** sequesters 5 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2$/year by 2050. **BECCS (combustion)** delivers around 6.9 $MtCO_2$/year from existing biomass plants, supported by a gradual scale up of CO_2 storage sites across Ravenna CCS, Jonio and Gela. **BECCS (combustion and gasification**) delivers around 9 $MtCO_2$/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 $MtCO_2$/year removals by 2050, , with the resulting CO_2 stored mostly in geological storage and partially in ex-situ mineralization).

National CO_2 storage capacity is assumed to reach 44 $MtCO_2$/year by 2050, with 22 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2$/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 CO_2 storage and other resource potential, resulting in a CDR capacity of more than **91 $MtCO_2$ per year** which, together with a natural sink exceeding 47 $MtCO_2$ per year (as per PNIEC-2024 and ISPRA-414 in the Reference scenario), results in a total carbon removal capacity of **almost 139 $MtCO_2$ annually** by 2050, achieving net-negative emissions when considering the natural sink. The CDR potential of this scenario is shown in Figure 23

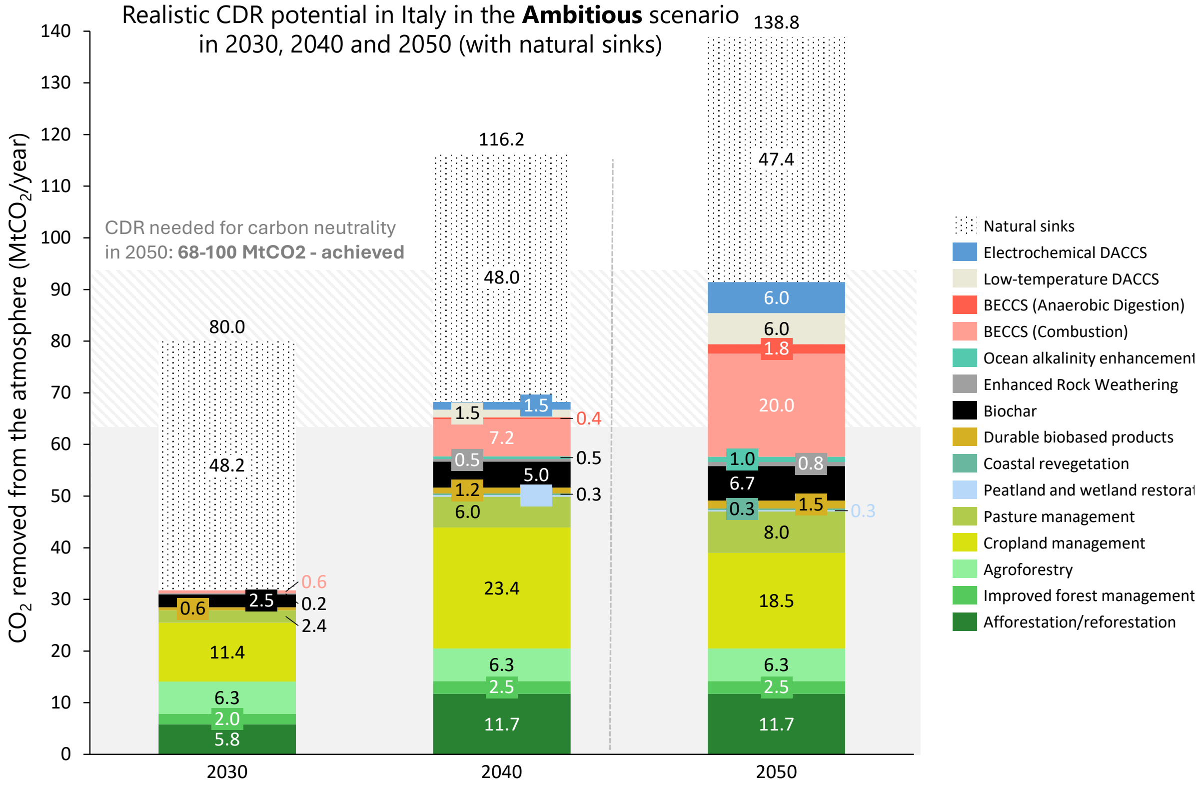


Figure 23. The Ambitious scenario across 2030, 2040 and 2050.

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 CO_2 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 $MtCO_2$/year by 2050, with 33 $MtCO_2$/year ring-fenced for high permanence CDR.

Ecosystem management methods collectively contribute almost 48 $MtCO_2$/year by 2050. **Cropland management** contributes the most (18.5 $MtCO_2$/year) supported by expanded CAP incentives that support soil carbon sequestration practices. **Afforestation, reforestation and certified forest management** contribute 14.2 $MtCO_2$/year, supported by enhanced and optimally distributed CAP-related funding, followed by Agroforestry and pasture management. **Coastal revegetation** of Posidonia meadows contributes 0.3 $MtCO_2$/year, while **wetland** and **peatland restoration** contribute with 0.14 $MtCO_2$/year and 0.16 $MtCO_2$/year respectively, thanks to policy and funding support

In this scenario, **biomass conversion methods** deliver around 30 $MtCO_2$/year by 2050. **Biochar** delivers over 6.7 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2$/year of storage capacity from ex-situ mineralization.

Enhanced rock weathering scales much faster in this scenario, reaching 0.81 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2$/year by 2050 in the Ambitious scenario, which is the maximum that can be deployed with the remaining geologcal CO_2 storage capacity, after point-source CCS (41 $MtCO_2$/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.***

CO_2 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, accounting[225] 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 OAE[226] 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.

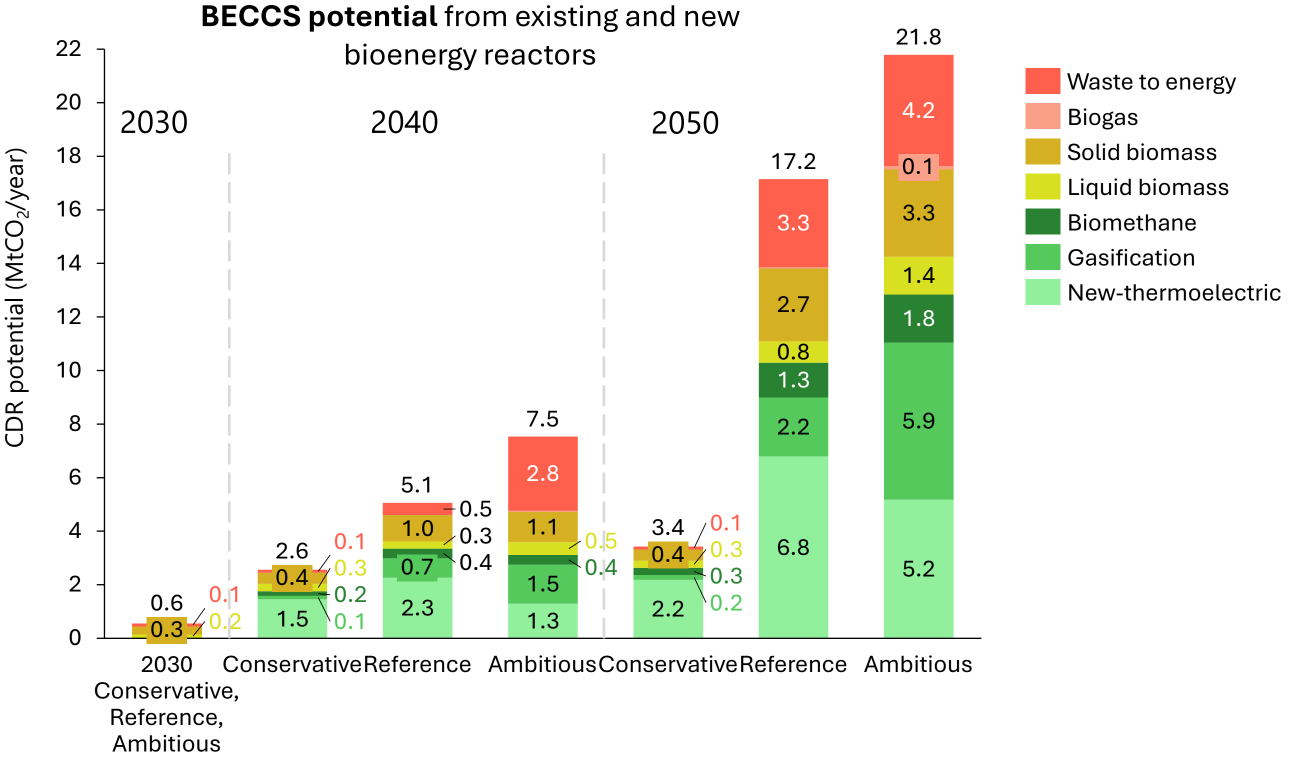


Figure 24. BECCS potential from existing biomass reactors (shades of red, yellow) and from potential mobilisation of residual biomass towards new bioenergy reactors (shades of green). BECCS deployment across the realistic scenarios is constrained by CO_2 injection capacity.

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 CO_2 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 2030,[18] increasing to 8-10 bcm by 2050[24] , 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 CO_2 storage

Market interest for CO_2 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 Hub[84]. Accounting for conservative discount factors, by 2050, geological storage projects could supply highly durable CO_2 storage of up to **14.4 MtCO$_2$/year** in the Conservative scenario, **44 MtCO$_2$/year** in the Reference scenario, and **74 MtCO$_2$/year** in the Ambitious scenario. Italy's Ravenna roadmap - 4 MtCO$_2$/year by 2030, 12 MtCO$_2$/year by 2035, and a 16–20 MtCO$_2$/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 MtCO$_2$ storage from 2030 and 2040 respectively, as per Snam market survey[127]. Figure 25 shows how geological storage CO_2 is assumed to be allocated across CCS, BECCS and DACCS in the realistic scenarios.

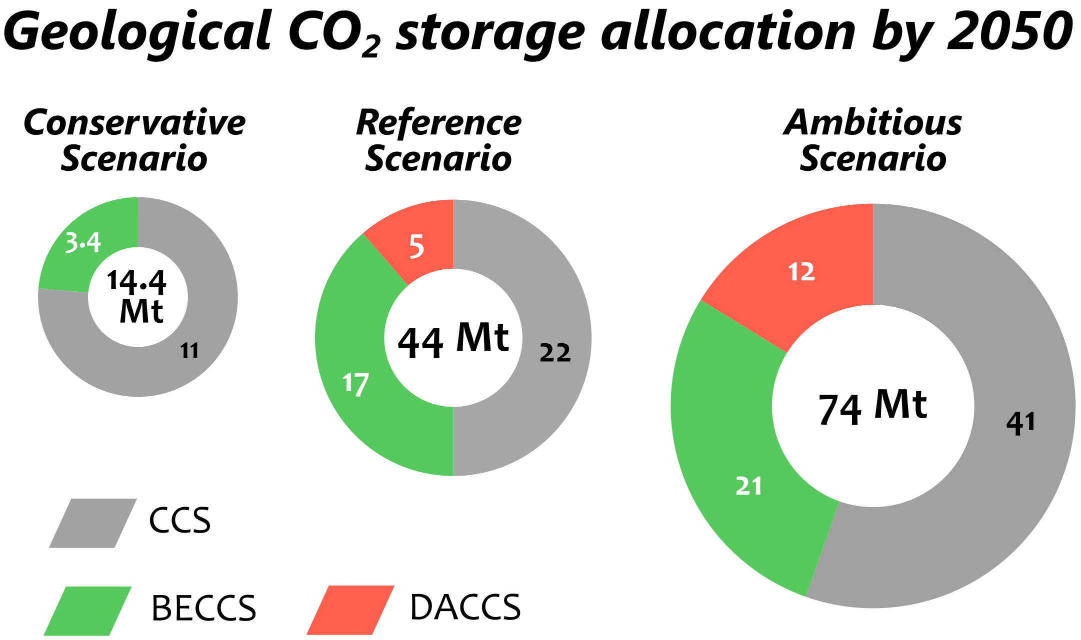


Figure 25. Allocation of geological CO_2 storage capacity in 2050 between CCS and CDR methods across the three realistic scenarios.

Geological CO_2 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 CO_2 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 CO_2 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 ofthe Ravenna hub stores about **14 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2$/year** of CO_2 storage by 2050 (compared to 129 in the theoretical potential). These values represent the total CO_2 geological storage potential; the next step is to allocate this capacity between CCS and CDR.

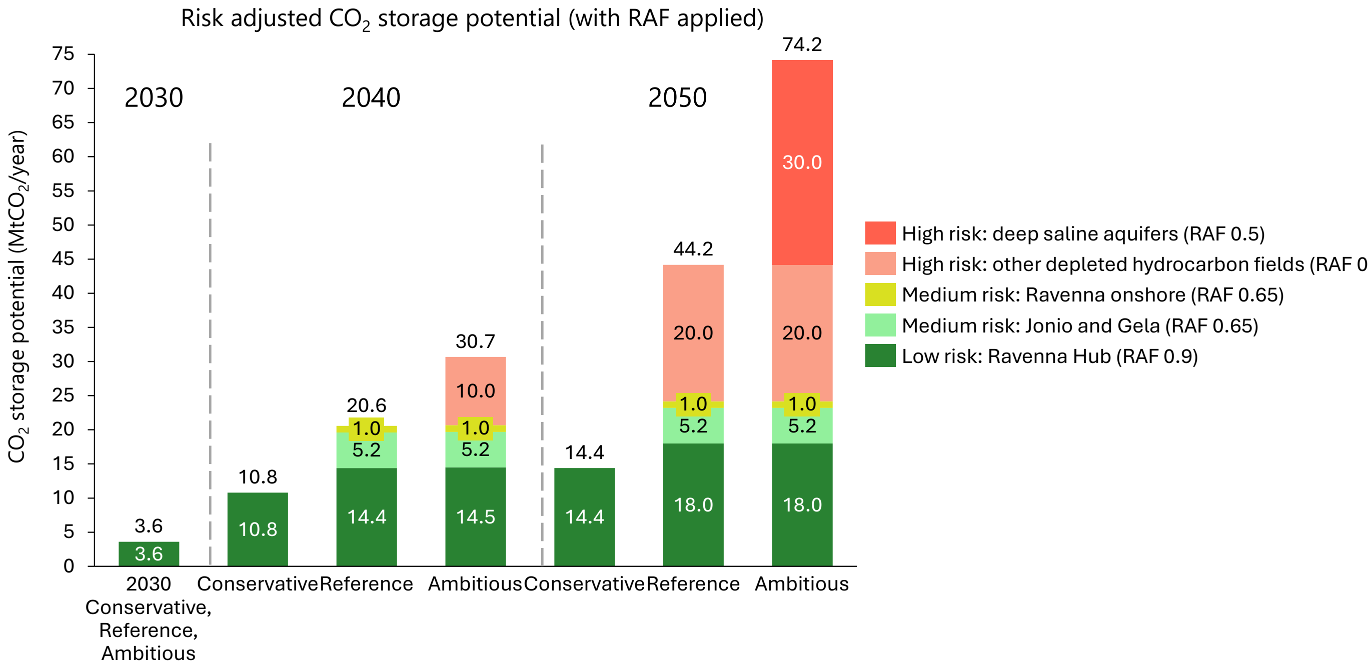


Figure 26. Risk-adjusted CO_2 storage potential ($MtCO_2e$/year). The risk adjustment factor (RAF) is applied on the theoretical CO_2 storage potential analysed in section 3.7.3

Geological CO_2 storage: allocating to CCS and CDR

To allocate CO_2 storage capacity to CCS and CDR in the realistic scenarios, this study started from the CCS marketinterest data from the Snam survey[127] (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 pointsource 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 CO_2 storage to CDR is therefore as follows:

- In the **Conservative scenario**, limited storage capacity lowers CCS interest. 11 $MtCO_2$/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 $MtCO_2$/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 CO_2 storage development enables industry to deliver its full projected CCS contribution of 41 $MtCO_2$/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 CO_2 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 CO_2 storage: allocating to BECCS and DACCS

With the realistically available geological CO_2 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 $MtCO_2$/year in the Reference scenario and 12 $MtCO_2$/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 CO_2 capture and storage and evaluated the share of emissions that could be addressed through point-source CCS. For each industrial sector, projected CO_2 capture volumes for 2030, 2040, and 2050 (extrapolated) were derived from the Snam market survey[127]. 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 $MtCO_2$/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 $MtCO_2$/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.

CO_2 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 CO_2 storage in Italy. As estimated in Chapter 4, the combined use of available olivine (1.72 MtCO2/year), steel slag (0.25 $MtCO_2$/year), cement kiln dust (0.03 $MtCO_2$/year), and concrete demolition waste (0.12 $MtCO_2$/year), could enable up to **2.12 $MtCO_2$/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 $MtCO_2$/year** in Lombardy alone[108].

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 $MtCO_2$/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 $MtCO_2$/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 CO_2 injection capacity.

This additional storage capacity given by ex-situ mineralization is allocated to BECCS with anaerobic digestion, reflecting strong alignment in CO_2 stream characteristics, infrastructure, and regional integration. Anaerobic digestion provides a concentrated, biogenic CO_2 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 CO_2 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 MtCO$_2$** per year in 2050, with a midpoint of **84 MtCO$_2$/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 MtCO$_2$ of biogenic emissions from agriculture and biogenicwaste sectors and 57 MtCO$_2$ 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 MtCO$_2$/year**, with 57 MtCO$_2$ classified as **fossil**, and 27 MtCO$_2$ as **biogenic**. Figure 27 describes how the designed scenarios apply the *like-for-like* principle.

The **Reference scenario** assumes point-source CCS for 22 MtCO$_2$/year from industry (independent from CDR), lowering the residual fossil emissions

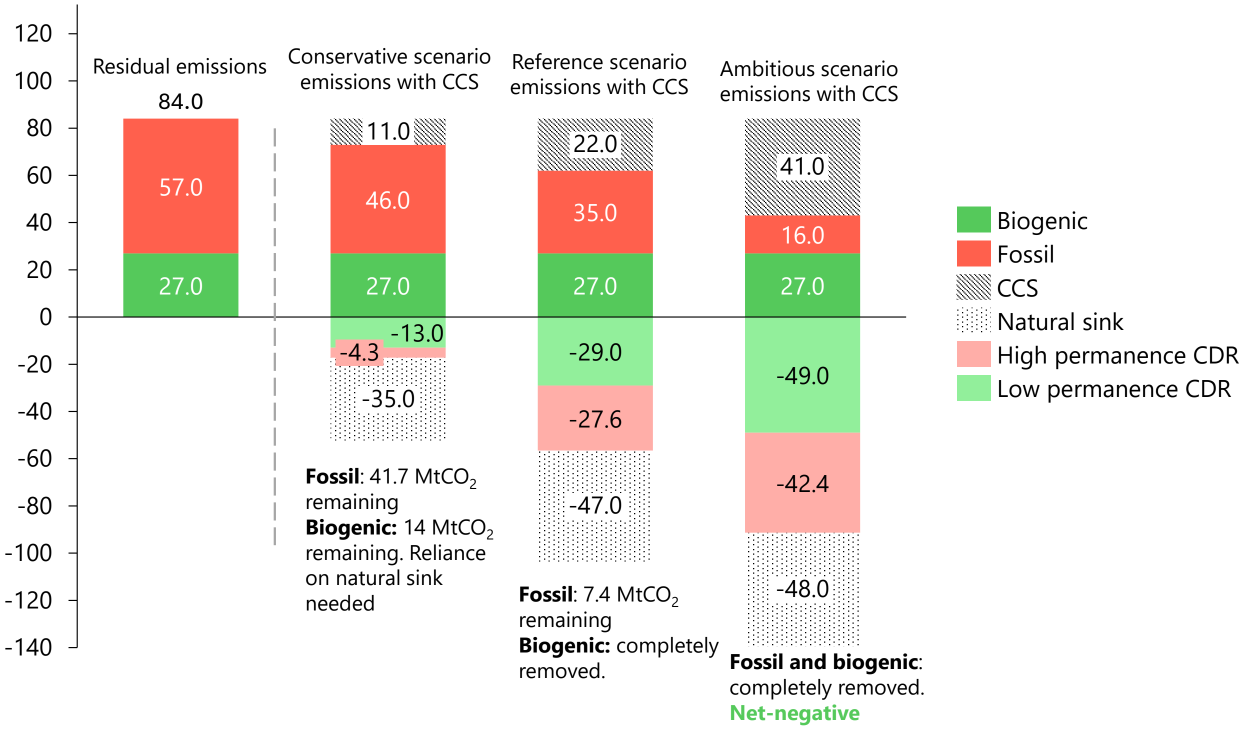


Figure 27. The like-for-like principle applied to the 2050 Conservative, Reference, and Ambitious scenarios. Biogenic emissions are completely removed by nature-based CDR methods without relying on the natural sink in the Reference and Ambitious scenarios. Fossil emissions are completely removed by highly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

to 35 $MtCO_2$/year. These are *almost* fully removed through durable CDR methods (DACCS, BECCS, biochar OAE and ERW), by using the full remaining CO_2 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 $MtCO_2$ 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 $MtCO_2$/year**, 2 Mt more than is theoretically needed, and without relying on the expected forest sink (47 $MtCO_2$/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 $MtCO_2$/year** of durable CDR methods and **11 $MtCO_2$/year** from point-source CCS by 2050, missing the like-for-like target by **41.7 $MtCO_2$/year**. Nature-based methods reach **13 $MtCO_2$/year** and require the expected **35 $MtCO_2$/year** from natural sinks to comply with the needed **27 $MtCO_2$/year** of biogenic emissions.

Conversely, in the **Ambitious scenario**, Italy exceeds *like-for-like* requirements, reducing **41 $MtCO_2$/year** through point source CCS, with additional durable removals of **42.4 $MtCO_2$/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 $MtCO_2$/year (48 $MtCO^2$/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 tCO_2) for each CDR method alongside projected removal volumes ($MtCO_2$) 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 expenditures[289-290]. 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 CO_2 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 MtCO$_2$/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 MtCO$_2$/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 MtCO$_2$/year by 2050**, dominated by ecosystem management methods (116 MtCO$_2$/year), biomass conversion methods (78 MtCO$_2$/year), and synthetic methods, i.e. DACCS (33 MtCO$_2$/year), with a smaller contribution from geochemical methods (6 MtCO$_2$/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 MtCO$_2$/year** in the Conservative scenario, **104 MtCO$_2$/year** in the Reference scenario, and **139 MtCO$_2$/year** in the Ambitious scenario. Only the Reference and Ambitious pathways are compatible with closing the average **84 MtCO$_2$/year** residual-emissions gap implied by Italy's Long-Term Strategy; the Ambitious scenario further enables net-negative outcomes of between 40–70 MtCO$_2$/year.

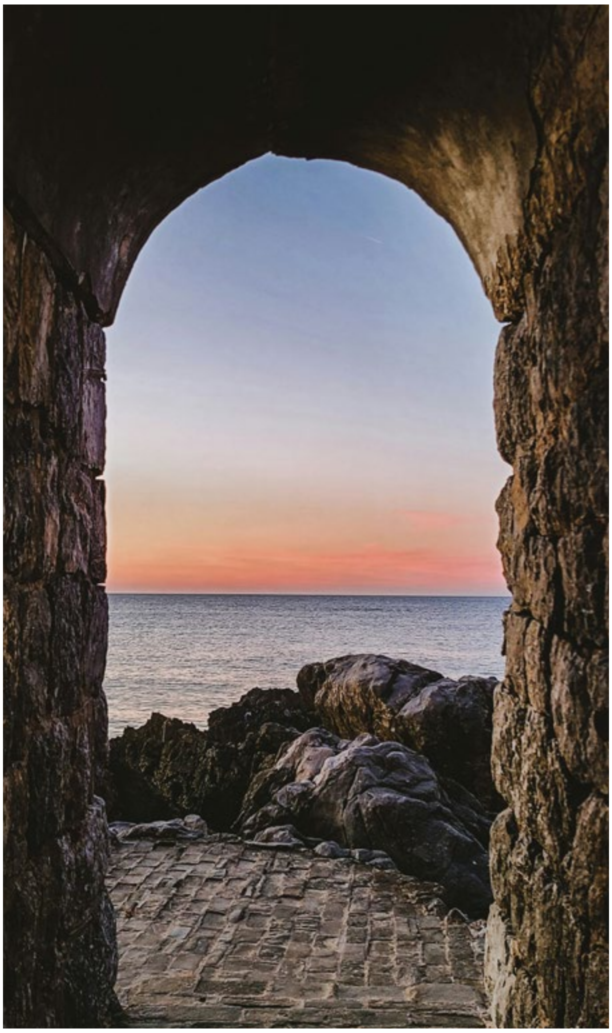
1.3 **Geological storage is the binding enabler.** Even with sufficient renewable electricity and waste-heat potentials, CO$_2$ injection capacity limits durable CDR. This assessment assumes a theoretical storage capacity of about 100 MtCO$_2$/year (98.5 MtCO$_2$/year geological plus 2.12 MtCO$_2$/year of mineralisation) as the long-term maximum, with realistic pathways delivering 14.4, 44, and 74 MtCO$_2$/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 MtCO$_2$/year, while soil-carbon, agroforestry, and cropland management together contribute around 81 MtCO$_2$/year in the theoretical case and 10–48 MtCO$_2$/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 MtCO$_2$/year under plausible policies.** With current and additional biomass streams, BECCS, biochar, and long-lived biobased products can sequester 23 MtCO$_2$/year in the Reference scenario and up to 30 MtCO$_2$/year in the Ambitious scenario by 2050, compared with only 5 MtCO$_2$/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 $MtCO_2$/year in the Reference scenario and 12 $MtCO_2$/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 $MtCO_2$/year in the Reference scenario and 1.8 $MtCO_2$/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 $MtCO_2$/year by 2030 and 116 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2$/yr** from these methods, even though combined potentials exceed **40 $MtCO_2$/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 $MtCO_2$/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 $MtCO_2/yr$ 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 $MtCO_2/yr$ by 2040 and ≥100 $MtCO_2/yr$ by 2050—clarifying the expected contributions of LULUCF, biomass conversion, geochemical methods, and DACCS.
- **Lock in CO_2 storage as a strategic asset.** MASE and relevant agencies and industries must move from a single-hub model (Ravenna, up to 20 $MtCO_2/yr$) to a national network capable of 45–75 $MtCO_2/yr$ injection by 2050, fast-tracking appraisal of Ionian, Sicilian, and onshore saline formations, and aligning CO_2 pipeline planning with industrial clusters and ports.
- **Make CAP and nature-restoration spending CDR-smart.** The difference between 10 $MtCO_2/yr$ (Conservative) and 30–48 $MtCO_2/yr$ (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 $MtCO_2/yr$ of these removals can be certified and traded by 2040, rising toward the 30–40 $MtCO_2/yr$ 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 CO_2, 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 $MtCO_2/yr$ 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 CO_2 infrastructure, and provide real-world cost and MRV data, paving the way for the 25–35 $MtCO_2/yr$ from biomass conversion and 5–16 $MtCO_2/yr$ 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 $MtCO_2/year$ 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.

References

1. Ministero dell'Ambiente e della Sicurezza Energetica - MASE. STRATEGIA ITALIANA DI LUNGO TERMINE SULLA RIDUZIONE DELLE EMISSIONI DEI GAS A EFFETTO SERRA. https://www.mase.gov.it/portale/documents/d/guest/lts_gennaio_2021-pdf (2021).

2. United Nations. Paris Agreement. https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf (2015).

3. The Intergovernmental Panel on Climate Change - IPCC. Climate Change 2022: Mitigation of Climate Change. Contrib. Work. Gr. III to Sixth Assess. Rep. Intergov. Panel Clim. Chang. (eds Shukla, P. R. al.) (Cambridge Univ. Press. 2022). (2022) doi:10.1017/9781009157926.

4. WMO, W. M. O.-. WMO Global Annual to Decadal Climate Update 2025-2029. https://wmo.int/sites/default/files/2025-05/WMO_GADCU_2025-2029_Final.pdf (2025).

5. The Intergovernmental Panel on Climate Change - IPCC. Global Warming of 1.5 °C. An IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-Industrial Levels. https://www.ipcc.ch/sr15/ (2018).

6. European Commission. The European Green Deal. COM(2019) 640 final https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640 (2019).

7. The Intergovernmental Panel on Climate Change - IPCC. Factsheet: Carbon Dioxide Removal (CDR). In: Climate Change 2022: Mitigation of Climate Change — Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). https://www.ipcc.ch/report/ar6/wg3/ (2022).

8. Smith, S. M., Geden, O., Gidden, M. J., Lamb, W. F., Nemet, G. F., Minx, J. C., B., H., Burke, J., Cox, E., Edwards, M. R., Fuss, S., Johnstone, I., Müller-Hansen, F., Pongratz, J. & Probst, B. S., Roe, S., Schenuit, F., Schulte, I., Vaughan, N. E. The State of Carbon Dioxide Removal 2024 - 2nd Edition. (2024). doi:10.17605/OSF.IO/F85QJ.

9. US Department of Energy. Carbon Dioxide Removal: Purpose, Approaches, and Recommendations. https://www.energy.gov/sites/default/files/2025-01/CDR Purpose%2C Approaches%2C and Recommendations Report.pdf (2025).

10. Gooding, J. L. Geologic perspective for carbon sequestration by woody biomass burial. Sci. Technol. Energy Transit. 78, 17 (2023).

11. Wu, J., Keller, D. P. & Oschlies, A. Carbon dioxide removal via macroalgae open-ocean mariculture and sinking: an Earth system modeling study. Earth Syst. Dyn. 14, 185–221 (2023).

12. Deep Ocean Stewardship Initiative - DOSI. DOSI. (2021) Impacts of Ocean Fertilization. Deep Ocean Stewardship Initiative Policy Brief. https://www.dosi-project.org/wp-content/uploads/Ocean-Fertilization-Policy-Brief-1.pdf (2021).

13. Trompoukis, C. et al. The Role of Direct Air Capture Technologies in the EU's Decarbonisation Effort. Publication for the Committee on Industry, Research and Energy, Policy Department for Transformation, Innovation and Health, European Parliament, Luxembourg https://www.europarl.europa.eu/RegData/etudes/STUD/2025/772474/ECTI_STU(2025 (2025).

14. Qiu, Y. et al. Environmental trade-offs of direct air capture technologies in climate change mitigation toward 2100. Nat. Commun. 13, (2022).

15. Oschlies, A., Bach, L. T., Fennel, K., Gattuso, J.-P. & Mengis, N. Perspectives and challenges of marine carbon dioxide removal. Front. Clim. 6, (2025).

16. The International Energy Agency - IEA. Energy systems of Italy. https://www.iea.org/countries/italy (2024).

17. Catanzaro, M. Italian nuclear industry revival on the table. Nat. Italy (2023) doi:10.1038/d43978-023-00130-8.

18. Ministero dell'Ambiente e della Sicurezza Energetica - MASE. Piano Nazionale Integrato per l'Energia e il Clima 2024 – revisione finale. at https://www.mase.gov.it/portale/documents/d/guest/pniec_2024_revfin_01072024-pdf (2024).

19. World Nuclear News. Italy's electricity could be 20% from nuclear by 2050. World Nuclear News. https://www.world-nuclear-news.org/articles/italy-s-electricity-could-be-20-from-nuclear-by-20 (2023).

20. European Commission. Small modular reactors explained. Energy Directorate-General. https://energy.ec.europa.eu/topics/nuclear-energy/small-modular-reactors/small-modular-reactors-explained_en (2024).

21. Terna & SNAM. Documento Di Descrizione Degli Scenari 2024. https://download.terna.it/terna/Documento_Descrizione_Scenari_2024_8dce2430d44d101.pdf (2024).

22. Laboratorio REF Ricerche. Scenari Elettrici 2050: Position Paper. https://laboratorioref.it/wp-content/uploads/ref-attachments/Position-Paper_Scenari-elettrici-2050-1.pdf (2024).

23. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Rapporto 414 - Le Emissioni Di Gas Serra in Italia: Obiettivi Di Riduzione e Scenari Emissivi. https://www.isprambiente.gov.it/files2025/pubblicazioni/rapporti/rapporto-414-2025.pdf (2025).

24. Gaeta, M., Nsangwe Businge, C. & Gelmini, A. Achieving Net Zero Emissions in Italy by 2050: Challenges and Opportunities. Energies 15, 46 (2021).

25. Paardekooper, S. et al. Heat Roadmap Italy: Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps. (2018).

26. Carbon-Free Europe. Italy: 2024 country modelling and decarbonisation pathway. https://www.carbonfreeeurope.org/modelling/stories/italy-2024 (2024).

27. Autorità di Regolazione per Energia Reti e Ambiente - ARERA. Delibera 214/2024/R/TLR - Relazione Annuale Sullo Stato Dei Servizi e Sull'attività Svolta. https://www.arera.it/fileadmin/allegati/docs/24/214-24.pdf (2024).

28. TEHA Group S.p.A. and Assoclima. Italian Industry and the Energy Transition: Executive Summary. https://www.anima.it/kdocs/2174900/executive_summary_eng.pdf (2025).

29. Pastore, L. M. & de Santoli, L. 100% renewable energy Italy: A vision to achieve full energy system decarbonisation by 2050. Energy 317, 134749 (2025).

30. European Parliament Council of the European Union. Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 establishing a framework for the certification of carbon removals and amending Regulation (EU) 2018/841. Official Journal of the European Union. Retrieved from at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023L2413 (2023).

31. Papapetrou, M., Kosmadakis, G., Cipollina, A., La Commare, U. & Micale, G. Industrial waste heat: Estimation of the technically available resource in the EU per industrial sector, temperature level and country. Appl. Therm. Eng. 138, 207–216 (2018).

32. Dénarié, A. et al. Assessment of waste and renewable heat recovery in DH through GIS mapping: The national potential in Italy. Smart Energy 1, 100008 (2021).

33. Mezzera, F., Fattori, F., Dénarié, A. & Motta, M. Waste-heat utilization potential in a hydrogen-based energy system - An exploratory focus on Italy. Int. J. Sustain. Energy Plan. Manag. 31, 95–108 (2021).

34. ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT - OECD & Nuclear Energy Agency - NEA. High Temperature Gas-Cooled Reactors: Overview of the Latest Developments in Technology and Applications. https://www.oecd-nea.org/upload/docs/application/pdf/2022-06/7629_htgr.pdf (2022).

35. eurostat - European Commission. Water Statistics. Eurostat Statistics Explained. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Water_statistics (2025).

36. ISTAT. Water consumption by sector (DCCV_CONSACQUA). ISTAT Data Browser. at https://esploradati.istat.it/databrowser/#/en/dw/categories/IT1,Z0920ENV,1.0/ENV_WATER/DCCV_CONSACQUA/IT1,12_60_DF_DCCV_CONSACQUA_1,1.0 (2024).

37. CMCC. Country climate risk profile: Italy. at https://files.cmcc.it/g20climaterisks/Italy.pdf (2021).

38. Italian Government. Piano Nazionale Di Ripresa e Resilienza (PNRR). https://www.italiadomani.gov.it/content/sogei-ng/it/it/home.html (2022).

39. Ministero delle Infrastrutture e dei Trasporti - MIT. PNRR leakage program. https://www.mit.gov.it/comunicazione/news/pnrr-il-mit-assegna-293-mln-per-ridurre-le-perdite-di-acqua-potabile (2023).

40. water-reuse-europe. Policy and Regulations. https://www.water-reuse-europe.org/about-water-reuse/policy-and-regulations/.

41. Ministero dell'Ambiente e della Sicurezza Energetica - MASE. Decreto-Legge 14 Aprile 2023, n. 39 (D.L. Siccità). (MASE, 2024).

42. FAO. The future of food and agriculture: Alternative pathways to 2050. at https://www.fao.org/global-perspectives-studies/food-agriculture-projections-to-2050/en/ (2018).

43. Ministero dell'Ambiente e della Sicurezza Energetica - MASE. Componente 4 M2C4 – Tutela del territorio e della risorsa idrica. at https://www.mase.gov.it/portale/componente-4-m2c4-tutela-del-territorio-e-della-risorsa-idrica (2024).

44. ISTAT. World Water Day 2024: Statistics for Water Resources and Uses in Italy. https://www.istat.it/wp-content/uploads/2024/06/WWD-2024-ENG.pdf (2024).

45. Ministero dell'Agricoltura della Sovranità Alimentare e delle Foreste - MASAF. Strategia forestale nazionale. Retrieved from at https://www.reterurale.it/foreste/StrategiaForestaleNazionale (2022).

46. European Commission. Italy – CAP strategic plan. Directorate-General for Agriculture and Rural Development. Retrieved from https://agriculture.ec.europa.eu/cap-my-country/cap-strategic-plans/italy_it (2025).

47. PAC, P. S. DELLA. Annual Performance Report 2024: Monitoring and Evaluation of the CAP Strategic Plan 2023–2027. https://www.reterurale.it/PAC_2023_27/MonitoraggioValutazione (2024).

48. European Commission, D.-G. for A. and R. D. The next chapter for the CAP. https://agriculture.ec.europa.eu/media/news/next-chapter-cap-2025-07-17_en.

49. European Parliament. CAP simplification package. https://www.europarl.europa.eu/legislative-train/theme-sustaining-our-quality-of-life-food-security-water-and-nature/file-common-agricultural-policy-simplification-package (2025).

50. FAO. The Future of Food and Agriculture: Drivers and Triggers for Transformation. (FAO, Rome, 2022). doi:10.4060/cc1024en.

51. European Agroforestry - EURAF. Agroforestry in Italy. Retrieved November 2, 2025, from http://europeanagroforestry.eu/countries/italy (2025).

52. Eurostat. Developments in organic farming. Statistics Explained. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Developments_in_organic_farming (2025).

53. Muska, A., Pilvere, I., Viira, A.-H., Muska, K. & Nipers, A. European Green Deal Objective: Potential Expansion of Organic Farming Areas. Agriculture 15, 1633 (2025).

54. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Ambiente in Italia: Annuario Dei Dati Ambientali 2023 - Rapporto 101/2024. https://indicatoriambientali.isprambiente.it/sites/default/files/pdf/ambiente-in-italia-2024/Ambiente in Italia-Annuario 2023.pdf (2024).

55. Mediterranean Posidonia Network. Posidonia Oceanica Distribution. Retrieved November 2, 2025, from https://medposidonianetwork.com/distribution/ (2025).

56. Monnier, B. et al. The Posidonia oceanica matte: a unique coastal carbon sink for climate change mitigation and implications for management. Vie Milieu / Life Environ. 70, (2020).

57. Pergent-Martini, C. et al. Contribution of Posidonia oceanica meadows in the context of climate change mitigation in the Mediterranean Sea. Mar. Environ. Res. 165, 105236 (2021).

58. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). PNRR MER (Marine Ecosystem Restoration). https://www.isprambiente.gov.it/it/progetti/cartella-progetti-in-corso/progetti-mare/pnrr-mer-marine-ecosystem-restoration/pnrr-mer-marine-ecosystem-restoration.

59. Bacci, T. et al. Long-term response of Posidonia oceanica meadow restoration at the population and plant level: implications for management decisions. Restor. Ecol. 33, (2025).

60. Dentamare, I. et al. Ecological Implications of Posidonia oceanica Banquette Removal: Potential Loss of Natural Capital and Ecosystem Services. Water 17, 1362 (2025).

61. European Commission. EU Maritime Atlas - Posidonia Oceanica distribution. Directorate-General for Maritime Affairs and Fisheries. at https://ec.europa.eu/maritimeaffairs/atlas/maritime_atlas/#lang=EN (2025).

62. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Wetlands of international importance. Environmental Indicators. Retrieved November 2, 2025, from at https://indicatoriambientali.isprambiente.it/en/protected-areas/wetlands-international-importance (2025).

63. Ramsar Wetlands. Wetland tool. https://ramsarwetlands.com.au/wetland-tool.html (2025).

64. WWF. Zone umide: La nostra difesa contro i disastri climatici. WWF-Italia Panda News. https://www.wwf.it/pandanews/ambiente/zone-umide-la-nostra-difesa-contro-i-disastri-climatici/ (2017).

65. Tanneberger, F. et al. Mires in Europe—Regional Diversity, Condition and Protection. Diversity 13, 381 (2021).

66. Tanneberger, F. et al. The peatland map of Europe. Mires Peat 19, 22 (2017).

67. Bajona, E., Di Gristina, E. & Venturella, G. An Overview of Upland Peatlands' Vegetation of Apennines, Sicily, and Sardinia (Italy). Plants 14, 1931 (2025).

68. WWF. WWF Italia & ANEPLA. (2021) La Rinaturazione Del Po: Programma per Un Primo Stralcio Di Interventi. Il Tratto Medio Padano. Proposta per Il Piano Nazionale Di Ripresa e Resilienza). https://www.wwf.it/uploads/2021_7_29-Proposta-rinaturazione.pdf (2021).

69. Agenzia Interregionale per il fiume Po - AIPO. Rinaturazione dell'area Po (Misura M2C4.3 – I. 3.3). Retrieved November 2, 2025, from https://www.aipo-pnrr.it/ambito/rinaturazione-dellarea-del-po (2025).

70. European Commission. Nature Restoration Regulation. Environment Directorate-General. https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-regulation_en (2024).

71. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Lo stato di severità idrica a scala nazionale. https://www.isprambiente.gov.it/pre_meteo/idro/SeverIdrica.html (2025).

72. Maanen, N. van, Theokritoff, E., Lanson, A., Menke, I. & Schleussner, C.-F. Climate Impacts in Italy: How Climate Change Is Affecting Italy's Environment and People. https://giudiziouniversale.eu/wp-content/uploads/2021/06/Climate-Impacts-in-Italy.pdf (2020).

73. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Precipitation. Environmental Indicators. at https://indicatoriambientali.isprambiente.it/en/water-sources-and-balance/precipitation (2025).

74. Luppichini, M., Bini, M., Giannecchini, R. & Zanchetta, G. High-resolution spatial analysis of temperature influence on the rainfall regime and extreme precipitation events in north-central Italy. Sci. Total Environ. 880, 163368 (2023).

75. Nomad Season. Climate and weather in Italy. https://nomadseason.com/climate/italy/index.html (2025).

76. European Parliament Council of the European Union. Regulation (EU) 2021/2088 on Sustainability-related Disclosures in the Financial Services Sector (SFDR). EUR-Lex. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX%3A32021R2088 (2021).

77. Ministero dell'Ambiente e della Tutela del Territorio e del Mare. Decreto 13 ottobre 2016, n264: Criteri indicativi per la qualifica dei residui di produzione come sottoprodotti e non come rifiuti ai sensi dell'articolo 184-bis del decreto legislativo 3 aprile 2006, n. 152. Normattiva. at https://www.normattiva.it/uri-res/N2Ls?urn:nir:ministero.ambiente.e.tutela.territorio.e.mare:decreto:2016-10-13 (2016).

78. ENEA. VALUTAZIONE DISPONIBILITÀ BIOMASSE AGRO-INDUSTRIALI A LIVELLO NAZIONALE E LORO PUBBLICAZIONE SUL PORTALE WEBGIS ATLANTE DELLE BIOMASSE (RT/2021/4). ENEA. https://iris.enea.it/retrieve/dd11e37c-efb1-5d97-e053-d805fe0a6f04/RT-2021-04-ENEA.pdf (2021).

79. Ruggeri, G., Mazzocchi, C., De Marchi, E., Banterle, A. & Sali, G. Provincial assessment of agricultural biomass residues for renewable energy in Italy. Energy Reports 13, 2946–2957 (2025).

80. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Rapporto Rifiuti Speciali – Edizione 2024 (Rapporti 402/2024). ISPRA. ISBN 978-88-448-1219-5. https://www.isprambiente.gov.it/it/pubblicazioni/rapporti/rapporto-rifiuti-speciali-edizione-2024 (2024).

81. FAO. Global Forest Resources Assessment 2020 - Report Italy. https://openknowledge.fao.org/server/api/core/bitstreams/88d2ca04-1f66-4c64-a89a-ce539ecf40f5/content (2020).

82. Gestori Servizi Energetici - GSE. Rapporto Statistico 2021: Fonti Rinnovabili in Italia (FER). https://www.gse.it/documenti_site/Documenti GSE/Rapporti statistici/Rapporto Statistico GSE - FER 2021.pdf (2022).

83. Gestori Servizi Energetici - GSE. Atalante Geographico delle rinnovabili. https://www.gse.it/dati-e-scenari/atlaimpianti.

84. Ravenna CCS Project. Ravenna CCS Hub. at https://ravennaccs.com/en-IT/project/ravenna-hub (2023).

85. Ministero dell'Agricoltura della Sovranità Alimentare e delle Foreste - MASAF. DECRETO LEGISLATIVO 29 Aprile 2010, n.75 - Riordino e Revisione Della Disciplina in Materia Di Fertilizzanti, a Norma Dell'articolo 13 Della Legge 7 Luglio 2009, n. 88.

86. Valagusa, M. Progetto AMMOCHAR Utilizzo del biochar per aumentare l'efficienza agronomico/ambientale dei derivati zootecnici quale alternativa alle concimazioni chimiche. at https://www.fondazioneminoprio.it/wp-content/uploads/2024/03/Biochar-Valagussa28062023.pdf (2023).

87. Rete Rurale Nazionale. Biochar e filiera agroenergetica. at https://www.reterurale.it/agroenergie/biochar_filiera (2023).

88. International Biochar Initiative - IBI. Global Biochar Market Report 2023 – Public Summary. IBI. https://biochar-international.org/wp-content/uploads/2024/06/Global-Biochar-Market-Report-2023-–-Public.pdf (2023).

89. European Biochar Industry (EBI) Consortium. European Biochar Market Report 2024. https://www.biochareurope.eu/market-report (2024).

90. Charm Industrial. Bio-Oil Sequestration: Protocol for Measurement, Reporting, and Verification (MRV). https://charmindustrial.com/Bio-oil_Sequestration__Protocol_for_Measurement_Reporting_and_Verification.pdf (2024).

91. ISTAT. Istat Data Browser - Cave e Miniere. https://esploradati.istat.it/databrowser/#/it/dw/categories/IT1,Z0920ENV,1.0/DCCV_CAVE_MIN/IT1,9_951_DF_DCCV_CAVE_MIN_2,1.0.

92. European Commission. Study on the Critical Raw Materials for the EU 2023 (ET0723116ENN). Publications Office of the European Union. https://www.eunews.it/wp-content/uploads/2023/10/study-on-the-critical-raw-materials-for-the-eu-2023-ET0723116ENN.pdf (2023) doi:10.2873/12230.

93. Caserini, S., Storni, N. & Grosso, M. The Availability of Limestone and Other Raw Materials for Ocean Alkalinity Enhancement. Global Biogeochem. Cycles 36, (2022).

94. ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT - OECD. The Circular Economy in Cities and Regions of the European Union. (OECD Publishing, Paris, 2025). doi:10.1787/e09c21e2-en.

95. Solutions, W. I. T. Trade statistics by product (HS 251820 – Dolomite, not calcined or sintered). World Integrated Trade Solution (WITS). https://wits.worldbank.org/trade/comtrade/en/country/ALL/year/2023/tradeflow/Exports/partner/WLD/product/251820 (2023).

96. Provincia Autonoma di Trento. Concessione mineraria per dolomite Dosseni. at https://www.provincia.tn.it/Amministrazione/Documenti/Concessione-mineraria-per-dolomite-Dosseni (2025).

97. Idoine, N. E. et al. World Mineral Production 2019-23. at https://nora.nerc.ac.uk/id/eprint/539285/1/WMP_2019-2023_COMPLETE.pdf (2025).

98. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). PROGRAMMA NAZIONALE DI ESPLORAZIONE - PNE - Art.10, DL n. 84/2024. https://www.isprambiente.gov.it/files2025/attivita/pne_finale.pdf (2025).

99. Rielli, A., Boschi, C. & Dini, A. Tectonically driven carbonation of serpentinite by mantle CO2: Genesis of the Castiglioncello magnesite deposit in the Ligurian ophiolite of central Tuscany (Italy). Ore Geol. Rev. 149, 105022 (2022).

100. Sevostyanov, V. S., Shatalov, A. V, Shatalov, V. A. & Golubeva, U. V. Processing of basalt fiber production waste. IOP Conf. Ser. Mater. Sci. Eng. 327, 042103 (2018).

101. Nuova CivesS.r.l. Nuova Cives. https://www.nuovacives.com/index.php.

102. Kremer, D. et al. Geological Mapping and Characterization of Possible Primary Input Materials for the Mineral Sequestration of Carbon Dioxide in Europe. Minerals 9, 485 (2019).

103. Regione Piemonte. DETERMINAZIONE DIRIGENZIALE A19000 - COMPETITIVITA' DEL SISTEMA REGIONALE A1906A - Polizia mineraria, cave e miniere. 354 del 20 settembre 2024: Avviso pubblico per il sostegno a progetti di innovazione nel settore dei materiali da costruzione. at https://bandi.regione.piemonte.it/system/files/D.D. 20 settembre 2024%2C n. 354.pdf (2024).

104. Rinder, T. & von Hagke, C. The influence of particle size on the potential of enhanced basalt weathering for carbon dioxide removal - Insights from a regional assessment. J. Clean. Prod. 315, 128178 (2021).

105. Rana, V. Enhanced rock weathering as a carbon dioxide removal technique: A sustainability assessment of its application in the Netherlands (Master's thesis). Utrecht University Repository. (Utrecht University, 2020).

106. Ahmed, H. M., Hefni, M. A., Ahmed, H. A. M. & Saleem, H. A. Cement Kiln Dust (CKD) as a Partial Substitute for Cement in Pozzolanic Concrete Blocks. Buildings 13, 568 (2023).

107. Schorcht, F., Kourti, I., Scalet, B. M., Roudier, S. & Delgado-Sancho, L. Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide Industrial Emissions Directive 2010/75/EU Integrated Pollution Prevention and Control. EC-JRC (2013) doi:10.2788/12850.

108. Biava, G. et al. Accelerated Direct Carbonation of Steel Slag and Cement Kiln Dust: An Industrial Symbiosis Strategy Applied in the Bergamo–Brescia Area. Materials (Basel). 16, 4055 (2023).

109. Li, L. & Wu, M. An overview of utilizing CO2 for accelerated carbonation treatment in the concrete industry. J. CO2 Util. 60, 102000 (2022).

110. Carriero, A., Masulli, M. & Torreggian, S. The Italian Steel Industry across National and European Challenges: What Prospects for Development? https://www.cdp.it/resources/cms/documents/CDP-Brief-Italian-Steel-Industry-ENG.pdf (2024).

111. Gao, W. et al. Comprehensive utilization of steel slag: A review. Powder Technol. 422, 118449 (2023).

112. Bronk & Company. Green Transformation needs clear orientation – Forecasting the steel demand in 2030. https://bronk-company.com/en/2023/01/forecast-steel-demand-2030/ (2023).

113. EUROFER, T. E. S. A.-. European Steel in Action 2025. EUROFER. https://www.eurofer.eu/assets/publications/reports-or-studies/european-steel-in-action-2025/European-Steel-In-Action-2025.pdf (2025).

114. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Re.Mi Project: National census of disused mining sites. at https://www.isprambiente.gov.it/en/projects/soil-and-territory/mines-and-quarries/remi-project-national-network-of-italian-mining-parks-and-museums/the-data-bases/national-census-of-mining-sites-disused (2006).

115. Ministero delle Imprese e del Made in Italy - MIMIT. Verbale Della 1443a Riunione Del Comitato Interministeriale per La Transizione Energetica (CITE). https://www.mimit.gov.it/images/stories/energia/1443rd27.pdf (2024).

116. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). National census of mining sites disused. https://www.isprambiente.gov.it/en/projects/soil-and-territory/mines-and-quarries/remi-project-national-network-of-italian-mining-parks-and-museums/the-data-bases/national-census-of-mining-sites-disused (2006).

117. CORDA, A. S., MUREDDU, A. & RENIS, M. Sinkholes in the Sardinia Region (Italy): Mines and karst Cavities. Mem. Descr. Cart. Geol. d'It XCIII, 183–202 (2013).

118. Burzi, I. Nuovi Paesaggi e Aree Minerarie Dismesse. Firenze University Press. vol. 18 (Firenze University Press, Florence, 2014).

119. Fuganti, A., Odorizzi, S. & Franzinelli, A. La miniera di dolomia Rio Maggiore Val di Non (Trento). Atti dell'Accademia roveretana degli Agiati. B, Cl. di Sci. Mat. Fis. e Nat. 3, 91–192 (2013).

120. Zhao, Y. et al. In-Situ Mineralization of CO2 at the Closed Coal Mines. (2023) doi:10.2139/ssrn.4484682.

121. StOrE – CO_2 Storage in Italy. StoreCO2. https://www.storeco2.it.

122. Baneschi, I., Boschi, C., Dini, A., Ricci, L. & Rielli, A. Advancing the storage of anthropogenic CO_2 emissions by understanding natural carbonation systems. in (National Research Council of Italy,Institute of Geosciences and Earth Resources (CNR-IGG)., 2024).

123. Anthonsen, K. L. & Christensen, N. P. European CO_2 Storage Resource Summary 2021 (GEUS Report 2021/34). Clean Air Task Force. https://cdn.catf.us/wp-content/uploads/2021/10/20183953/EU-CO2-storage-summary_GEUS-report-2021-34_Oct2021.pdf (2021).

124. Donda, F., Volpi, V., Persoglia, S. & Parushev, D. CO2 storage potential of deep saline aquifers: The case of Italy. Int. J. Greenh. Gas Control 5, 327–335 (2011).

125. Italian Government. LEGGE 2 Febbraio 2024, n. 11. (Senato della Repubblica, 2024).

126. Clean Air Task Force - CATF. Tracking CO_2 storage project capacity in Europe. https://www.catf.us/carbon-capture/storage-project-capacity-europe/ (2024).

127. ENI & SNAM. CCS Market Survey: Results Presentation. Ravenna CCS. https://ravennaccs.com/assets/files/CCS market survey - Results presentation.pdf (2024).

128. European Suppliers of Waste-to-Energy Technology - ESWET. From Carbon Neutral to Carbon Negative: Waste-to-Energy on the Path to Carbon Capture, Utilisation and Storage. https://eswet.eu/wp-content/uploads/2023/02/ESWET-CCUS-WG-REPORT-6.pdf (2023).

129. CO_2GeoNet. CO2GeoNet (2021): State-of-Play on CO2 Geological Storage in 32 European Countries — an Update. https://co2geonet.com/state-of-play/ (2021).

130. Callisto Project. Callisto PCI: CO_2 transport and storage infrastructure. Retrieved November 2, 2025, from https://www.callisto-pci.com/it (2025).

131. Energean. Prinos CO_2 storage project – Greece. https://www.energean.com/operations/greece/prinos-co2/ (2024).

132. Publications Office of the European Union. Shaping the Future CO_2 Transport Network for Europe. https://data.europa.eu/doi/10.2760/582433 (2024) doi:10.2760/582433.

133. Clean Air Task Force - CATF. Building future-proof CO_2 transport infrastructure in Europe. https://www.catf.us/resource/building-future-proof-co2-transport-infrastructure-europe/ (2024).

134. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). I dati sul consumo di suolo in Italia. https://www.isprambiente.gov.it/it/attivita/suolo-e-territorio/suolo/il-consumo-di-suolo/i-dati-sul-consumo-di-suolo (2025).

135. Italian Government. Decreto Legislativo 22 Gennaio 2004, N. 42: Codice dei beni culturali e del paesaggio, ai sensi dell'articolo 10 della legge 6 luglio 2002, n. 137. Normattiva. (2004).

136. Italian Government. Decreto Legislativo 3 Aprile 2006, N. 152: Norme in materia ambientale, Articolo 94 – Tutela delle acque destinate al consumo umano. Normattiva. (2006).

137. Italian Government. Decreto Legislativo 14 Settembre 2011, N. 162: Attuazione della direttiva 2009/31/CE relativa allo stoccaggio geologico di anidride carbonica, nonché che modifica le direttive 85/337/CEE, 2000/60/CE, 2001/80/CE, 2004/35/CE, 2006/12/CE, 2008/1/CE e il regolamento (CE) n. 1013/2006. Normattiva. (2011).

138. Ministero dell'Ambiente e della Sicurezza Energetica - MASE. Accordo per l'applicazione degli ILG al programma sperimentale di stoccaggio geologico di anidride carbonica (CCS) Ravenna – Fase 1. UNMIG – Ufficio Nazionale Minerario per gli Idrocarburi e le Georisorse. https://unmig.mase.gov.it/accordo-per-lapplicazione-degli-ilg-al-programma-sperimentale-di-stoccaggio-geologico-di-anidride-carbonica-ccs-ravenna-fase-1/ (2024).

139. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Ecosistemi Terrestri Ed Incendi Boschivi in Italia: Stagione Degli Incendi 2024 (Rapporto 401/2024). https://www.isprambiente.gov.it/files2024/attivita/ecosistemi-ed-incendi-boschivi/si2024_signed.pdf (2024).

140. Cardinael, R. et al. Increased soil organic carbon stocks under agroforestry: A survey of six different sites in France. Agric. Ecosyst. Environ. 236, 243–255 (2017).

141. MIPAAF. (2018) Relazione SFN, 31 Gennaio 2018 (Ministero Delle Politiche Agricole Alimentari e Forestali. https://www.innoveneto.org/wp-content/uploads/2022/02/MIPAAF_Strategia-Forestale-Nazionale_Relazione_31_01.pdf (2018).

142. MASAF. MASAF. Piano Strategico Nazionale PAC 2023–2027, versione 5.1 (Ministero dell'Agricoltura, della Sovranità Alimentare e delle Foreste, 2025). at https://www.masaf.gov.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/12126 (2023).

143. EEA. Climate Action Progress Report 2023: Country Profile – Italy. https://climate-energy.eea.europa.eu/topics/policies-and-measures/climate-and-energy-policies-and-measures/data (2023).

144. European Union. Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ("European Climate Law"). EUR-Lex Official Journal of the European Union, L 243, 1–17. at https://eur-lex.europa.eu/eli/reg/2021/1119/oj/eng (2021).

145. European Parliament Council of the European Union. Council of the European Union - Fit for 55. https://www.consilium.europa.eu/en/policies/fit-for-55/ (2025).

146. Union, E. Regulation (EU) 2023/839 of the European Parliament and of the Council of 17 April 2023 Amending Regulations (EU) 2018/841 and (EU) 2018/1999 as Regards Greenhouse Gas Emissions and Removals from Land Use, Land Use Change and Forestry and Reporting Obliga. Official Journal of the European Union, L 104, 1–26. (2023).

147. European Union. Update of the Nationally Determined Contribution of the European Union and Its Member States: Submission by Spain and the European Commission on Behalf of the European Union and Its Member States. UNFCC. https://unfccc.int/sites/default/files/NDC/2023-10/ES-2023-10-17 EU submission NDC update.pdf (2023).

148. European Union, C. Long-term low greenhouse gas emission development strategy of the European Union and its Member States: Submission by Croatia and the European Commission on behalf of the European Union and its Member States. UNFCCC. at https://unfccc.int/sites/default/files/resource/HR-03-06-2020 EU Submission on Long term strategy.pdf (2020).

149. European Commission. Securing Our Future: Europe's 2040 Climate Target and Path to Climate Neutrality by 2050 – Building a Sustainable, Just and Prosperous Society (COM(2024) 63 Final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52024DC0063 (2024).

150. Jallal, C. Mediterranean carbon capture and storage close to start of operations. Riviera Maritime Media. https://www.rivieramm.com/news-content-hub/news-content-hub/mediterranean-carbon-capture-and-storage-close-to-start-of-operations-86153 (2025).

151. European Parliament Council of the European Union. 2040 climate target: Council and Parliament agree on a 90% emissions reduction. Retrieved from. https://www.consilium.europa.eu/en/press/press-releases/2025/12/10/2040-climate-target-council-and-parliament-agree-on-a-90-emissions-reduction/ (2025).

152. MASAF, C. Crediti di Carbonio forestali: al via il Registro Nazionale affidato al CREA [Press release]. https://www.crea.gov.it/-/crediti-di-carbonio-forestali-al-via-il-registro-nazionale-affidato-al-crea (2025).

153. European Union. Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. at https://eur-lex.europa.eu/eli/dir/2003/87/oj/eng (2003).

154. European Commission. What is the Innovation Fund? at https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund_en (2025).

155. Marcegaglia Ravenna S.P.A. AdriatiCO2: Marcegaglia. https://ec.europa.eu/assets/cinea/project_fiches/innovation_fund/101191172.pdf (2025).

156. Accierie Bertoli Safau S.P.A. CUSTARD: carbon Capture and Use at the STeel plant with an Advanced solution to Reach Decarbonisation. https://ec.europa.eu/assets/cinea/project_fiches/innovation_fund/101156745.pdf.

157. Princess Cruise Lines LTD. INDIGO: Pioneering Passenger Ship Decarbonization Platform: Retrofitting for Enahnced Operational Efficiency and Emissions Reduction. https://ec.europa.eu/assets/cinea/project_fiches/innovation_fund/101191181.pdf.

158. S.P.A., S. Re-Tyre CO2: Sustainable Recycling of waste tyres through CO2-saving pyrolytic process: production of new alternative fuel, carbon black and circular gas utilization. https://ec.europa.eu/assets/cinea/project_fiches/innovation_fund/101191400.pdf (2025).

159. 159. European Union. Regulation (EU) 2021/695 of the European Parliament and of the Council of 28 April 2021 establishing Horizon Europe – the Framework Programme for Research and Innovation, laying down its rules for participation and dissemination, and repealing Regulations. at https://eur-lex.europa.eu/eli/reg/2021/695/oj/eng (2021).

160. Commission, E. European Agricultural Fund for Rural Development (EAFRD). https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/european-agricultural-fund-rural-development-eafrd_en (2021).

161. Union, E. Directive 2009/31/EC of the European Parliament and of the Council on the Geological Storage of Carbon Dioxide and Amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC . Official Journal of the European Union, L 140, 114–135. (2009).

162. Italian Government. Stato, I. P. E. Z. D. (n.d.-a). DECRETO-LEGGE 16 Luglio 2020, n. 76 - Normattiva. (2020).

163. Italian Government. Stato, I. P. E. Z. D. (n.d.-b). DECRETO-LEGGE 31 Maggio 2021, n. 77 - Normattiva. (2021).

164. Italian Government. Stato, I. P. E. Z. D. (2024a, November 25). DECRETO LEGISLATIVO 25 Novembre 2024, n. 190 - Normattiva. (2024).

165. Ministero dell'Ambiente e della Sicurezza Energetica - MASE. Decreto 21 giugno 2024 – Disciplina per l'individuazione di superfici e aree idonee per l'installazione di impianti a fonti rinnovabili. Gazzetta Ufficiale della Repubblica Italiana, n. 155 (2 luglio 2024). at https://www.reteambiente.it/normativa/54478/dm-ambiente-21-giugno-2024/ (2024).

166. IMO. Amendment to Article 6 of the 1996 Protocol to the Convention on the Prevention of a Marine Pollution By Dumping of Waste and Other Matter 1972: Adopted on 30 October 2009. (2011).

167. Slaughter & May. From vision to reality – A regulatory guide to carbon capture, usage and storage in Europe. https://www.slaughterandmay.com/insights/horizon-scanning/from-vision-to-reality-a-regulatory-guide-to-carbon-capture-usage-and-storage-in-europe/ (2024).

168. Union, E. Directive 2011/92/EU of the European Parliament and of the Council on the assessment of the effects of certain public and private projects on the environment (codification). Official Journal of the European Union, L 26, 1–21. at https://eur-lex.europa.eu/legal-content/IT/TXT/PDF/?uri=CELEX:32011L0092 (2011).

169. Italian Government. Stato, I. P. E. Z. D. (2024b, December 13). LEGGE 13 dicembre 2024, n. 191 - Normattiva. at https://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:legge:2024-12-13 (2024).

170. European Commission. Strategic Energy Plan - SET. https://energy.ec.europa.eu/topics/research-and-technology/strategic-energy-technology-plan_en (2007).

171. Bird & Bird. Biomethane Decree 2022: Legal framework and application procedures. at https://www.twobirds.com/-/media/new-website-content/insights/pdfs/alert_biomethane-decree-2022_eng.pdf (2023).

172. Lot, B. et al. NECPs Assessments: Carbon Capture and Storage in the National Energy and Climate Plans - Bellona REPORT. https://network.bellona.org/content/uploads/sites/6/2025/06/NECP-Assessments-Report.pdf (2025).

173. Ministero dell'Ambiente e della Sicurezza Energetica - MASE. Studio per Lo Sviluppo Della Filiera CCUS in Italia: Analisi Degli Aspetti Tecnici, Economici e Normativi Funzionali Allo Sviluppo Della Filiera CCUS. MASE. https://www.mase.gov.it/portale/documents/d/guest/mase_studio_ccus_2025-pdf (2025).

174. Climate, E. Italy's Climate Governance Gap: How Politics, Power and Polarisation Are Weakening Climate Action[Impact Report]. ECCO Think Tank. https://eccoclimate.org/wp-content/uploads/2025/04/ECCO-Bilancio-Sociale-2023-1.pdf (2023).

175. Meyer-Ohlendorf, Nils, Deyana Spasova (2022): Carbon Dioxide Removals in EU Member States. Ecologic Institute, Berlin. https://www.ecologic.eu/sites/default/files/publication/2022/50084-ECF-CDR-report-web.pdf

176. Ministero dell'Ambiente e della Sicurezza Energetica - MASE. Regolamento (UE) 2024/1735 Trasparenza Dei Dati Sulla Capacità Di Stoccaggio Di CO2. Government of Italy. https://unmig.mase.gov.it/informazioni/attuazione-regolamento-ue-2024-1735/ (2024).

177. ISTAT. GDP and general government net borrowing - Year 2023. https://www.istat.it/en/press-release/gdp-and-general-government-net-borrowing-year-2023/.

178. ISTAT. ISTAT Data Browser. https://esploradati.istat.it/databrowser.

179. Statista. Unemployment rate in the largest European countries from 2004 to 2024, with forecasts until 2029. Statista. https://www.statista.com/statistics/1173907/unemployment-in-largest-european-countries/ (2025).

180. United Nations Development Programme - UNDP. Human Development Reports: Italy. Human Development Data Center. https://hdr.undp.org/data-center/specific-country-data#/countries/ITA (2025).

181. OECD. OECD Economic Outlook, Volume 2025 Issue 1. vol. 2025 (OECD Publishing, 2025).

182. European Commission. European Innovation Scoreboard 2025. Directorate-General for Research and Innovation. https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en (2025).

183. Accetturo, A. et al. Il Divario Nord-Sud: Sviluppo Economico e Intervento Pubblico. Banca d'Italia, Seminari e Convegni, N. 25. https://www.bancaditalia.it/pubblicazioni/collana-seminari-convegni/2022-0025/index.html (2022).

184. Verzichelli, L., Marino, B., Marangoni, F. & Russo, F. The Impossible Stability? The Italian Lower House Parliamentary Elite After a "Decade of Crises". Front. Polit. Sci. 4, (2022).

185. Europe, P. Europe poll of polls: Italy. POLITICO. Retrieved October 28, 2025, from https://www.politico.eu/europe-poll-of-polls/italy/ (2025).

186. Biancalana, C., Ladini, R. & Visconti, F. Climate change in Italy: Towards the politicization of an issue. Ital. Polit. Sci. 18(3), 177–193. (2024) doi:10.69101/IPS.2023.18.3.1.

187. Commission, E. Special Eurobarometer 538: Climate Change – National Factsheet: Italy. Brussels: European Union. https://climate.ec.europa.eu/document/download/552f5f99-a2ed-4eea-999d-201f51f2828c_en?filename=it_climate_2023_en.pdf (2023).

188. Commission, E. Standard Eurobarometer 103: Spring 2025 – National Factsheet: Italy. Brussels: European Union. at https://europa.eu/eurobarometer/surveys/detail/3372 (2025).

189. Beltrame, L., Bucchi, M. & Loner, E. Climate Change Communication in Italy. in Oxford Research Encyclopedia of Climate Science (Oxford University Press, 2017). doi:10.1093/acrefore/9780190228620.013.462.

190. Cabeza, L., Ronchi, S. & Sallabera, P. Public Support for Climate Policies in a Context of Low Politicisation: Evidence from Italy. Ital. Polit. Sci. 18(3), 338–370. (2024) doi:10.69101/IPS.2023.18.3.8.

191. Antronico, L., Coscarelli, R., De Pascale, F. & Di Matteo, D. Climate Change and Social Perception: A Case Study in Southern Italy. Sustainability 12, 6985 (2020).

192. Biddau, F., Rizzoli, V., Cottone, P. & Sarrica, M. "These industries have polluted consciences; we are unable to envision change": Sense of place and lock-in mechanisms in Sulcis coal and carbon-intensive region, Italy. Glob. Environ. Chang. 86, 102850 (2024).

193. Misuraca, L. Ravenna, al via l'impianto di cattura del carbonio Eni-Snam contestato da scienziati e ambientalisti |. Il Salvagente. https://ilsalvagente.it/2024/09/03/ravenna-al-via-limpianto-di-cattura-del-carbonio-eni-snam-contestato-da-scienziati-e-ambientalisti/#:~:text=In Italia%2C le associazioni ambientaliste,%2C Dipartimento di Chimica "G (2024).

194. Kapetaki, Z., Hetland, J., Le Guenan, T., Mikunda, T. & Scowcroft, J. Highlights and Lessons from the EU CCS Demonstration Project Network. Energy Procedia 114, 5562–5569 (2017).

195. [NBFC], N. B. F. C. Primo Rapporto Annuale Sulla Biodiversità in Italia. Forum Nazionale della Biodiversità. Nature. (2023, May 30). Could Italy embrace nuclear power again? Nature Italy. https://www.nbfc.it/assets/files/Primo_rapporto_annuale_sulla_biodiversità_in_italia_NBFC.pdf (2024).

196. Italian Government. Legge costituzionale 11 febbraio 2022, n. 1: Modifiche agli articoli 9 e 41 della Costituzione in materia di tutela dell'ambiente. Normattiva. at https://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:legge:2022-02-11 (2022).

197. Zamponi, L., Ferro, A. & Cugnata, G. Strikes, assemblies and blockades: The dynamics of repertoire change in grassroots climate action in Italy (2018-2023). Ital. Polit. Sci. 18(3), 257–293. (2024) doi:10.69101/IPS.2023.18.3.5.

198. Law, S. C. for C. C. Greenpeace Italy, ReCommon, & 12 citizens v. Eni S.p.A., the Italian Ministry of Economy and Finance, and Cassa Depositi e Prestiti S.p.A. Climate Change Litigation Database, Columbia Law School. at https://www.climatecasechart.com/document/greenpeace-italy-et-al-v-eni-s-p-a-the-italian-ministry-of-economy-and-finance-and-cassa-depositi-e-prestiti-s-p-a_d341 (2023).

199. Nedeva, S. Individuals and NGOs vs corporations in the pursuit of climate accountability. In the Spotlight: the Italian oil major ENI. https://centaur.reading.ac.uk/114690/ (2024).

200. Brunetti, I., Frattini, F. F., Kuntze, M., Ricci, A. & Vona, F. Exploring Skills in the Green Transition: New Insights from Italian Data World. (INAPP, 2025). doi:10.53223/InappWP_2025-134.

201. Symbola Foundation, U. Rapporto GreenItaly 2024: In Italia 3,1 Milioni Di Green Jobs, Il 13,4% Degli Occupati. Fondazione Symbola. Retrieved from https://symbola.net/approfondimento/rapporto-greenitaly-2024-in-italia-31-milioni-di-green-jobs-il-134-degli-occupati/ (2024).

202. Asikainen, T., Bitat, A., Bol, E., Czako, V., Marmier, A., Muench, S., Murauskaite-Bull, I., Scapolo, F. and Stoermer, E. The Future of Jobs Is Green. https://publications.jrc.ec.europa.eu/repository/handle/JRC126047 (2021) doi:10.2760/218792.

203. Ministri, P. del C. dei. Superbonus 110%. Casa Italia. at https://www.casaitalia.governo.it/generali/approfondimenti/superbonus-110/ (2025).

204. Iodice, S., Garbarino, E., Cerreta, M. & Tonini, D. Sustainability assessment of Construction and Demolition Waste management applied to an Italian case. Waste Manag. 128, 83–98 (2021).

205. Massa, M. et al. Exploring the potential of sewage sludge ash for CO_2 sequestration and resource recovery. Resour. Conserv. Recycl. Adv. 18, 100312. (2025) doi:10.1016/j.rcradv.2025.100312ù.

206. ISTAT. Statistiche sulle attività estrattive – Anno 2018. Istat. at https://www.istat.it/wp-content/uploads/2021/05/Mining-and-quarrying-extraction-activities_year-2018.pdf (2020).

207. Chen, X., Yao, D., Ji, L. & Jin, Y. Recent developments in CO2 permanent storage using mine waste carbonation. Mater. Today Sustain. 29, 101070 (2025).

208. Porthos. Porthos project. https://www.porthosco2.nl/en/project/ (2025).

209. JV, N. L. What we do. at https://norlights.com/what-we-do/ (2025).

210. Martinez Castilla, G. et al. Clean Energy Technology Observatory: Carbon capture, utilisation and storage in the European Union – 2024 status report on technology development, trends, value chains and markets. Publ. Off. Eur. Union. (2024) doi:10.2760/0287566.

211. Maddahi, R. & Talus, K. Carbon dioxide utilization and storage through mineralization under European Union law: a legal analysis of the EU CCS Directive and the EU Emissions Trading System. J. World Energy Law Bus. 18, (2025).

212. ISTAT. Stima preliminare dei conti economici dell'agricoltura – Anno 2024. Istituto Nazionale di Statistica. at https://www.istat.it/wp-content/uploads/2025/01/stima-andamento-economia-agricola-2024.pdf (2025).

213. McDonald, H. et al. Temporary Carbon Units from Carbon Farming and EU Agri-Food Climate Policy: Assessment of Risks, Opportunities, and Alternatives for Promoting Temporary Carbon Sequestration. Ecologic Institute and Öko-Institut. https://carbonmarketwatch.org/wp-content/uploads/2025/11/FINAL_Temporary-carbon-units-from-carbon-farming-and-EU-agri-food-climate-policy-.pdf (2025).

214. EASAC. Forest Bioenergy Update: BECCS and Its Role in Integrated Assessment Models. EASAC. https://easac.eu/fileadmin/PDF_s/reports_statements/Negative_Carbon/EASAC_BECCS_Commentary_2022_WEB_final.pdf (2022).

215. Lucchi, E., Adami, J. & Stawinoga, A. E. Social acceptance of photovoltaic systems in heritage buildings and landscapes: Exploring barriers, benefits, drivers, and challenges for technical stakeholders in northern Italy. Sustain. Energy Technol. Assessments 60, 103544 (2023).

216. Indelicato, A., Rocco, R. M. P. Di, Martín, J. C. & Marinello, V. Bridging Attitudes and Evidence: Climate Change Perspectives in Italy. Challenges 16, 2 (2024).

217. Ministero dell'Ambiente e della Sicurezza Energetica - MASE. Piano per La Transizione Ecologica (PTE). https://www.programmazioneeconomica.gov.it/media/q5hnvwoz/pte-definitivo.pdf (2022).

218. European Scientific Advisory Board on Climate Change. Scaling up Carbon Dioxide Removals – Recommendations for Navigating Opportunities and Risks in the EU. Publications Office of the European Union. https://climate-advisory-board.europa.eu/reports-and-publications/scaling-up-carbon-dioxide-removals-recommendations-for-navigating-opportunities-and-risks-in-the-eu (2025) doi:10.2800/3253650.

219. Rete Rurale Nazionale. SRD - Investimenti compresi gli investimenti nell'irrigazione. https://www.reterurale.it/PAC_2023_27/SRD.

220. Rete Rurale Nazionale. SRA - Impegni in materia di ambiente e di clima e altri impegni in materia di gestione. https://www.reterurale.it/PAC_2023_27/SRA.

221. Rete Rurale Nazionale. SRB - Vincoli naturali o altri vincoli territoriali specifici. https://www.reterurale.it/PAC_2023_27/SRB.

222. European Biochar Certification (EBC). European Biochar Certificate (EBC). "EBC-Guidelines for the Certification of Biochar-Based Carbon Sinks," . https://www.european-biochar.org/media/doc/2/c_en_sink-value_2-1.pdf (2020).

223. European Commission. Energy Performance of Buildings Directive (EU/2024/1275, EPBD). https://energy.ec.europa.eu/topics/energy-efficiency/energy-performance-buildings/energy-performance-buildings-directive_en (2024).

224. European Commission. European Green Deal: Commission proposes certification of carbon removals to help reach net zero emissions. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7156 (2022).

225. ICF S.A., Cerulogy, E. Support to the Development of Methodologies for the Certification of Permanent Carbon Removals: Review of Carbon Removals through Enhanced Rock Weathering. https://www.cerulogy.com/wp-content/uploads/2025/09/ICF_CRCF-ERW-Review_Jul2025.pdf (2025).

226. ICF S.A., Cerulogy, E. Support to the Development of Methodologies for the Certification of Permanent Carbon Removals: Review of Carbon Removal by Ocean Alkalinity Enhancement. https://www.cerulogy.com/wp-content/uploads/2025/09/ICF_CRCF-OAE-Review_Jul2025.pdf.

227. Isometric. Quantifying the world's first OAE credits. https://isometric.com/writing-articles/quantifying-the-worlds-first-oae-credits (2025).

228. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Bilancio Idrologico Nazionale: Stime BIGBANG e Indicatori Sulla Risorsa Idrica. https://www.isprambiente.gov.it/public_files/Rapporto_BIGBANG.pdf (2023).

229. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). WEI WATER EXPLOITATION INDEX PLUS. https://indicatoriambientali.isprambiente.it/it/risorse-idriche-e-bilancio/wei-water-exploitation-index-plus (2023).

230. CREA. SIGRIAN: National information System for the management of water resources in agriculture. https://sigrian.crea.gov.it/index.php/en/home-3/.

231. Galli, N., Nanesha, H., Tolazzi, A., Chiarelli, D. D. & Rulli, M. C. The AIDA 1 km resolution crop-specific rainfed and irrigated areas and green and blue water demands for Italy. Sci. Data 12, 1041 (2025).

232. Carbon Gap. CRRA. https://carbonremovalreadiness.org/.

233. Leslie, G. et al. WATER FOR CLIMATE MITIGATION: ESTIMATING THE GLOBAL FRESHWATER REQUIREMENTS OF CLIMATE MITIGATION MEASURES. http://hdl.handle.net/1959.4/102824 (2024) doi:10.26190/unsworks/30417.

234. Rosa, L., Sanchez, D. L., Realmonte, G., Baldocchi, D. & D'Odorico, P. The water footprint of carbon capture and storage technologies. Renew. Sustain. Energy Rev. 138, 110511 (2021).

235. Realmonte, G. et al. An inter-model assessment of the role of direct air capture in deep mitigation pathways. Nat. Commun. 10, 3277 (2019).

236. Beerling, D. J. et al. Potential for large-scale CO2 removal via enhanced rock weathering with croplands. Nature 583, 242–248 (2020).

237. Pastor, A. V., Ludwig, F., Biemans, H., Hoff, H. & Kabat, P. Accounting for environmental flow requirements in global water assessments. Hydrol. Earth Syst. Sci. 18, 5041–5059 (2014).

238. Ministero dell'Ambiente e della Sicurezza Energetica - MASE. Piano Nazionale Di Adattamento Ai Cambiamenti Climatici. https://www.mase.gov.it/portale/documents/d/guest/pnacc_documento_di_piano-pdf (2023).

239. European Commission. Water Framework Directive. https://environment.ec.europa.eu/topics/water/water-framework-directive_en.

240. De Fioravante, P. et al. Ecosystem Mapping and Accounting in Italy Based on Copernicus and National Data through Integration of EAGLE and SEEA-EA Frameworks. Land, 12(2), 286. (2023) doi:10.3390/land12020286.

241. S2Biom. S2Biom Project. https://www.s2biom.eu/en/publications-reports/s2biom.html.

242. Giocoli, A. et al. Advanced biomethane potential from local sources in Italy. J. Environ. Manage. 389, 126154 (2025).

243. Ugolini, M., Recchia, L., Guandalini, G. & Manzolini, G. Novel Methodology to Assess Advanced Biofuel Production at Regional Level: Case Study for Cereal Straw Supply Chains. Energies 15, 7197 (2022).

244. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Rapporto Rifiuti Urbani – Edizione 2023(Rapporti 393/2023). https://www.isprambiente.gov.it/files2023/pubblicazioni/rapporti/rapportorifiutiurbani_ed-2023_n-393_versioneintegrale.pdf (2023).

245. L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). Italian Greenhouse Gas Inventory 1990–2023: National Inventory Document 2025 (Report No 411). 411\2025). Istituto Superiore per la Protezione e la Ricerca Ambientale. https://www.isprambiente.gov.it/en/publications/reports/italian-greenhouse-gas-inventory-1990-2023-national-inventory-document-2025 (2025).

246. Demichelis, F. et al. Agro-food waste conversion into valuable products in the Italian scenario: current practices and innovative approaches. J. Environ. Chem. Eng. 13, 115458 (2025).

247. Scarlat, N., Fahl, F., Dallemand, J.-F., Monforti, F. & Motola, V. A spatial analysis of biogas potential from manure in Europe. Renew. Sustain. Energy Rev. 94, 915–930 (2018).

248. The International Energy Agency - IEA. Gasification of Waste for Energy Carriers: A Review. https://www.ieabioenergy.com/wp-content/uploads/2019/01/IEA-Bioenergy-Task-33-Gasification-of-waste-for-energy-carriers-20181205-1.pdf.

249. Malinauskaite, J. et al. Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. Energy 141, 2013–2044 (2017).

250. EBA. European Biogas Association Statistical Report 2024. https://www.europeanbiogas.eu/wp-content/uploads/2024/12/EBA_stats_report_complete_241204_preview.pdf (2024).

251. The Climate Registry. 2023 Emission factors. https://theclimateregistry.org/wp-content/uploads/2023/06/2023-Default-Emission-Factors-Final-1.pdf (2023).

252. Markkanen, J., Koponen, K. & Lehtilä, A. Sustainable negative emissions in Europe: evaluating scenarios to meet carbon neutrality by 2050. Environ. Res. Lett. 19, 114050 (2024).

253. Furre, A.-K., Warchoł, M. J., Alnes, H. & Pontén, A. S. M. Sleipner 26 years: how well-established subsurface monitoring work processes have contributed to successful offshore CO2 injection. Geoenergy 2, geoenergy2024-015 (2024).

254. Northern Lights. Northern Lighst: reports, analysis and assessments. https://norlights.com/reports-2/.

255. Alberta Department of Energy & SHELL Canada LTD. Quest Carbon Capture and Storage Project, 2024 ANNUAL STATUS REPORT. https://open.alberta.ca/dataset?tags=CCS+knowledge+sharing+program&tags=Quest+Carbon+Capture+and+Storage+project.

256. CO2 Datashare. Illinois Basin - Decatur Project Dataset. https://co2datashare.org/dataset/illinois-basin-decatur-project-dataset#orgf13c469 (2023).

257. Japan CCS Co. Ltd. (JCCS). Report of Tomakomai CCS Demonstration Project at 300 Thousand Tonnes Cumulative Injection ("Summary Report"). https://www.japanccs.com/wp/wp-content/uploads/2020/05/report202005_overview_en.pdf (2020).

258. Grude, S., Dvorkin, J., Clark, A., Vanorio, T. & Landrø, M. Pressure Effects Caused by CO2 Injection in the Snøhvit Field. https://scispace.com/pdf/pressure-effects-caused-by-co2-injection-in-the-snohvit-2kfs8l43a3.pdf (2013).

259. Li, L. et al. Overview of Typical Projects for Geological Storage of CO2 in Offshore Saline Aquifers. Liquids 4, 744–767 (2024).

260. Ringrose, P. S. et al. The In Salah CO2 Storage Project: Lessons Learned and Knowledge Transfer. Energy Procedia 37, 6226–6236 (2013).

261. Wright, I. W. Three Years CO2 Geological Storage at In Salah. in vol. Internatio IPTC-11326-MS (2007).

262. WA Government. Gorgon carbon dioxide injection project. https://www.wa.gov.au/organisation/department-of-mines-petroleum-and-exploration/gorgon-carbon-dioxide-injection-project (2025).

263. LETDF. Low Emission Technology Demonstration Fund (LETDF) Post Project Report. https://www.dcceew.gov.au/sites/default/files/documents/letdf-post-project-report-year-2-chevron.pdf (2024).

264. Heidelberg Materials. Brevik CCS. https://www.brevikccs.com/en/project-update (2025).

265. Heidelberg Materials. LEILAC ROADMAP 2050. https://www.leilac.com/wp-content/uploads/2022/09/LEILAC-Roadmap.pdf (2021).

266. Axens. Successful demonstration in Dunkirk of the CO2 capture DMXTM process. https://www.axens.net/resources-events/news/pr-successful-demonstration-dunkirk-co2-capture-dmx-process (2024).

267. NSG Group. Successful Start to Europe's First Carbon Capture Trial in Flat Glass Industry. (2024).

268. The European Ceramic Industry Association. CERAMIC ROADMAP TO 2050. https://www.cerameunie.eu/media/zyqdwwwp/ceramic-roadmap-to-2050.pdf (2021).

269. Svante Technologies Inc. Svante and Södra Launch EU-Based Carbon Capture Pilot to Advance Biogenic CO_2 Utilization. https://www.svanteinc.com/press-releases/svante-and-sodra-launch-eu-based-carbon-capture-pilot-to-advance-biogenic-co$_2$-utilization (2025).

270. Porthos. CO2 reduction through storage under the North Sea. https://www.porthosco2.nl/en/ (2026).

271. Yara International. Yara Integrated Report 2024. https://www.yara.com/investor-relations/latest-annual-report/ (2025).

272. CEWE. Hafslund Oslo Celsio, Norway – Carbon Capture and Storage project. https://www.cewep.eu/hafslund-oslo-celsio-norway-ccs-project.

273. NZT. NZT Power aims to be the world's first gas-fired power station with carbon capture and storage. https://www.netzeroteesside.co.uk/.

274. Churkina, G. et al. Buildings as a global carbon sink. Nat. Sustain. 3, 269–276 (2020).

275. Environmental Defense Fund, Natural Resources Defense Council, & O. C. (NRDC). Ocean Alkalinity Enhancement: At a Glance. https://www.edf.org/sites/default/files/documents/Ocean Alkalinity Enhancement.pdf.

276. Bellona Europa. (2024). Italy NECP assessment.
https://network.bellona.org/content/uploads/sites/6/2024/11/Italy-NECP-Assessment.pdf

277. ISPRA Certifcazione di gestione forestale sostenible. https://indicatoriambientali.isprambiente.it/it/selvicoltura/certificazione-di-gestione-forestale-sostenibile).(2025)

278. ISPRA. Gli Indicatori del Clima in Italia nel 2020. Anno XVI. https://www.isprambiente.gov.it/it/pubblicazioni/stato-dellambiente/rapporto_clima_2020-1.pdf (2021).

279. Senato della Repubblica. XIX Legislatura. Fascicolo Iter. DDL S. 1836. https://www.senato.it/leg/19/BGT/Schede/FascicoloSchedeDDL/ebook/59987.pdf (2026)

280. Ministero degli Affari Esteri e della Cooperazione Internazionale. (2025). Sustainability means quality: The new perception among Italian consumers. https://www.esteri.it/en/sala_stampa/archivionotizie/diplomazia-economica/2025/07/sostenibilita-e-qualita-la-nuova-percezione-dei-consumatori-italiani/

281. Regione Lombardia. (2025). Legge clima. https://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioRedazionale/servizi-e-informazioni/cittadini/Tutela-ambientale/Qualita-dell-aria/legge-clima/legge-clima

282. Legambiente. (2021). Comunità energetica rinnovabile CommOn Light. https://www.comunirinnovabili.it/comunita-energetica-rinnovabile-common-light/

283. 283 European Parliament (2025). The role of Direct Air Capture technologies in the EU's decarbonisation effort. https://www.europarl.europa.eu/RegData/etudes/STUD/2025/772474/ECTI_STU%282025%29772474_EN.pdf

284. Churkina, G. et al. Buildings as a global carbon sink. Nat. Sustain. 3, 269–276 (2020)

285. Saharudin, S. H., et al. (2023). Techno-economic assessment of bioenergy with carbon capture systems. Applied Energy, 343, 121345.https://doi.org/10.1016/j.apenergy.2023.121345

286. Sher, F., et al. (2025). A review of carbon capture technologies for bioenergy systems. Renewable and Sustainable Energy Reviews, 189, 114334.

287. Sanna, A., Uibu, M., Caramanna, G., Kuusik, R., & Maroto-Valer, M. M. (2014). A review of mineral carbonation technologies to sequester CO_2. Chemical Society Reviews, 43(23), 8049–8080. https://doi.org/10.1039/C3CS60342J

288. Mühlbauer, A., et al. (2024). Cost assessment of carbon dioxide removal technologies. Energy & Environmental Science. https://doi.org/10.1039/D4EE03166K

289. IEA. (2023) Tracking the impact of government support. https://www.iea.org/topics/fossil-fuel-subsidies

290. OECD (2025) Fossil Fuel Support. https://www.oecd.org/en/topics/fossil-fuel-support.html

291. Fasihi et al. (2022), Nature Climate Change https://www.sciencedirect.com/science/article/pii/S0959652619307772 and

292. Noah McQueen et al 2021 Prog. Energy 3 032001. https://iopscience.iop.org/article/10.1088/2516-1083/abf1ce/pdf

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 $MtCO_2$ each year** – mostly from combustion processes (about 46.6 $MtCO_2$), with a smaller share (around 1.9 $MtCO_2$) 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 plants[250], and 40% for bioliquids. Fuel properties follow standard values from the IPCC[7]: 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 IPCC[7] default emission factor for wood-type fuels is 110 kg CO_2 per GJ, combined with a LHV of 18.5 GJ/t for wood, times 90% capture rate yields a factor of 1.83 tCO_2 per ton of dry biomass (its inverse is 0.55 tDM/tCO_2). Similarly, using the 2023 Climate Registry Default Emissions Factors[251], the emissions per GJ of energy were transformed into biomass basis. These result in conversion factors for MSW biomass (1.30 tDM/tCO_2), biogas (captured methane, 1.11 t/tCO_2), and Biomethane (1.23 t/tCO_2, 0.4t gas), which was treated like natural gas, with IPCC/IEA emissions of 56 $kgCO_2/GJ$.

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
Bioliquids (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 $MtCO_2$/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 CO$_2$ 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 CRCFaligned rules in place - covering quantification, additionality, longterm storage, and sustainability (QU.A.L.ITY criteria[224]) - 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 CO2 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 CO_2 storage additional notes

This annex provides supporting detail for the CO_2 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 CO_2 storage scenarios

Developing realistic scenarios for CO_2 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 CO_2 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 CCS[84] (Phase 1) illustrates a low risk case: its nameplate capacity of 0.025 $MtCO_2$/year and observed injection rate of 0.0225 $MtCO_2$/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 CO_2 storage demand from industrial CCS by storage site (2030–2050)

Table C.2 presents the projected theoretical CO_2 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 survey[127], 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 CO_2 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 CO_2 storage from point-source industrial CCS. Values for 2050 were linearly projected based on the Snam market survey[127].

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 survey[127] (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.

	2030			2040			2050			
Sector	**Total**	**DAC**	**Point-source CCS**	**Total**	**DAC**	**Point-source CCS**	**Total**	**DAC**	**Point-source CCS**	**Split rationale**
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 MtCO$_2$/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 MtCO$_2$e in 2030 and stagnate above 200 MtCO$_2$e through 2040, relying almost entirely on LULUCF (~28–36 MtCO$_2$/year) with minimal CCS (4 MtCO$_2$/year by 2030, rising to 16–40 MtCO$_2$/year by 2040 depending on the scenario). With additional measures (WAM), emissions fall to 291 MtCO$_2$e by 2030, and the more ambitious Decarbonisation and Global Ambition scenarios (DE-IT, GA-IT) push gross emissions down to 185–192 MtCO$_2$e by 2040, with combined CCS and LULUCF removals of 70–76 MtCO$_2$/year. For 2050, Terna-Snam's extrapolated Neutrality scenario — aligned with Italy's LTS, PNIEC and ISPRA 414 — targets approximately 80 MtCO$_2$e of gross residuals compensated by 40 MtCO$_2$/year of CCS/BECCS/DACCS and 35–40 MtCO$_2$/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 MtCO$_2$/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 MtCO$_2$e), with CDR dominated by soil carbon sequestration, afforestation, and nascent BECCS (4–9 MtCO$_2$/year of net removals). By 2040, the scenarios diverge sharply: the technology-led TEC pathway reaches 155 MtCO$_2$e gross with up to 120 MtCO$_2$/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 MtCO$_2$e gross with 54–86 MtCO$_2$/year removals. By 2050, all scenarios project net-negative outcomes (−46 to −63 MtCO$_2$/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 MtCO$_2$ between 2023 and 2050**, with the LTS still about 100 MtCO$_2$ 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 MtCO$_2$ per year and potentially up to 55 MtCO$_2$ 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 MtCO$_2$ 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 MtCO$_2$). These enhancements bend the curve more decisively, lowering residual emissions to roughly 175 MtCO$_2$ per year by mid century. Figure D.3.1 illustrates Italy's emissions trajectories as per official scenarios from ISPRA, PNIEC and the LTS.

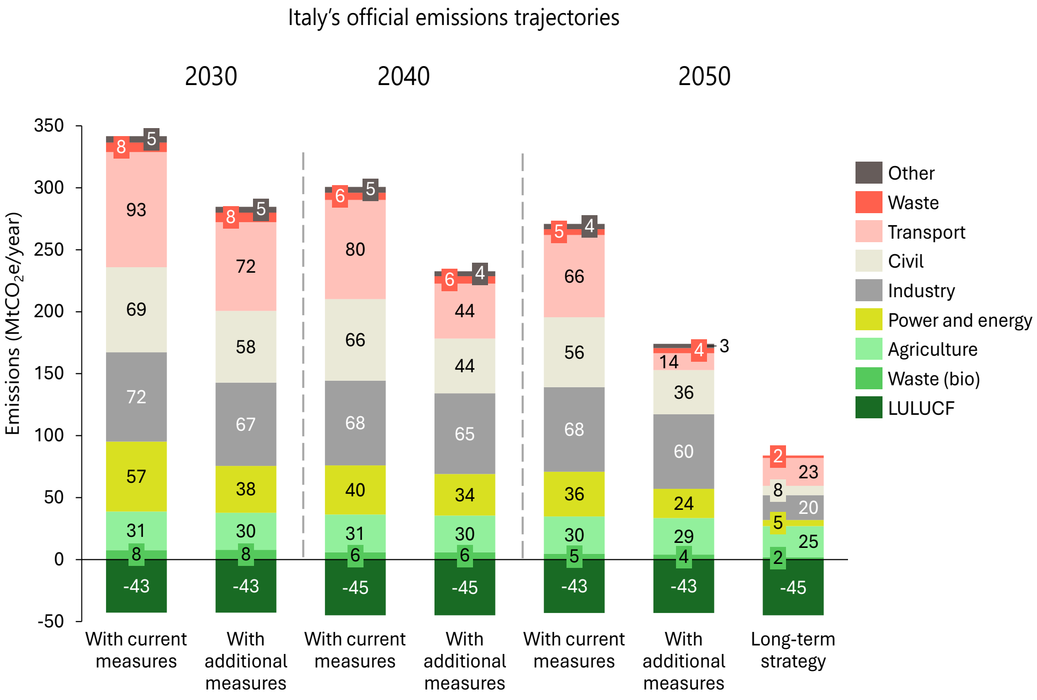


Figure D.3.1. Official national emission trajectories according to the ISPRA-WM (with current measures), ISPRA-WAM (with additional measures), and the LTS (long-term strategy) scenarios.

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 $MtCO_2$/year by 2050, broadening the original LTS range of 65-85 $MtCO_2$/year by 2050[1]. 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 ($MtCO_2e$)	Net removals (LULUCF + engineered) ($MtCO_2e$)	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 CO_2 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; flex-ible demand; minimal gas with CCS; repower bio units for BECCS. The power sector has the potential to achieve net-negative.
Industry (combus-tion + 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 sol-vents 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-CO$_2$)	38	29	35	18	25	Enteric methane inhibitors; improved manure man-agement; 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 incin-erators; 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 (€/tCO_2)** 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 CO_2 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, CO_2 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 firstofakind or earlydeployment 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 supplychain constraints, labour markets, and regional infrastructure buildout - also influence longterm 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.

		Conservative Scenario				Reference Scenario				Ambitious Scenario			
		2030		2050		2030		2050		2030		2050	
	Unit cost (€/tCO_2 removed)	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 MtCO$_2$.

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 Report[47].

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 (livestock 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 (eco-system 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 retuned 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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