LEAP
Laboratorio Energia e Ambiente Piacenza

CCS chain optimisation

The project develops an optimization model based on Mixed-Integer Linear Programming (MILP) to plan CCS (Carbon Capture and Storage) chains, essential for reducing emissions in Italy's hard-to-abate industrial sectors. The model minimizes implementation and operational costs for CO capture, transport, and storage, considering variables such as capture technologies (post-combustion, oxy-combustion), transport modes (pipeline, train, truck, ship), and an offshore storage site in the Adriatic. Applied to 61 industrial plants (cement, steel, refineries, and WtE), it enables infrastructure planning to decarbonize up to 22 MtCO/year by 2050. The model provides a flexible, scalable tool for policymakers and investors, supporting strategic decisions and long-term economic assessments for efficient and sustainable CCS infrastructure

"MILP-based optimisation model for CO2 capture, transport and storage chain planning"

Laboratory	LEAP
Specialization Area	Energy and Sustainability
Contacts	Matteo Zatti
Keyword	CO2 Capture and storage, Chain optimisation, Hard-to-abate sector, Mixed-integer linear programming

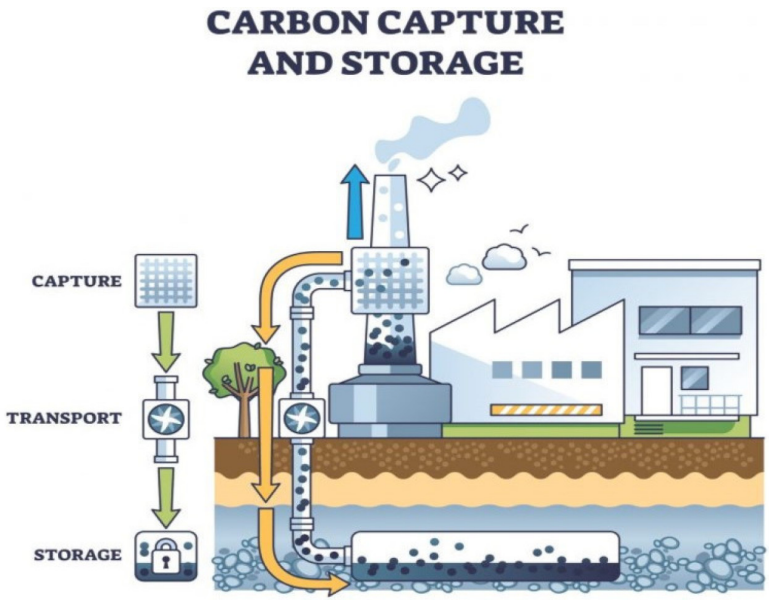


Fig. 1: Carbon Capture and Storage chain (source: iStock)

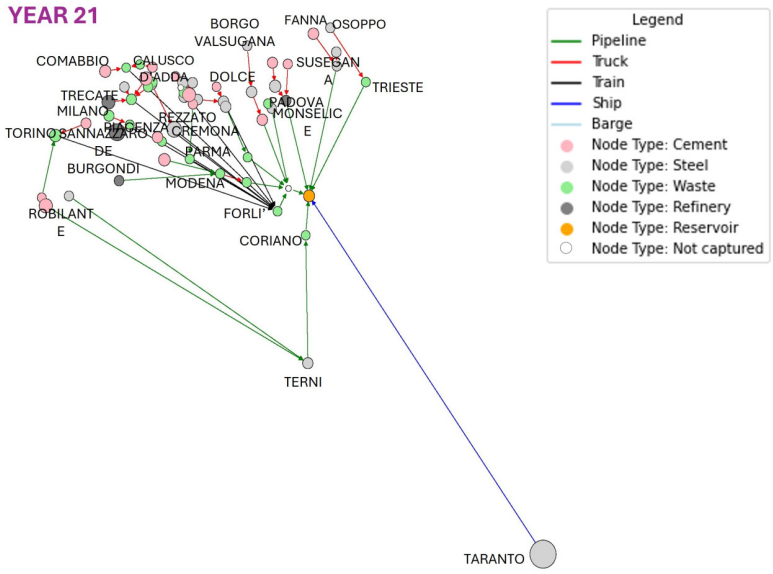


Fig. 2: Infrastructure projects planned with the MILP model

Description

The project presents an optimization model based on Mixed-Integer Linear Programming (MILP) to design Carbon Capture and Storage (CCS) chains, a key technology for decarbonizing hard-to-abate industrial sectors. These sectors, including cement plants, steel mills, refineries, and Waste-to-Energy (WtE) plants, are characterized by high CO₂ emissions and limited alternative solutions for significant reductions.
The model is aimed at policymakers, investors, and industrial planners, providing strategic support for CCS infrastructure implementation. By minimizing the Total Annualized Costs (TAC), it encompasses all CCS chain stages: CO₂ capture at emission sites, multimodal transport (pipeline, trains, trucks, ships), and final offshore storage in the Adriatic Sea. Its functionality relies on detailed inputs, including site emissions, capture and transport technology costs and performance, and decarbonization targets.
This model serves as a flexible and scalable tool, enabling simulations across diverse scenarios and targets, up to 22 MtCO₂/year sequestered by 2050. It ensures an optimized approach balancing economic and environmental needs, facilitating strategic decisions for sustainable long-term CCS infrastructure.

Innovative aspects

The project introduces an innovative MILP optimization model that combines detailed geographic granularity with a modular approach for CCS chain planning. Compared to the state of the art, the model integrates sector-specific and technological variables (e.g., capture technologies tailored for cement, steel, and WtE) with multimodal transport options, enabling flexible and scalable planning.
A key innovation lies in the simultaneous optimization of capture, transport, and storage, balancing costs, performance, and environmental constraints over a 20-year horizon. By leveraging high-resolution inputs, such as localized emissions and specific CAPEX/OPEX costs, the model allows customized simulations, overcoming the rigidity of traditional continental-scale models.
Additionally, the application to the Italian context, with a focus on multimodal infrastructure and offshore storage, provides cost-effective strategies to accelerate the decarbonization of hard-to-abate sectors.

Potential applications

The model is applicable to hard-to-abate sectors such as cement, steel, refineries, and Waste-to-Energy (WtE), optimizing tailored CCS chains to reduce CO₂ emissions. It supports policymakers and investors in planning decarbonization infrastructures, contributing to climate targets. Also adaptable to diverse geographic and temporal contexts, the model enables strategic decisions for sustainable transitions in high-emission industrial sectors.

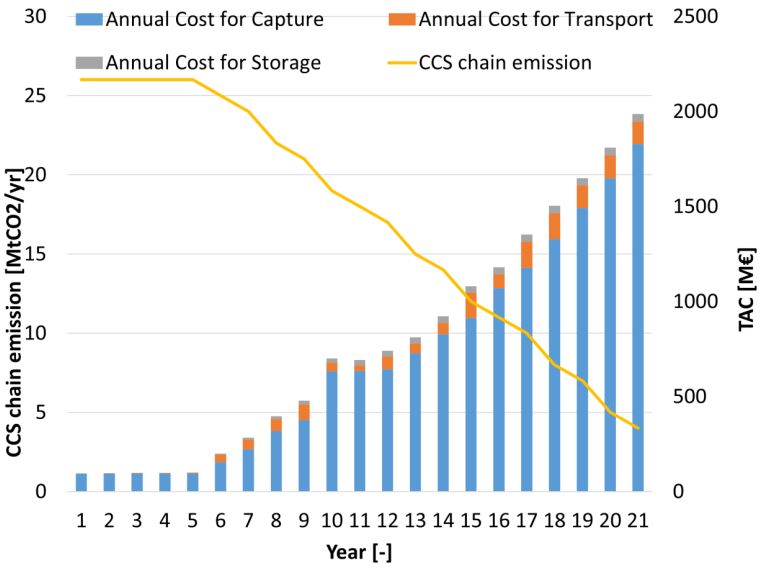


Fig. 3: Breakdown of annual costs for capture, transport and storage (primary axis) versus CCS emission chain (secondary axis)

Involved partners	LEAP, Politecnico di Milano
Implementation Time	6 person months
Technology Readiness Level	TRL5 - Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
Exploitation	The model can be valorized through collaborations with companies in hard-to-abate sectors to customize and apply the tool to their specific needs. Partnerships with industrial operators and public institutions are planned to implement CCS infrastructure at regional and national scales, with potential for creating spin-offs focused on consultancy and technological development.

Application example

Application of the MILP Model for CCS Chain Planning in Italy's Hard-to-Abate Sectors: Capture, Transport, and Storage of up to 22 MtCO₂/year

The MILP model was applied to CCS chain planning in Italy, analyzing 61 industrial plants across cement, steel, refineries, and WtE sectors. The goal was to optimize CO₂ capture, transport, and storage costs, balancing economic and environmental constraints over a 20-year horizon. By year 21, the infrastructure captures 25 MtCO₂/year with approximately 2000 km of pipelines. The total annualized cost (TAC) is 6775 M€, with 89% tied to capture, 8% to transport, and 3% to storage. Pipelines are preferred for medium-long distances, while trucks and trains are optimal for short routes and distances over 150 km.
The model identified optimal strategies for progressive infrastructure deployment, starting with cement plants (cheapest), followed by WtE, steel mills, and refineries. The minimum Annualized Cost of Stored Carbon (ACSC) of 29.2 €/tCO₂ is achieved in year 18. The application demonstrated the feasibility of scalable, sustainable CCS infrastructure to support national climate targets.

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LEAP è stato costituito nel maggio 2005 a Piacenza su iniziativa della Sede di Piacenza del Politecnico di Milano ed è uno dei laboratori della Rete Alta Tecnologia della Regione Emilia-Romagna. Racchiude tra i suoi soci eccellenze dal mondo universitario ed industriale e le principali istituzioni territoriali piacentine.
Obiettivi di LEAP sono la ricerca, l'erogazione di consulenze e servizi, l'esercizio di azioni di trasferimento tecnologico per industria ed enti pubblici. Svolge attività sperimentali e prove su impianti e sull'ambiente, organizza corsi di formazione ed iniziative di divulgazione scientifica.
Le attività LEAP sono distribuite su 4 aree di competenza: (i) Waste to Value – Materia ed Energia da rifiuti, residui e biomasse, (ii) Low Carbon Technologies – Tecnologie Energetiche e processi industriali a basse emissioni di CO_2, (iii) Smart Energy Systems – Energie rinnovabili ed Efficienza Energetica e (iv) Emissions & Air Quality – Emissioni Gassose, polveri e qualità dell'aria.
LEAP offre soluzioni flessibili e adattabili alle esigenze del cliente, senza perdere il rigore scientifico che mantiene a tutti i livelli. È coinvolto in progetti di ricerca nazionali e internazionali di alto rigore scientifico, come partner e come coordinatore. Allo stesso tempo, offre consulenze industriali in cui dominano l'innovazione, l'attenzione al contesto normativo e la capacità di interfacciarsi con soggetti diversi per natura, dimensione, cultura e vocazione.

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