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Zero Carbon Technology Roadmap

Carbon Capture & Storage: a strategic lever for the decarbonisation and competitiveness of Italy

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Colophon

The Strategic Study was conducted by The European House - Ambrosetti on behalf of Eni and Snam.

The project team consists of a Scientific Committee, responsible for the strategic direction of the research, whose members provided scientific advice, and by a Working Group in charge of developing the Strategic Study.

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Special thanks go to the management of Eni and Snam, who contributed to the development of the Strategic Study through confidential interviews:

- **Adriano Alfani**, Chief Executive Officer, Versalis, Eni
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In order to identify the best strategies for using CCS as an opportunity to increase the economic competitiveness of industries and identify policy gaps related to CCS adoption in the of CCS in the European and Italian context, two working tables with the following 63 stakeholders.

Working Table #1: Economic Competitiveness of Industries

- **Ricardo Aguiar**, Portugal's Directorate-General of Energy and Geology
- **Matteo Battaini**, Chief Sustainability and Future Mobility Officer, Pirelli
- **Sabina Bigi**, Professor, Department of Earth Sciences of the University of Rome
- **Guido Bortoni**, Chairman, CESI
- **Francesco Bragagni**, Energy Manager, Mercegaglia
- **Andrew Brown**, Chief Operating Officer, Storegga
- **Sara Budinis**, Energy Analyst, International Energy Agency
- **Davide Chiaroni**, Director, Energy & Strategy, Politecnico di Milano
- **Cedric De Meeus**, Vice President, Government Relations, HOLCIM
- **James Eyton**, Head of CCUS Developments, Viridor
- **Heinz Felder**, Senior Vice President, Group Technology & Investiments, Stora Enso
- **Roberto Ferrario**, Head of CCUS Innovation Solutions, Eni
- **Aldo Fiorini**, Chief Operations Officer, Mercegaglia
- **Marco Geneletti**, Energy Senior Director, Tenaris
- **Stefano Granella**, Chief Strategy & Growth, A2A
- **Marco Guala**, BU Service Head, Paul Wurth Italia
- **James Henderson**, Chairman, Energy Transition Research Initiative; Gas Research Programme, Oxford Institute for Energy Studies
- **Georges Madessis**, Italy Country manager, Ineos Inovyn
- **Marco Mazzotti**, Professor, ETH Zürich
- **Sergio Menendez**, President, Cemex EMEAA
- **Barbara Merson**, Technologist, National Institute of Oceanography and Experimental Geophysics
- **Massimo Nicolazzi**, Senior Advisor; Professor, ISPI's Energy Security Program; Turin University
- **Arvid Nottveit**, Strategic Advisor Energy, NORCE
- **Davide Paganelli**, Energy Manager, Marazzi Group
- **Astrid Ute Friderike Palmieri**, Sustainability Manager, BASF
- **Babette Pettersen**, Vice President Europe, Lanzatech
- **Florina Magdalena Pînzaru**, Full Professor and Dean, SNSPA
- **Agostino Rizzo**, Cement Operations Manager, Italcementi
- **Luca Sassoli**, Chief Executive Officer, Burgo Energia and Group Energy Manager, Burgo
- **Carlo Stagnaro**, Research and Studies Director, Istituto Bruno Leoni
- **Paolo Testini**, Director, CCS Projects and Carbon Removal Development, Snam
- **Michele Zitti**, Director, Decarbonisation and Sustainable Business Development, Yara
- **Olav Oye**, Senior advisor, Climate and Industry, Bellona Europa

Working Table #2: Policy Gaps in Europe and Italy

- **Simona Benedettini**, Associate, MRC Consultants and Transaction Advisers
- **Victor Bernabeu**, Director & Senior Policy Advisor, Eurogas
- **Christoph Beuttler**, President and Co-Founder, Negative Emissions Platform; Chief Climate Policy Officer, Climeworks; Senior Expert, Energy & Climate, Risk Dialogue Foundation
- **Guido Bortoni**, Chairman, CESI
- **Adriano Carrara**, Head of CCUS R&D Unit, A2A
- **Francesco D'Apolito**, Research Executive, Rud Pedersen Public Affairs
- **Chris Davies**, Director, CCS Europe
- **Caterina De Matteis**, Senior Policy Manager, IOGP
- **John C. Dwelle**, Chief Operations Officer, Landwärme GmbH
- **Bassam Fattouh**, Director, Oxford Institute for Energy Studies
- **Marianna Frison-Roche**, Gas Asset Regulation and Market Design Expert, Engie
- **Per-Olof Granström**, Secretary General, Zero Emission Platform; EU Director, CCSA
- **Claudia Hanisch**, Representative EU, VNG AG
- **Christopher Jones**, Professor, European University Institute
- **Diego Lelli**, Business Operations Leader, Baker Hughes
- **Toby Lockwood**, European Director, CCUS Technology and Markets, CATF
- **Mario Mattioli**, President, Confitarma
- **Barbara Merson**, Technologist, National Institute of Oceanography and Experimental Geophysics
- **David Nevicato**, Board Member, CO2Club
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The contents of this Strategic Study refer exclusively to the analysis and research carried out by The European House - Ambrosetti and represent its opinion, which may not coincide with the opinions and views of those interviewed and involved in the initiative.


CO2

Preface

Foreword by Claudio Descalzi

This study comes to light at a pivotal moment in the international community's debate about what commitments should be made to effectively address climate change and its impacts, as part of the roadmap leading up to the upcoming COP28 in Dubai.

In a context that sees this debate igniting and highlighting different positions, the impracticability of a solution capable of ensuring, on its own, sufficiently rapid decarbonization to achieve the objectives defined by the Paris Agreements is now increasingly evident. This is even more true for the so-called Hard to Abate sectors, which are particularly emissive but, at the same time, strategic for the vitality of the economic structure and of which it is, therefore, essential to ensure continuity and competitiveness. It is undoubtedly essential to reaffirm the principle, now affirmed by multiple participants in this debate, of technological neutrality and to reason from the perspective of using a wide range of solutions.

In this framework, the development of carbon capture and storage (CCS) takes a prominent position.

Leading international organizations-including the IEA, IPCC, and IRENA-consider CCS critical to achieving climate goals and include it in the mix of solutions needed to achieve carbon neutrality by 2050.

In recent months, Europe has also taken a clear stance that rapid development of the CCS supply chain is indispensable to keep to the planned decarbonization course and target net zero.

Last March, as part of its proposed Net-Zero Industry Act, the European Commission included CCS as one of the Strategic Net-Zero Technologies, recognizing its significant contribution to reducing CO_2 emissions by 2030 and, more importantly, the need and opportunity to develop it rapidly. Based on these premises, the Commission has proposed a European injection capacity target of 50 million tons of CO_2 per year by 2030. This is a challenging target, but one that is, nevertheless, only the starting point when we consider that, according to the Commission's own estimates, the Union may need to capture up to 550 million tons of CO_2 per year by 2050.

For some Hard to Abate sectors, CCS is the only decarbonization option available, in the scenario where this is missing the only alternative is to emit CO_2 into the atmosphere, with severely negative impacts on the environment and an additional burden on the emission budgets of countries and companies.

From a technological point of view, this is a mature process, based on established technologies that have been applied for decades, even in different technical contexts, not only with CO_2 but also with methane. Moreover, a massive engineering and research effort has been concentrated in this area in recent years, which is leading to the development of increasingly efficient and less expensive technologies, particularly in the field of capture. The same can be said for the health and safety aspects: the CO_2 is a gas that is easy to handle, with storage occurring within deep geological formations suitable for safe containment.

Eni believes strongly in the importance of CCS and has included it among the key levers of its decarbonization strategy, setting a goal of achieving total annual storage of 30 million tons by 2030.

In addition to being a partner in the Sleipner project in Norway, which has already stored about 20 million tons of carbon dioxide safely since it began operations in 1996, Eni is involved in numerous projects, at various stages of progress including, most notably HyNet North West in the United Kingdom, where CCS is considered among the indispensable levers toward Net Zero, in Libya (Bahr Essalam), Egypt, Australia, and the United Arab Emirates.

In Italy, Eni decided to integrate its know how with that of a partner of excellence such as Snam to develop Ravenna CCS, a project based on the reuse of depleted gas fields in the offshore Adriatic Sea, exploiting a total storage potential estimated at 500 million tons of CO_2 .

The first phase of the project, for which a permit has already been obtained, will start in the first quarter of 2024, while the start of the industrial phase, sized to store 4 million tons of CO_2 per year, is planned to start in 2026, with possible subsequent expansions up to a capacity of 16 million tons per year.

Ravenna CCS can become a reference point for decarbonization of Hard to Abate sectors and is a candidate to become the main CCS hub in Southern Europe, capable of meeting the decarbonization needs of both Italian industrial sites and international emitters in the Mediterranean area.

Therefore, it not only offers the unmissable opportunity for our country to be able to have this decarbonization option already in the horizon of 2026, but it is also a unique opportunity in the entire area of Southern Europe, which benefits the competitiveness of the national production structure and allows Italy to play a pivotal role in the Mediterranean, including through the implementation of cross-border CCS projects.

Seizing this opportunity requires strong teamwork and collaboration among all stakeholders.

It is necessary to build from the ground up a new industrial supply chain in which many players are integrated: operators of storage sites and transport networks and emitters, who are called upon to invest in capture projects.

The public policymaker plays a key role in facilitating this teamwork through full recognition of the role of CCS in the country's and Europe's decarbonization pathway, which must be followed by timely creation of the relevant enabling conditions.

Equally central, then, is fostering awareness of this decarbonization option and related debate among institutions, citizens, the business community and research institutes to ensure its smoother diffusion.

For this, I thank The European House - Ambrosetti, the members of the Advisory Board, my colleagues at Eni and Snam, and all the experts who, in various capacities and bringing different points of view, have enriched the work that led to the publication of this study, which will surely contribute to increasing widespread awareness of the importance of CCS for the decarbonization and competitiveness of Italy.

Claudio Descalzi
Chief Executive Officer, Eni

Preface by Stefano Venier

The CCS technology could – if governments commit to specific policies – account for nearly one-fifth of the emissions reduction required to cut GHG emissions from energy use in half by 2050.

The scale of potential future deployment of CCS is enormous.

This is what the IEA stated back in 2012, in its Policy Strategy for Carbon Capture and Storage. A decade later, this awareness has indeed spread across Europe, creating a positive context for carbon capture, transportation, and storage technologies.

It's no longer a mystery to anyone in the field that CCS is a significant lever for decarbonization among the various ways to reduce CO_2 emissions into the atmosphere. Industries, infrastructure operators, institutions: at all levels, CCS is strengthening its position as a solution for achieving challenging emission reduction and zero-emission goals in certain Hard-to-Abate sectors.

Snam has embraced this challenge and, alongside Eni, has taken the lead in developing Italy's first carbon capture and storage project, CCS Ravenna. This project stands as one of the largest initiatives in the Mediterranean and Europe. We believe in the potential of this technology to guide Italy and Europe toward Net Zero. We understand the need to view it as a piece in a larger and diverse puzzle, yet we are also convinced that this technology can be one of the most mature solutions, with increasingly competitive and appealing costs.

Furthermore, we believe that the CCS Ravenna project will be a crucial infrastructure for the country, supporting the future of the vital industrial structure and potentially attracting new establishments (thus generating wealth and jobs) that can opt for decarbonized production.

As Snam, with 80 years of history in natural gas transportation and storage, we bring added value to the initiative launched with Eni. This solid foundation guarantees Italy a strong starting point for the development of a dedicated CO_2 transportation network and a renewed use of depleted fields in the North Adriatic, this time in support of the decarbonization of the Italian industry.

The presence of offshore fields near the Adriatic coast is a characteristic that Italy shares with Northern European countries like England and Norway, which are already active in developing projects for CO_2 capture, transportation, and storage. These countries demonstrate a favourable combination of institutional commitment and industrial investment. This model is perfectly replicable in Italy, and the strategic position as well as the high storage potential of the North Adriatic fields represent an interesting opportunity for cross-border collaboration.

"If governments commit to specific policies," as IEA suggested all the way back in 2012, but we are aware that the regulatory framework, not only nationally, still struggles to fully support the development of projects for CO_2 capture, transportation, and storage. Thus, it becomes imperative to incorporate, within a comprehensive and up-to-date strategic analysis, the latest technological advancements, potential future progressions, and the policy and regulatory pathways to effectively empower this sector. We have chosen The European House - Ambrosetti as a partner in this journey, and we have sought the support of a diverse and competent Advisory Board and Scientific Committee, ensuring a final product that can serve as a starting point for expanding the debate, both in Italy and in Europe, on the importance of diverse decarbonization strategies, the role of CCS within the array of possibilities available to the national and European industry, and the need for firm and resolute intervention by Institutions to ensure that the regulatory framework genuinely supports the development and growth of these technologies.

Stefano Venier
CEO, Snam

Prefazione by Valerio De Molli

"Addressing the climate challenge presents a golden opportunity to promote prosperity, security and a brighter future for all."
Ban Ki-Moon (former Secretary-General, United Nations)

It is now clear that **decarbonization will be the challenge of our century**.

Globally, we are observing a **significant lag in achieving decarbonization goals**. Over the past three decades, despite numerous commitments, **governments, institutions and businesses have failed to implement concrete and effective measures to reduce climate-changing gas emissions**. In fact, as shown by a recent study by the World Meteorological Organization, with a 66 percent probability the annual average global temperature between 2023 and 2027 will reach the limit of 1.5°C above pre-industrial levels (threshold established by the Paris Agreements).

Therefore, **a gear shift on decarbonization of the whole society is needed** in order to reduce greenhouse gas emissions faster than hitherto, multiplying the abatement rate of the last decade by four to reach net zero emissions in 2050, without sacrificing welfare, industrial competitiveness and social equity.

To this end, research and development of new technologies are our most important allies. As early as 2022, The European House - Ambrosetti through the Zero Carbon Technology Roadmap Strategic Study demonstrated how, for the achievement of decarbonization goals, it is essential to refer to the **principle of technology neutrality**, exploiting the synergic and complementary contribution of all available technologies to achieve the goal of zero net CO_2 emissions by 2050. The debate that has arisen, both at the Italian and European level, since the presentation of the Strategic Study has been instrumental in directing deep, nonideological and fact-based reflection among policy makers and the business community.

The Strategic Study 2023 "**Zero Carbon Technology Roadmap - Carbon Capture & Storage: a strategic lever for the decarbonization and competitiveness of Italy**" aims to explore in greater detail the role and potential impact of CO_2 capture technologies for the decarbonization of economic and industrial systems.

CO_2 capture and storage technologies are an **important lever for decarbonizing** and **sustaining the competitiveness of** Hard to Abate **economic activities**, which will face a significant increase in the cost of emissions in the coming years, resulting in non-negligible risks on European industrial competitiveness. The Strategic Study shows how only through the development of Carbon Capture & Storage technologies can the **complete decarbonization** of Hard to Abate sectors be achieved.

This evidence is supported by rigorous analysis, supported by the study of **160 sources of academic-scientific literature** and intensive discussions with **63 international stakeholders**, including experts from academia, representatives of industry associations, and managers of major European Hard to Abate supply chains.

For Italy, the achievable benefit is twofold.

First, the important CCS infrastructures being developed around the **Ravenna Hub** represent a unique opportunity in Southern Europe, which can be exploited to give a **competitive advantage to national Hard to Abate supply chains,** which will already be able in the short term to have a safe, competitive and scalable decarbonization lever, as well as one that can be implemented without disrupting production assets. The econometric model carried out by The European House - Ambrosetti estimates that the full exploitation of the potential of the Ravenna Hub will be able to make a decisive contribution to supporting the competitiveness of Hard to Abate supply chains capable of generating **€62.5 billion and supporting the employment of 1.27 million workers by 2050**.

Second, the implementation of wide-ranging CCS projects in Italy can foster the development of a new specialized national supply chain, capable of generating, for the project pertaining to the Ravenna Hub alone, **30 billion Euros of cumulative added value between 2026 and 2050** and more than **17 thousand new jobs by 2050.** Moreover, this supply chain will be able to have an international projection and cultivate opportunities in a market estimated to be worth up to 400 billion Euros globally by 2050.

In order to maximize the potential of these opportunities, the Strategic Study has identified **ten** timely and concrete **policy proposals** that we want to bring to the attention of policy makers. The proposals address the need to create a **regulatory framework consistent** with European CO_2 capture and storage goals and to **support the development of projects according to market logic**, consistent with the principle of technology neutrality that guided this Strategic Study.

The development of the analyses contained in the Strategic Study benefited from the participation of **63 stakeholders**, from different economic sectors and academia, who were consulted in two Working Tables. To all of them goes my heartfelt thanks.

I would like to thank, for their valuable contribution to the Strategic Study, the Advisory Board, composed of **Claudio Descalzi** (CEO, Eni), **Stefano Venier** (CEO, Snam), **Markus Kerber** (Strategy Advisor, CDU; Managing Director, 1886 Ventures; former State Secretary, Ministry of the Interior - Government of the Federal Republic of Germany; former CEO, Bundesverband der Deutschen Industrie - BDI), **Emma Marcegaglia** (Chairwoman and Managing Director, Marcegaglia; Chairwoman, University Luiss Guido Carli; Board Member, Bracco and Gabetti Property Solutions; former Chairwoman, BusinessEurope; Former Chairwoman, Eni; Former Chairwoman, Confindustria) and **Andris Piebalgs** (Professor, Florence School of Regulation; former European Commissioner for Development [2010-2014]; former European Commissioner for Energy [2004-2010]).

Thanks also to the 23 managers of Eni and Snam, who have contributed, through interviews and face-to-face moments to the analyses contained in this Strategic Study.

Finally, a heartfelt thanks to my colleagues in The European House - Ambrosetti Working Group composed, in addition to myself, by Corrado Panzeri, Alessandro Viviani, Gherardo Montemagni, Giorgia Rusconi, Arianna Basso, Ege Ondes, Maria Mazza and Lucia Contini.

Valerio De Molli
Managing Partner & CEO, The European House - Ambrosetti

Preface by Markus Kerber

The 2023 Zero Carbon Technology Roadmap study by Ambrosetti and ENI was a landmark study as it demonstrated the technological feasability of a decarbonized Europe. The mapping of 100 decarbonisation technologies together with principle of technology neutrality was the basis for the claim of a zero carbon Europe. Among the 100 technologies mapped, Carbon Capture and Storage (CCS) proves to be a unique solution to combat certain emissions such as process emissions, standard fossil fuel emissions, the non-green hydrogen production emissions, as well as negative emissions in for instance the agriculture sector. CCS is among the most relevant zero-carbon technologies together with electrification and RES.

Based on this groundbreaking study, Ambrosetti together with Eni and Snam in 2023 undertook a deep dive study in the field of CCS in Europe, and in particular, in Italy highlighting the social and economic opportunities for Italy in exploiting CCS to decarbonise and sustain the competitiveness in hard to abate sectors. By analysing and testing all necessary parameters of the CCS technologies in 160 academic papers and with the help of 63 stakeholders involved from 39 entities from leading international corporations, universities and EU associations, the study produced further evidence for the overdue application of CCS in Italy and Europe. Furthermore it produced clear and forward looking policy proposals for national and European regulators alike.

CCS is a mature, safe and cost-competitive policy option that must not be discarded, ignored or overlooked. With technology readiness levels of between 8-9 and capture efficiency between 85% and 95% CCS is mature. Theoretical models and the vast know how pool of the oil and gas industries underline a 99.99% non-leaking safety level. Maybe most importantly, the study shows that by 2050 the average cost of CCS in Italy will be around 95 Euros per ton of CO_2 captured, thus well below the prospected cost for emissions allowances under the ETS mechanism. These prospective costs can even be lowered by the learning curve effect and economies of scale, which again speaks for fast and broad application of CCS in the EU.

As all of the currently operative projects in the EU are based in the North Sea the Italian CCS project in Ravenna will be of utmost importance for the creation and operation of a decarbonisation hub in Southern Europe. With more and more hydrogen-related projects developing in the MENA region which will need pipeline ports in the Mediterranean, Italy could become a major player in the decarbonization and transformation industries within the EU as the industrial core regions in Southern Germany and the Czech Republic for instance are much closer to Southern Europe and will benefit from CCS assets in Italy.

The policy implications of our findings in four areas – soft infrastructure, sector applications, strategic planning and de-risking - are clear and must not be overlooked by regulators in Itay and the EU. We need, inter alia, a common EU-wide technical standard for transport and storage, as well as a uniform regulatory system among EU member states so as to prevent asymmetries and inefficiencies. Furthermore, the promotion of the application of the principle of technology neutrality by considering leveraging the complementarity between mature decarbonization solutions and those that will only be available in the medium term, will be a key aspect of smart regulation. Governments and EU institutions alike must understand that they have a key role to play in engaging stakeholders when defining concrete and appropriate infrastructure development plans that meet the expectations of industries and leverage private investment. Member states and the EU should perceive our CCS study as a clear indicator for a successful zero-carbon technology roadmap realisation.

Markus Kerber
Strategy Advisor, CDU; Managing Director, 1886 Ventures;
former State Secretary, Ministry of the Interior - Government of the Federal Republic of Germany;
former CEO, Bundesverband der Deutschen Industrie - BDI

Preface by Emma Marcegaglia

Combating climate change means "containing the rise in the Earth's average temperatures well below the critical 2-degree threshold and as close as possible to the 1.5-degree threshold" by setting a goal of "a 45 percent cut in carbon dioxide emissions compared to 2010, to be implemented by 2030, and the achievement of net zero emissions around mid-century," as outlined by the recommendations of the COP-26 in Glasgow. To achieve this fundamental goal, there is no single solution, but different actions need to be promoted based on scope, maturity of technologies and their sustainability. This concept applies particularly to the Hard to Abate sectors, those most difficult to convert that use fossil fuels as an energy source: cement factories, paper mills, ceramics, steel industry and glass industry.

Among existing technologies, CCUS is a key factor in the decarbonization strategy. CCUS (Carbon Capture, Utilisation and Storage) technologies enable the retention of CO_2 emitted by industrial processes while avoiding its emission into the atmosphere, having the possibility of using it (Utilisation) as a raw material for the production of fuels, chemicals or construction materials or storing it permanently in underwater reservoirs (Storage).

In particular, Ravenna has the ideal conditions for a CCUS-based project: an industrial hub with Hard to Abate sites (chemical industry, steel processing, cement factories), a chemical complex that can collect CO_2 from industrial sites, rail and maritime infrastructure through which to receive CO_2 with different origins, former submarine gas fields where to inject the captured CO_2. Marcegaglia, Yara, Cabot and Versalis, with technical and infrastructural support from Eni and Snam, have built a consortium aimed at reducing nearly 1 million tons of CO_2 per year and reusing or storing it.

In the steel processing sector (typical of Marcegaglia), although it constitutes a relatively low component of Scope 1 and Scope 2 (less than 10 percent) compared to the Scope 3 represented by steel mills, the technology to replace natural gas is not yet ready; either the costs are not as sustainable as electrification of processing lines or scientific and technological research has not yet enabled the use of 100 percent hydrogen in the combustion phase to heat annealing furnaces.

Otherwise, CCUS is a ready, mature and safe technology that has already found application in various fields with great success. But in the field of post-combustion flue gas (a typical application in steel processing), the percentage of CO_2 contained in the emitted flue gas is low and more difficult to capture. Large investments accompanied by high operating costs are needed, making CCUS unsustainable. Therefore, a financial livelihood policy is needed to calm CAPEX and OPEX in a context where "everyone has to do their part" (point 8 Glasgow COP26 Agreement).

Parallel to CCUS, the commitment to continuous reduction of emissions until their elimination must be maintained by moving from a virtuous reduction of consumption to the application of technologies (when they are ready and tested) suitable for the total replacement of natural gas with green energy or hydrogen. In the former case the amounts of energy obtained from renewable sources needed are extremely high and not available today, while for hydrogen, we still lag behind in terms of technological knowledge.

Decarbonization to achieve Net-Zero-Emissions in 2050 is undoubtedly a big challenge. Research, innovation, industry, banks, investors, tech providers, each in their own field must contribute to the achievement of a single goal. There is no one-size-fits-all solution; emission reductions will have to be gradual as knowledge and technological development increases. We need to abandon ideological positions and implement the solutions that can already help with the goal, such as CCUS.

Emma Marcegaglia
Chairwoman and Managing Director, Marcegaglia; Chairwoman, University Luiss Guido Carli; Board Member, Bracco and Gabetti Property Solutions; former Chairwoman, BusinessEurope; Former Chairwoman, Eni; Former Chairwoman, Confindustria

Preface by Andris Piebalgs

The summer of 2023 has been marked by severe heatwaves and widespread forest fires across the Mediterranean, echoing a global alarm about the immediate necessity to address climate change. As this urgency escalates, it is glaringly evident that we need to exploit every technological advancement at our disposal to limit greenhouse gas (GHG) emissions. The European Union (EU), rising to this challenge, has committed to achieving carbon neutrality by 2050. While energy efficiency and renewable energy serve as pivotal tools to realize this objective, there is a pressing need to consider additional strategies, among which Carbon Capture and Storage (CCS) stands as a largely unexplored avenue.

CCS technology offers an immediate tool to address the climate crisis. This process involves capturing carbon dioxide from industrial sources, transporting it to a storage site, and injecting it into suitable underground geological formations for permanent storage. It emerges as the only decarbonization option in sectors with Hard to Abate GHG emissions, such as cement. In other energy-intensive industries, it is a prerequisite for affordable GHG reductions during the transition to clean energy. Furthermore, when coupled with biomethane, CCS can act as a significant carbon sink, delivering negative emissions. Despite its immense potential, the deployment of CCS on a large scale remains impeded by the complexities of the value chain, limited economic incentives, and inadequate political focus.

However, a promising shift is evident with the proposed introduction of the Net-Zero Industrial Act. This Act acknowledges the potential of CCS technologies to significantly contribute to the goal of achieving net-zero emissions by 2050. And CCS is set to play an important role in strengthening the EU's strategic autonomy. A Union-wide target has been proposed, aiming for an annual operational carbon dioxide injection capacity of 50 million tonnes by 2030, primarily through obligations imposed on oil and gas producers.

The evolution of the carbon pricing mechanism, which now approaches three digits per ton of emissions, and the proposed phase-out of free allowances combined with the Carbon Border Adjustment Mechanism, offer additional impetus for CCS deployment. While coordinating the entire CCS value chain remains challenging, these initiatives have significantly improved prospects.

Historically, the development of CCS in Europe has been predominantly associated with activities in the North Sea area, primarily led by the Netherlands and Norway. However, the South of Europe is equally significant. The broad deployment of CCS carries significant implications for industrial policy across the EU, acting as a key facilitator of decarbonisation in challenging industrial sectors.

The Strategic Study, offering essential insights for a European and more specifically, an Italian strategy for utilizing CCS, is pivotal. It provides an analysis of technological maturity, a review of the regulatory framework, the impact on industrial sectors, and a mapping of the ecosystems underlying CCS project development. Although it maintains a global perspective, it focuses particularly on Italy, aiming to protect and enhance economic competitiveness in Hard to Abate sectors.

The release of the Strategic Study is indeed timely, advocating for an ambitious political compromise on the proposed Net-Zero Industrial Act and contributing robust input for the forthcoming EU CCUS Strategy. Amid a changing climate, such strategies offer valuable insights for sustainable industrial growth and a move towards climate neutrality. The EU requires a detailed blueprint encompassing the construction of the CO_2 grid, the development of adequate storage facilities, the timeline and structure of the grid, the financing, and a stable regulatory regime.

Carbon Capture, Usage, and Storage (CCUS) must form an integral part of the EU's decarbonisation strategy. However, any decarbonisation solution demands considerable political guidance and support. The Strategic Study provides the necessary arguments to address queries related to the broader deployment of CCS, bolstering our fight against climate change.

Andris Piebalgs
Professor, Florence School of Regulation


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Executive Summary

The Strategic Study '**Zero Carbon Technology Roadmap - Carbon Capture & Storage: a strategic lever for the decarbonisation and competitiveness of Italy**', conducted by The European House - Ambrosetti on behalf of Eni and Snam, intends to investigate in detail the role and potential impact of CO_2 capture technologies for the decarbonisation of economic and industrial systems.

The Strategic Study presents, with the utmost authority and according to super partes criteria, a reference framework on the most current technological developments of CCS solutions, delving into the most exemplary case studies and identifying their impacts in the European and national context.

Through a mapping of the current needs and gaps in the industrial capacity of the ecosystems underpinning CCS project development and a review of the regulatory framework, areas for action were highlighted to create a favourable environment for industrial development and market deployment of CCS solutions.

Furthermore, through a proprietary theoretical model, the potential environmental, economic, and social impacts on some Italian industrial Hard to Abate sectors were measured. In addition, the impact of creating a new industrial supply chain linked to the development of CCS projects was assessed.

Based on this evidence, key elements for a European and Italian 'CCS Strategy' were outlined to foster the deployment of CCS technologies and maximise the decarbonisation results of the Hard to Abate sectors.

The Initiative was guided by an Advisory Board, responsible for the strategic direction of the research, whose members provided scientific advice and guided the development of the Strategic Study. The Advisory Board is composed of:

- Claudio Descalzi, CEO, Eni;
- Stefano Venier, CEO, Snam;
- Valerio De Molli, Managing Partner & CEO, The European House - Ambrosetti;

- Three Scientific Advisors:
  - Markus Kerber, Strategy Advisor, CDU; Managing Director, 1886 Ventures; former State Secretary, Ministry of the Interior - Government of the Federal Republic of Germany; former CEO, Bundesverband der Deutschen Industrie -BDI;
  - Emma Marcegaglia, Chairwoman and Managing Director, Marcegaglia; Chairwoman, University Luiss Guido Carli; Board Member, Bracco and Gabetti Property Solutions; former Chairwoman, BusinessEurope; Former Chairwoman, Eni; Former Chairwoman, Confindustria;
  - Andris Piebalgs, Professor, Florence School of Regulation; former European Commissioner for Development (2010 - 2014); former European Commissioner for Energy (2004 -2010).

The Initiative relied on an intense stakeholder engagement activity: 63 stakeholders, belonging to different economic sectors and the academic world, were consulted in two Working Tables to address this analysis and gather strategic insights.

In addition, the management of Eni and Snam also contributed to the development of the Strategic Study through 23 dedicated interviews.

The entire stakeholder engagement process was conducted following a bottom-up approach, with the aim of gathering different points of view. Finally, the results of the stakeholder engagement activities were coupled with the analysis of 160 sources of scientific literature.

The sixteen questions that guided the development of the Strategic Study are summarised in the figure below.

First, the reference context was identified, through an overview of emissions and the role of CCS in decarbonisation scenarios; then, the main technologies available for CCS, their applications and the main features in terms of safety and efficiency were mapped; then, the most relevant projects at global level were mapped, which contributed to the definition of the actions needed to foster the deployment of CCS in Italy and Europe and the related opportunities in terms of decarbonisation and economic development; finally, some policy proposals were developed to foster and accelerate the development of CCS projects in Italy and Europe.

Figure 1

The guiding questions of the Strategic Study.

Source: The European House - Ambrosetti proprietary data, 2023.

Area	No.	Guiding questions
Emissions overview and the role of CCS as a key technology for the decarbonisation process	1	What are the CO_2 emissions scenarios in Italy and Europe? What actions are needed to reach the 2050 climate targets?
	2	What role can CCS technologies play? Where can CCS technologies act to reduce CO_2?
CCS technologies: technology mapping and main characteristics	3	Why is CCS a safe, scalable and competitive technology?
	4	What impact can they generate in achieving climate neutrality?
	5	What different technologies are available for the different contexts? What are the relative economics?
Worldwide benchmarking: key case studies	6	What are the main use cases worldwide? What are the lessons learnt and key success factors?
	7	Who are the players involved? What is the role of governments?
Actions needed for CCS deployment in Europe and Italy	8	What are the factors (e.g. infrastructural, regulatory, acceptance, etc.) that need to be addressed in order to maximise the diffusion of CCS technologies in the European context?
	9	What is the potential role of Italy? Which are its key assets that can be exploited?
	10	Which new business models could support the creation of a supply chain ecosystem for CCS? What public support should be implemented to kickstart new project developments and foster the technology adoption by emitters?
Opportunities for Europe and Italy	11	What are the opportunities in terms of sustainability and decarbonisation?
	12	What development can CCS-related projects achieve in Italy and Europe?
	13	What contribution can CCS make to safeguarding the economic competitiveness of the Italian and European HTA sectors?
Policy Proposals	14	What are the policy choices needed to promote the deployment of CCS technologies in Italy and Europe?
	15	What are the needs for infrastructure cooperation and development among EU Member States?
	16	What recommendations for the Italian position?

KEY MESSAGE 1

In the European Union, an increase in the rate of emission reductions is required to comply with the decarbonisation targets, and it can only be achieved exploiting all available technologies following a technology-neutral approach to preserve the industrial competitiveness of important economic sectors.
It is therefore urgent to make available technological solutions that enable companies to implement decarbonisation investments already in the short term, while at the same time safeguarding industrial competitiveness.

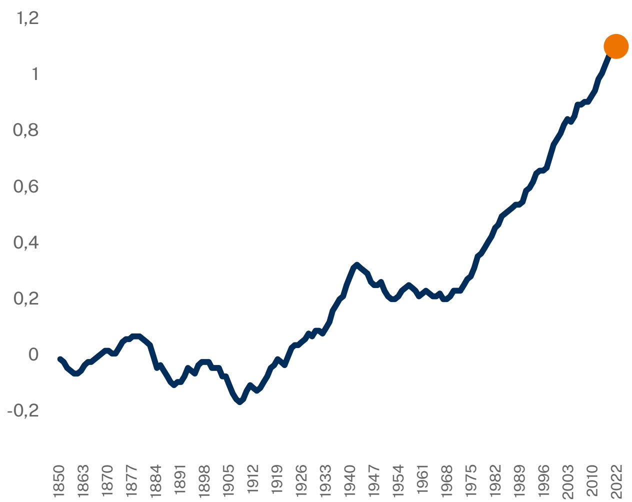
The Paris Agreement was signed in 2015 to limit the global temperature increase to below 1,5°C. In 2022, the temperature was 0.86°C higher than the 20th century average (of 13.9°C) and 1.06°C higher than the pre-industrial period. According to the World Meteorological Organisation, there is a **66% probability that the annual average temperature near the earth's surface between 2023 and 2027 will rise by more than 1.5°C above pre-industrial levels**. The occurrence of this phenomenon could have significant impacts on societies due to a consequent increase in extreme weather events, such as rainfall and temperature anomalies.

Figure 2

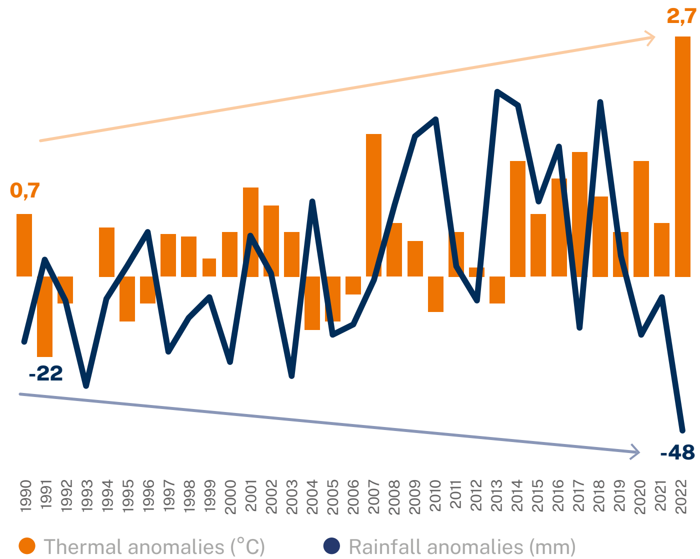
Global temperature change, temperature anomalies and resulting rainfall anomalies

Source: The European House - Ambrosetti on International Panel on Climate Change (IPCC), Community Valore Acqua and European Environmental Agency data, 2023.

Annual global temperature changes
(Degree Celsius), 1850-2022



Thermal and rainfall annual anomalies compared to the 1981-2010 average
(change in Degrees Celsius and mm), 1990-2022



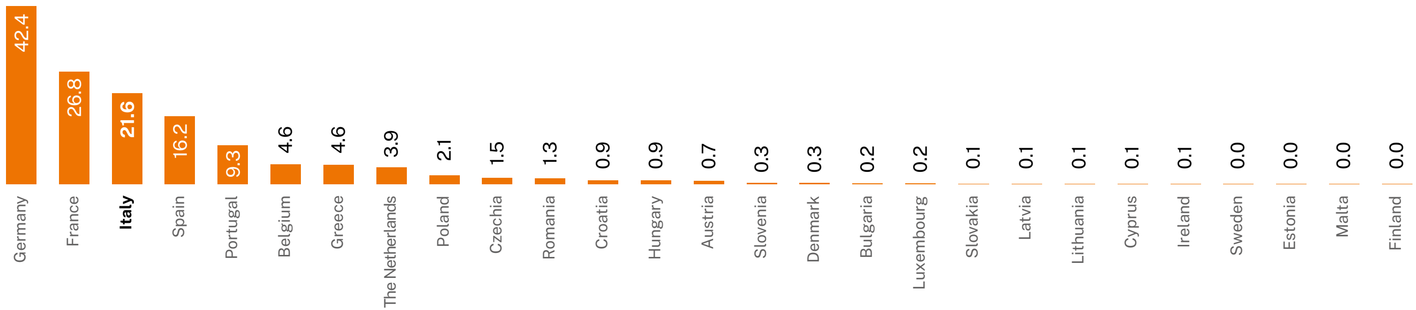
Climate change also has negative social and economic impacts: in the European Union, over the past 40 years, more than 138,000 **deaths have been attributed to extreme weather events, and the economic damage caused by climate-related extreme events has exceeded 487 billion Euros**.

Figure 3

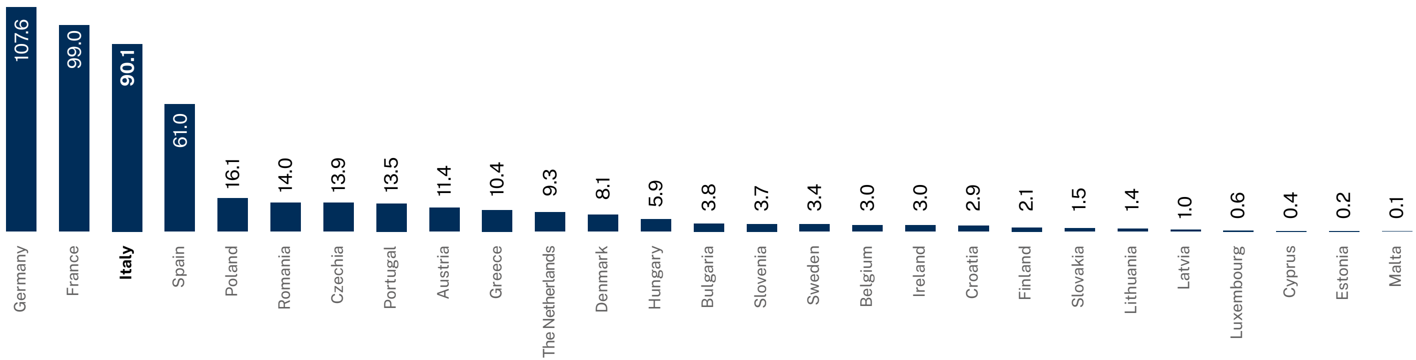
Deaths and economic damage related to extreme events (1980-2020)

Source: The European House - Ambrosetti on European Environmental Agency data, 2023.

Deaths caused by extreme weather and climate events in the European Union per country
(thousands), 1980-2020



Economic damage caused by extreme weather and climate events in the European Union per country
(EUR Billion), 1980-2020



As the issue of rising temperatures and the consequent social and economic damages caused by extreme weather events becomes increasingly pressing, agreements have been outlined at the global and European level. The **European Union's Green Deal** identifies a series of targets and defines measures to urge businesses and citizens to reduce their carbon footprints.

Figure 4
Key elements of the Paris Agreement and the European Green Deal
Source: elaboration The European House - Ambrosetti, 2023.

PARIS2015 UN CLIMATE CHANGE CONFERENCE COP21·CMP11

KEY ELEMENTS OF THE PARIS AGREEMENT

- Signed in 2015 by **196 countries.**
- Goal: 'limit global warming to **preferably 1.5 degrees Celsius,** compared to pre-industrial levels'.
- **Every five years, countries will have to review their emission reduction targets** and measures.
- The Paris Agreement calls for **accelerating innovation, especially clean tech,** and international technology transfer.

Commissione Europea

THE EUROPEAN GREEN DEAL (2019)

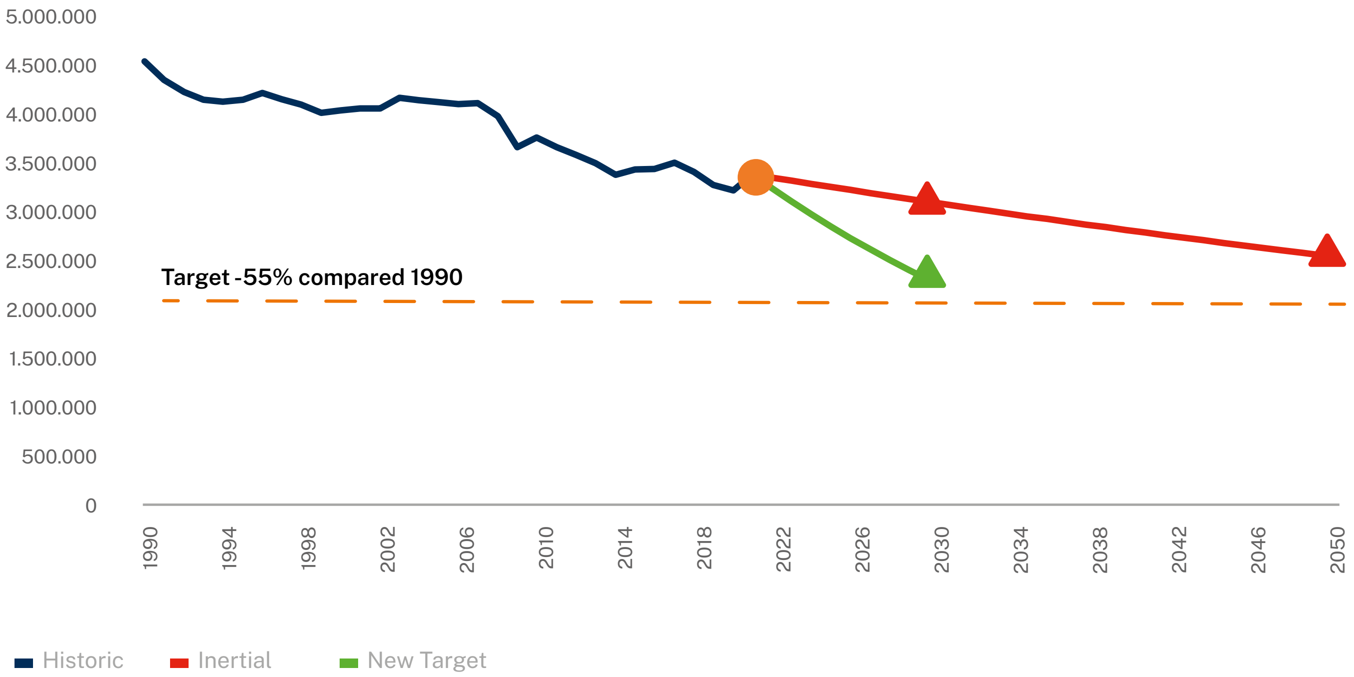
- The European Green Deal is a set of legislative initiatives for the achievement of the climate goals, in line with the Paris agreement.
- The 2030 targets of the Fit for 55:
  - **-55%** of greenhouse gases emissions compared to 1990;
  - at least **42.5%** of energy consumption from renewable sources;
  - **+38%** of final energy consumption (40.5% for primary energy).
- A relevant part of the Fit for 55 strategy consists in reforming ETS and ESR:
  - **Emission Trading System (ETS)** for most energy intensive sectors;
  - **Effort Sharing Regulation (ESR)** to allocate targets among Member States.

The European Union needs to accelerate its decarbonisation process to meet its 2030 emission reduction targets. At the current pace, climate gas emissions will be reduced by 32% in 2030 compared to 1990 levels, 23 percentage points below the pre-determined ‘Fit for 55’ target of -55%. Moreover, this target will not even be reached in 2050.

Figure 5

Climate-changing gas emissions in the (KtonCO_2), 1990-2021 and forecast

Source: elaboration by The European House - Ambrosetti on data from the European Commission, 2023.



Throughout this decarbonisation journey, companies face several **challenges to maintain their industrial competitiveness**. The most pressing ones relate to changing legislation, increasing competitive pressure and the need to access competitive sources of financing.

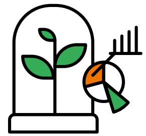
Figure 6
Main challenges for the decarbonisation of industrial systems
Source: elaboration The European House - Ambrosetti, 2023.

LEGISLATION TO REDUCE INDUSTRY EMISSIONS

Companies have to meet the decarbonisation targets set by the European Commission, facing costs and changes in business models.

COMPETITIVE PRESSURE ON GREEN PRODUCTS FROM THE REST OF THE WORLD

Globally, there is an increasing focus on sustainable products that address the decarbonisation of indirect emission scopes.



ADDITIONAL CONSTRAINTS FOR ACCESS TO FUNDING SOURCES

Access to competitively priced sources of finance has increasingly shifted towards those who focus on sustainability.

Starting from the legislative context, **CO_2 emissions are becoming a very important cost item for European industries due to the increasing cost of ETS allowances[1] and the gradual decrease of free allowances**. Furthermore, from 2026 free allowances will be phased out and, at the same time, the Carbon Border Adjustment Mechanism (CBAM), which complements the ETS to ensure the competitiveness of European companies, will enter into force. Importers will have to buy CBAM certificates at the ETS price to cover the emissions embedded in imported products. **However, the sectors most affected by the ETS and CBAM have raised some criticism and doubts about the ability to preserve export competitiveness**.

Figure 7

Criticism of the ETS and CBAM by affected sectors' representatives

Source: elaboration The European House - Ambrosetti on various sources, 2023.

> The latest proposals on ETS and CBAM weaken carbon leakage provisions, further **increase unilateral regulatory costs and harm the competitiveness of European industries** in EU or international markets

Open letter by over 450 energy intensive industries CEOs employing around 2.6 million workers

> CBAM must be compatible with WTO to avoid **retaliation from third countries,** and the EU should have a long-term ambition for a **climate club** instead of unilateral masures

Confederation of European Business

BUSINESSEUROPE

> In the initial phase, **CBAM should co-exist with ETS free allowances**

Koen Coppenholle, *CEO, CEMBUREAU*

CEMBUREAU The European Cement Association

> "As free allocations are being phased out and the **CBAM does not entail a carbon cost compensation for EU exports**, final costs will be higher and competitiveness will decrease

Peter Botschek, Director Industrial Policy and Competitiveness, European Chemical Industries Council

cefic

> The **phase-out of free allocations could jeopardize decarbonisation**, as resources available to invest would decrease due to higher production costs

Francesc Rubiralta Rubio, *CEO, Eurofer*

EUROFER THE EUROPEAN STEEL ASSOCIATION

In order to maintain industrial competitiveness, it is crucial to make available technological solutions for decarbonisation that enable industries subject to ETS mechanisms to implement decarbonisation investments in a concrete and sustainable manner already in the short term

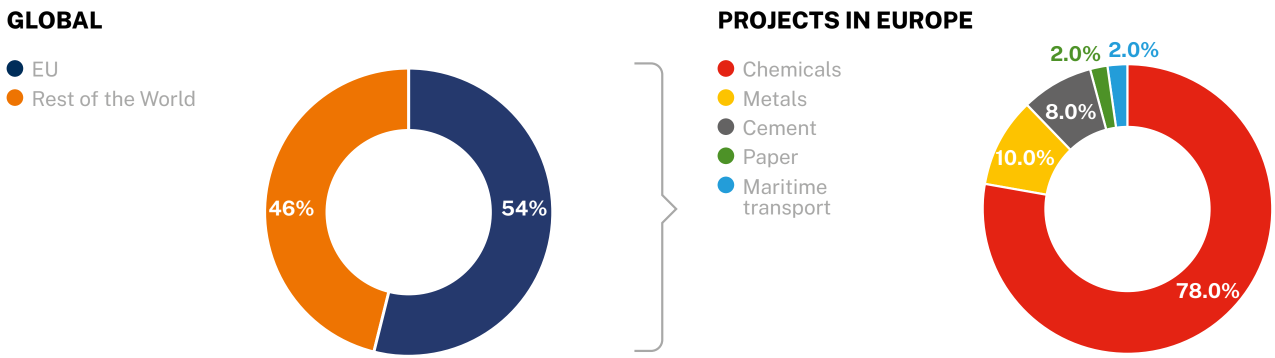
1 The EU Emissions Trading Scheme (ETS) operates according to the 'cap-and-trade' principle. Under the EU ETS, regulated entities buy or receive emission allowances that they can trade with each other as needed. At the end of each year, regulated entities must surrender enough allowances to cover all their emissions. In addition, the ETS sets an absolute limit or 'cap' on the total amount of certain greenhouse gases that can be emitted each year by the covered economic sectors. This cap is reduced over time so that total emissions decrease.

A second element to consider is the competitive pressure on '**clean technology demonstration projects**' from the rest of the world. Currently, Europe is developing 54% of such projects in the Hard to Abate sectors, but to continue to play a leading role in the creation of new green supply chains globally, it is necessary to leverage scalable and competitive decarbonisation technologies.

Figure 8

Share of clean technology demonstration projects in Europe compared to the rest of the world (left) and distribution of sectors of European projects (right) (% of projects), 2015-2030

Source: The European House - Ambrosetti on IEA data, 2023.



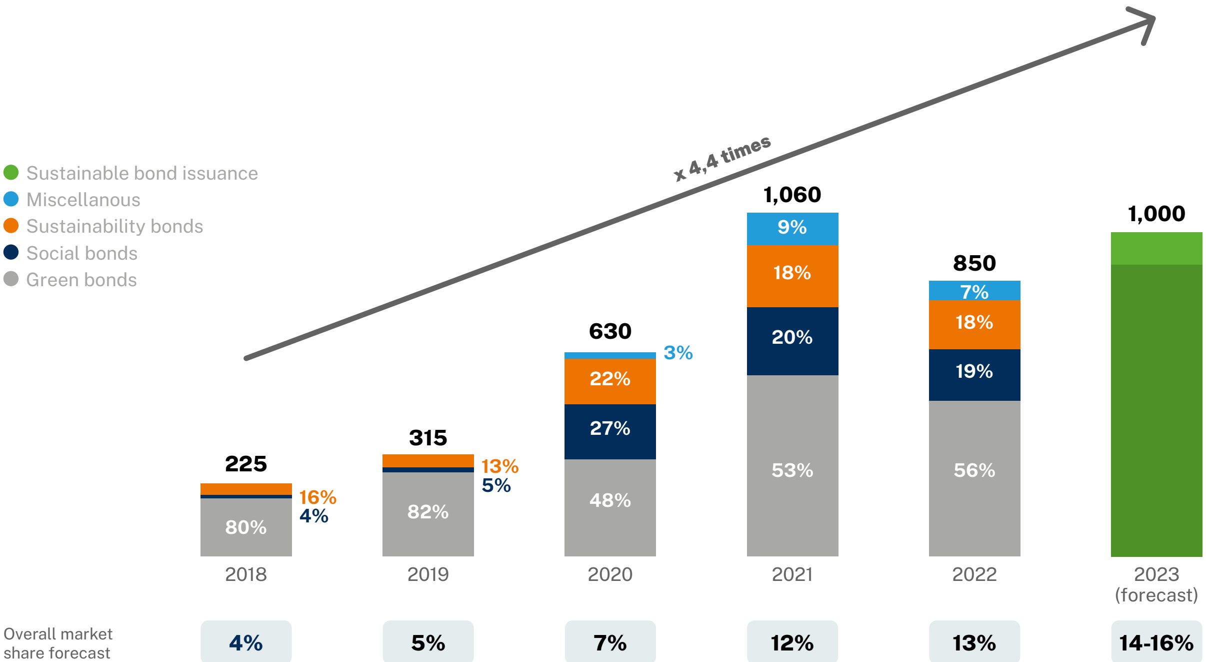
Clean technology demonstration project: projects aimed at reducing emissions from products of Hard to Abate industries through changes in the design of the production itself or the sourcing of sustainable materials

It is necessary to leverage scalable and competitive decarbonisation technologies to preserve Europe's leading role in the creation of new global green supply chains

The third and last element to consider is the **growing interest of the financial markets in projects with significant sustainability impacts** that not only guarantee adequate returns on investment, but also improve the quality and riskiness of portfolios.

Industries that are able to reduce their impact on the climate through emission-reducing investments will have an increasing advantage in accessing the capital market (e.g., through lower interest rates) over their competitors.

Figure 9
Global sustainable bond issuance (USD billion), 2018 - 2022 and forecast 2023
Source: The European House - Ambrosetti on Standard & Poor's data, 2023.



KEY MESSAGE 2

CCS is a **mature, safe, and competitive solution.** It is the only viable option to reduce **process emissions** and **concretely accelerate the decarbonisation of fossil fuel combustion emissions in industrial sectors.**
The use of CCS will help preserve the competitiveness of Italy's Hard to Abate sectors, which account for **94 billion Euros in Value Added** (5% of Italian GDP) and **1.25 million employees** (4.5% of the national workforce).
In addition, CCS can help promote the development of **hydrogen**, support the deployment of renewables for the decarbonisation of the electricity grid by supplementing its intermittent and non-programmable nature with a **dispatchable, low-carbon energy source**, and make it possible to generate **negative emissions** through the application of CCS to bioenergy production or the capture of CO_2 directly from the atmosphere.

There are mature and commercially available CO_2 capture technology solutions with a **high Technology Readiness Level (TRL) and a capture efficiency close to 90-95%.** Currently, 30 projects are operational worldwide, capturing and storing about 40 million tonnes of CO_2 per year. The first Enhanced Oil Recovery (EOR) project[2] dates back to 1971 (Terrell, USA), while Sleipner is the first geological storage project (not EOR) operational since 1996. For transport, there are more than 50 CO_2 pipelines in the USA, totalling more than 8,000 km and about 70 million tonnes transported[3] . For storage, CCS shares much of the injection and monitoring technology with the natural gas storage industry.

Figure 11

CCS technology solutions, TRL[4] and efficiency

Source: The European House - Ambrosetti on data from IEA, US National Energy Technology Laboratory and Global CCS Institute, 2023.

Technology family	Technology	TRL	Capture efficiency (%)
POST COMBUSTION	Physical absorption	9	85-90
	Chemical absorption	9	90-95
	Fluidized solid adsorption (Chemical Looping)	7	90-95
	Polymeric membrane	4	80-90
PRE COMBUSTION	Physical absorption	9	85-90
	Chemical absorption	9	90-95
	Static solid adsorption (Pressure/Temperature Swing Adsorption)	9	90-95
	Cryogenic absorption	8	90-95
OXY COMBUSTION	Pure oxygen combustion	6	90-95
	Supercritical CO_2 cycles	5	>98

2 EOR solutions allow CO_2 to be stored in wells that have not yet been depleted. However, this solution is not considered within the scope of this Strategic Study.
3 Source: elaboration by The European House - Ambrosetti on Global CCS Institute data, 2023.
4 The TRL of each technology is variable with respect to applications (power generation, hydrogen, cement, etc.) and the TRL shown in the figure corresponds to the maximum level among the different application areas.

MythBusters

CCS is an experimental technology still in the research phase

FALSE

CCS is a mature technology, known and tested for decades Today, the know how of oil & gas companies can be harnessed for the development of decarbonisation and sustainability projects based on CCS solutions

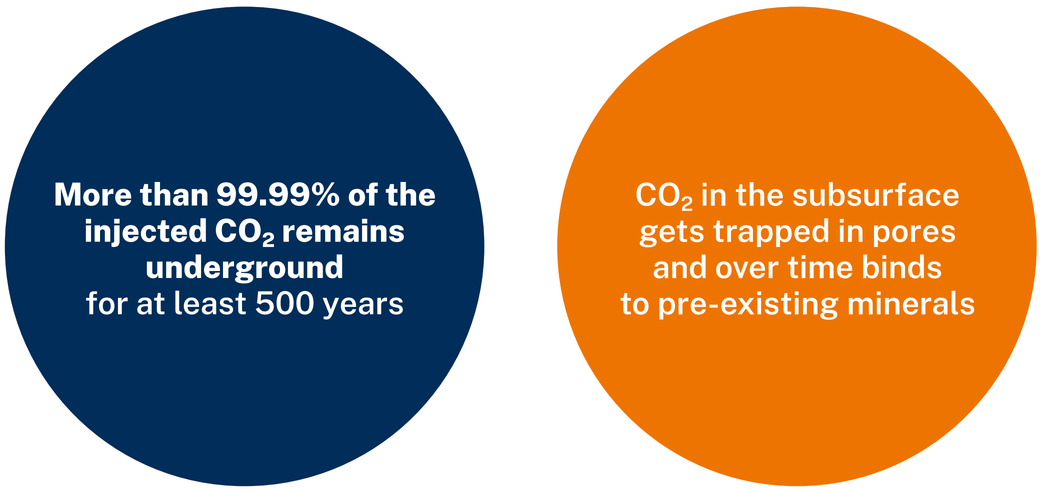
TRUE

Besides its technological maturity, **CCS is a safe technological solution**. In the EU, the 2009 Directive on the storage of CO_2 defined a set of regulations and requirements that ensure the identification of suitable storage sites and the safety of subsequent operations, as it outlines a clear and comprehensive framework for safely assessing, monitoring and managing CO_2 storage sites. The provisions of the Directive set important technical and financial prerequisites for the development of CCS in Europe, ensuring that operators take the maximum safeguards. Furthermore, various theoretical models have shown that **more than 99.99% of the CO_2 does not escape from storage sites over a period of 500 years**[5].

Figure 12

Theoretical risk of CO_2 leakage from storage sites

Source: The European House - Ambrosetti on Report "CO_2 Storage Safety in the North Sea: Implications of the CO_2 Storage Directive", European Zero Emission Technology and Innovation Platform (2019), 2023.



5 Source: elaboration The European House - Ambrosetti on Report "CO_2 Storage Safety in the North Sea: Implications of the CO_2 Storage Directive", European Zero Emission Technology and Innovation Platform (2019), 2023.

MYTHBUSTERS

CCS is unsafe because it can cause explosions and CO_2 leaks

FALSE

CO_2 is an inert, non-flammable, non-explosive gas. CO_2 transport is based on mature technologies that have been safely applied for decades in various industries.
Leaks from storage sites are highly unlikely and have never happened in the past.
Even in the unlikely event of a leak, these would not pose a safety risk, but a re-entry of CO_2 into the atmosphere.
Moreover, CO_2 storage shares most of the technology and know how with natural gas storage, a sector with excellent safety standards where the energy industry has decades of experience

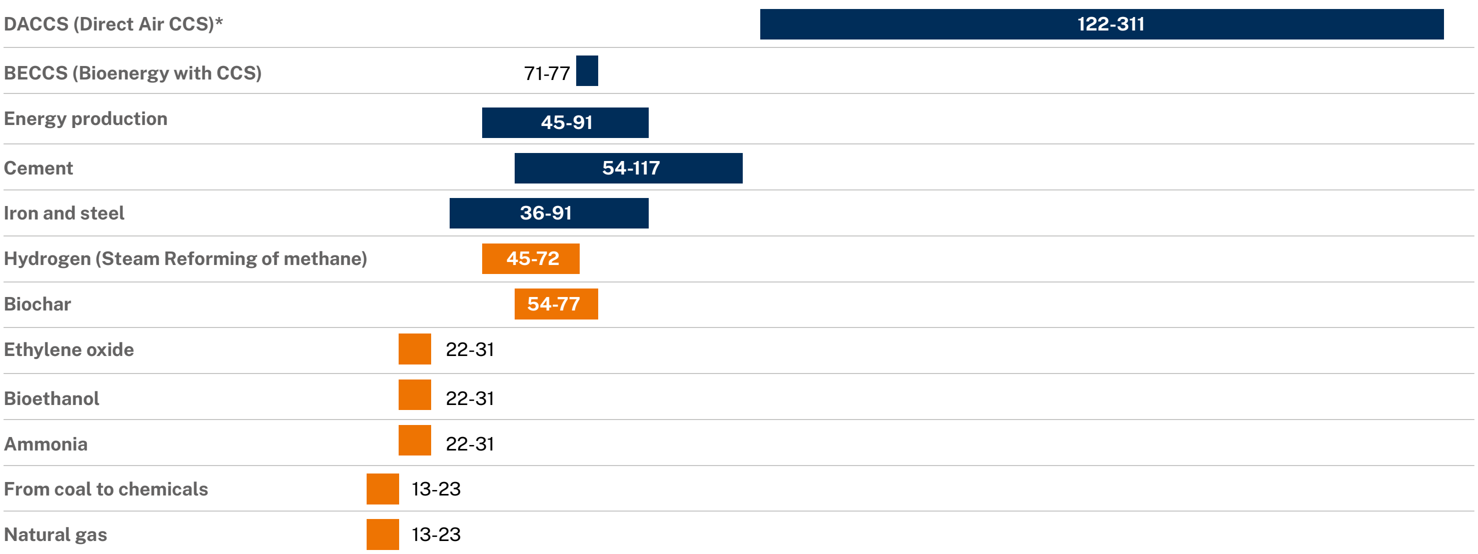
TRUE

The cost of CO_2 capture is highly dependent on the CO_2 concentration of the emitting source, pressure and temperature. Despite the maturity of capture technologies, **costs can be optimised by exploiting a technology portfolio approach and increased know how associated with integration capacity in different types of industrial plants**. It is therefore crucial to accelerate the practical application of mature CCS technologies on an industrial scale to generate knowledge on the integration of different solutions, develop the market and reduce costs.

Figure 13

Levelised cost of CO_2 capture[6] by sector and initial CO_2 concentration, (Euro/Ton CO_2), latest available data

Source: The European House - Ambrosetti on IEA data and Report 'Realising Carbon Capture and Storage (CCS) technologies globally', DNV (2023), 2023.



*According to some studies, the cost of DACCS can reach $600 (553 Euros) per ton of CO_2.
Source: elaboration The European House - Ambrosetti on Bloomberg and World Resources Institute data, 2023.

Note: These costs do not include transportation and storage costs.

Source: elaboration The European House - Ambrosetti on IEA analysis, based on GCCSI (2017), Global costs of carbon capture and storage, 2017; IEAGHG (2014), CO_2 capture at coal based power and hydrogen plants; Keith et al. (2018), A Process for Capturing CO_2 from the Atmosphere; NETL (2014), Cost of capturing CO_2 from Industrial sources; Rubin, E. S., Davison, J. E. and Herzog, H. J (2015), The cost of CO_2 capture and storage.

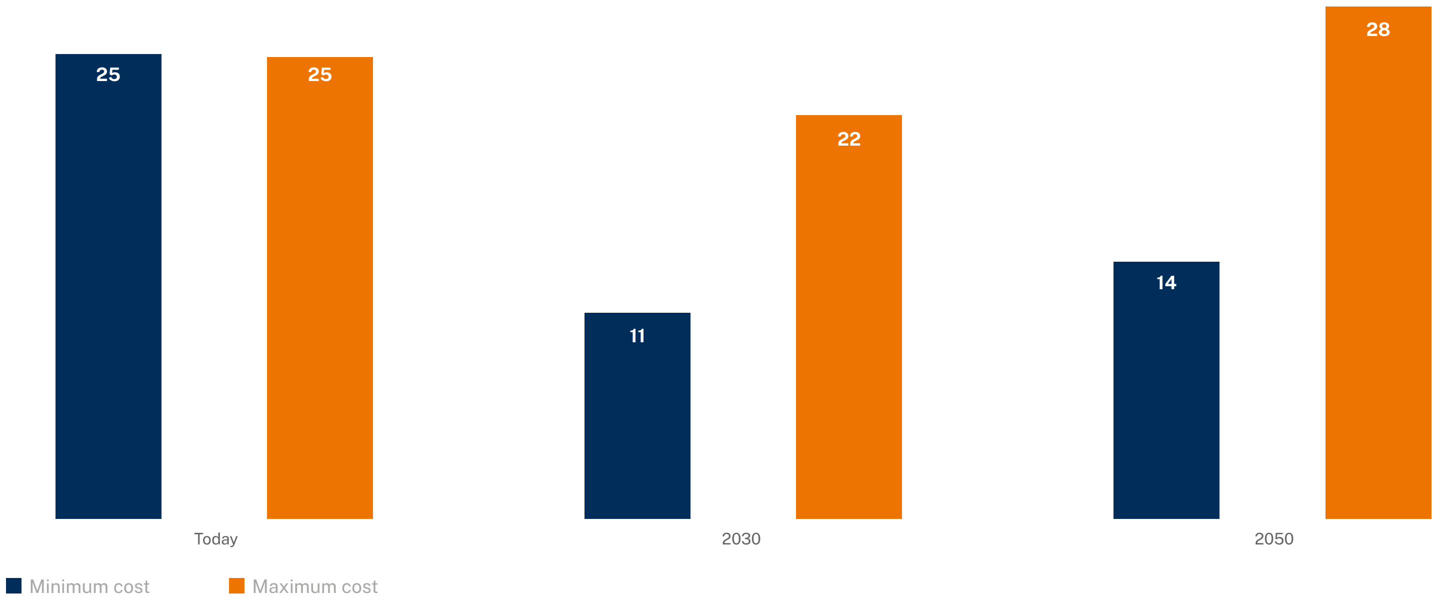
6 Capture costs do not include transport and storage costs.

Moreover, high capture volumes optimise the overall cost of CCS: **the greater the number of emitters participating in a CCS project, the lower the overall costs.** In addition, to enable CCS, the transportation infrastructure, understood as a pipeline, plays a key role: although in cost it has little weight compared to the other components, it has development time important that requires regulatory and normative clarity and is indispensable for project implementation. The operators of gas networks are well positioned for the development of this infrastructure because of the know-how acquired in the development and management of molecule transport infrastructure and regulated/semi-regulated business management.

Figure 14

Percentage difference between the levelized cost of CCS, stand-alone projects vs. multi-utility hubs[7] (percentage value)

Source: The European House - Ambrosetti on data from Wood Mackenzie, Paper "Tightening EU ETS targets in line with the European Green Deal: Impacts on the decarbonisation of the EU power sector", Pietzcker et Al., Potsdam Institute for Climate Impact Research (2023), 2023.



7 CCS hubs: capture projects are developed separately from transport and storage projects; CO_2 is captured by different industries. Examples of hubs considered in the analysed Paper are the East Coast Cluster (UK), the Northern Light Project (Norway). The Hubs indicated in the text are those analyzed in the Study of the Postdam Institute for Climate Impact Research.

Given the characteristics of CCS in terms of maturity, safety, and the possibility to compress costs through experimentation and large-scale projects, CCS is receiving much attention in the EU, varying according to the sector in which it is applied and the emission scope to which it is applied. To promote the deployment of CCS solutions and achieve climate goals, it will be crucial to **apply the principles of technology neutrality and exploit the complementarity of available solutions for decarbonisation**. The Italian NECP draft, delivered at the end of June 2023, is inspired by these principles, and can be considered a first tool to pave the way for structured considerations in the EU.

Figure 15
Focus of EU institutions on different areas of CCS use
Source: elaboration The European House - Ambrosetti, 2023.

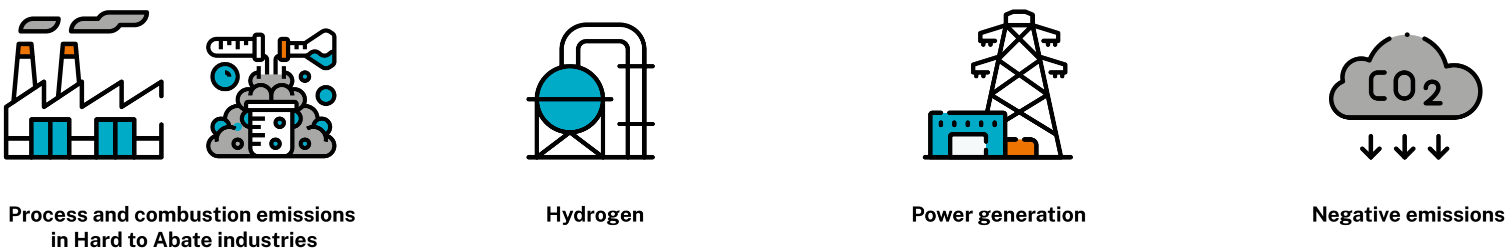
CCS APPLICATIONS	KEY MEASURES TO ACHIEVE CLIMATE NEUTRALITY PRINCIPLES
Process emissions	**Leverage CCS as the only available solution to decarbonise these emissions**
Emissions from fossil fuel in industrial plants	**Take advantage of the complementarity between different solutions available, enhancing the potential of the more mature technologies that can be more easily integrated into existing systems**
Carbon-neutral hydrogen production	**Leverage CCS to foster the creation of the renewable hydrogen market**
Power generation	**Consider the beneficial role of gas in providing the adequacy and flexibility needed to maximize RES integration**
Negative emissions	**Exploit bioenergy production technologies with CCS (BECCS) and atmospheric CO_2 capture (DACCS) to offset negative emissions in line with the principle of technology neutrality**

Based on a careful analysis of the application contexts covered in the EU, a review of 160 academic papers and the evidence from the stakeholder engagement activities, which involved 63 actors including industrial players, representatives of research centres and institutions, The European House-Ambrosetti identified **four priority CCS application areas**: process and fossil fuel combustion emissions in Hard to Abate industries, hydrogen, fossil fuel power generation, and negative emissions.

Figure 16

Focus of the Strategic Study on different areas of CCS use

Source: elaboration The European House - Ambrosetti, 2023.

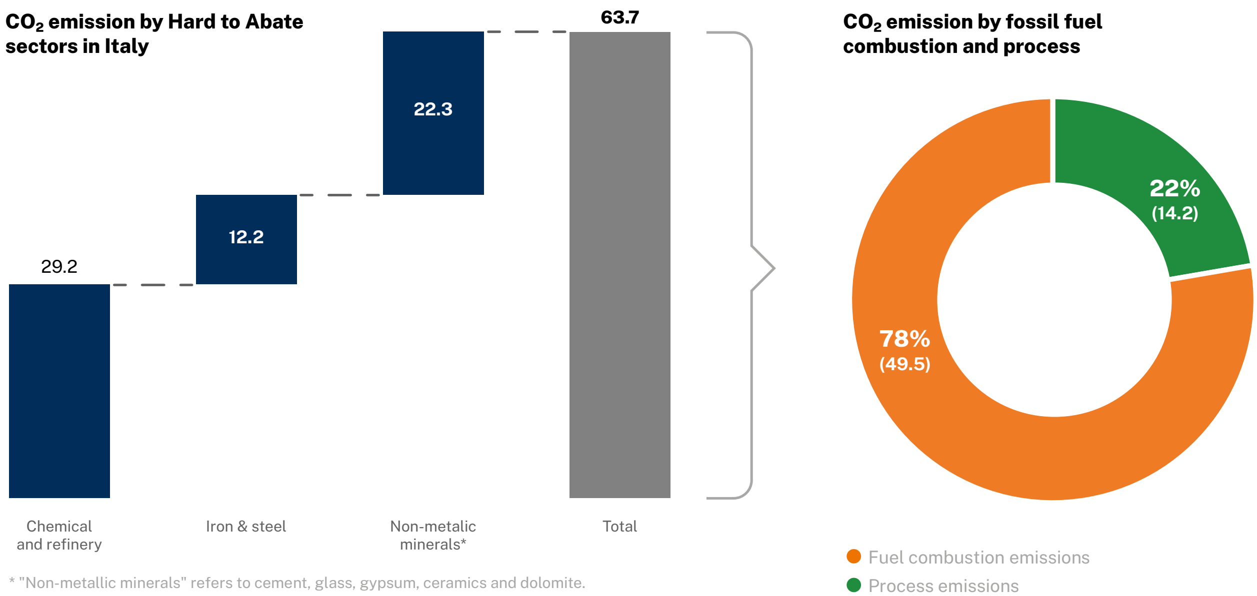


Considering the first area of application, at national level, **Hard to Abate industrial sectors[8] emit a total of 63.7 million tonnes of CO_2 per year**, of which 78% from fossil fuel emissions and 22% from industrial processes.

Figure 17

CO_2 emissions from Hard to Abate sectors in Italy (Mton CO_2), 2021 and CO_2 emissions from fossil fuels and processes (percentage value and Mton CO_2), 2021

Source: The European House - Ambrosetti on Ispra data, 2023.



* "Non-metallic minerals" refers to cement, glass, gypsum, ceramics and dolomite.

8 The paper production sector is considered Hard to Abate because most emissions are biogenic and therefore electrification is not an economically and environmentally viable alternative. However, the sector is not included in this study as the emissions - 5.3 million tonnes of CO_2 in 2021 - are residual compared to the Hard to Abate sectors considered.

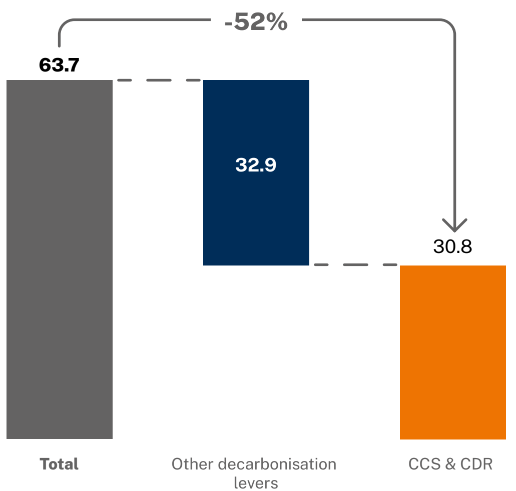
Emissions from the Hard to Abate sectors[9] can be reduced with various technological levers such as electrification, energy efficiency, bioenergy, hydrogen and feedstock change, but **48% of emissions can only be abated through CCS** for two reasons: first, overall**, 22% of emissions come from the production process related to chemical or physical reactions**; second, a large part of the energy demand in the Hard to Abate sectors is used to provide high temperature heat. **Switching from fossil fuels to low CO_2 to generate this heat would require plant modifications and a substantial increase in the need for renewable electricity**. In addition, **converting fossil-fuel based production processes to electric or hydrogen-based technologies requires major reconfigurations of production set-ups with high initial investments and operating costs**. In the coming years, it will be crucial to exploit all available levers to decarbonise the Hard to Abate industries and preserve their competitiveness, especially considering their significant economic and social weight.

Figure 18

Levers for decarbonisation of Hard to Abate sectors (Mton CO_2), 2021 and economic and social relevance of Hard to Abate sectors

Source: The European House - Ambrosetti on Ispra and Istat data, 2023.

Levers for the decarbonisation of Hard to Abate sectors



Economic and social relevance of Hard to Abate sectors

94
EUR Billion

value added
of HTA sectors at the Italian level
(**35%** of VA in manufacturing;
5% of GDP)

1,25
Million

employees in HTA industries
at the Italian level
(**32%** of employed in manufacturing;
4,5% of total Italian employed)

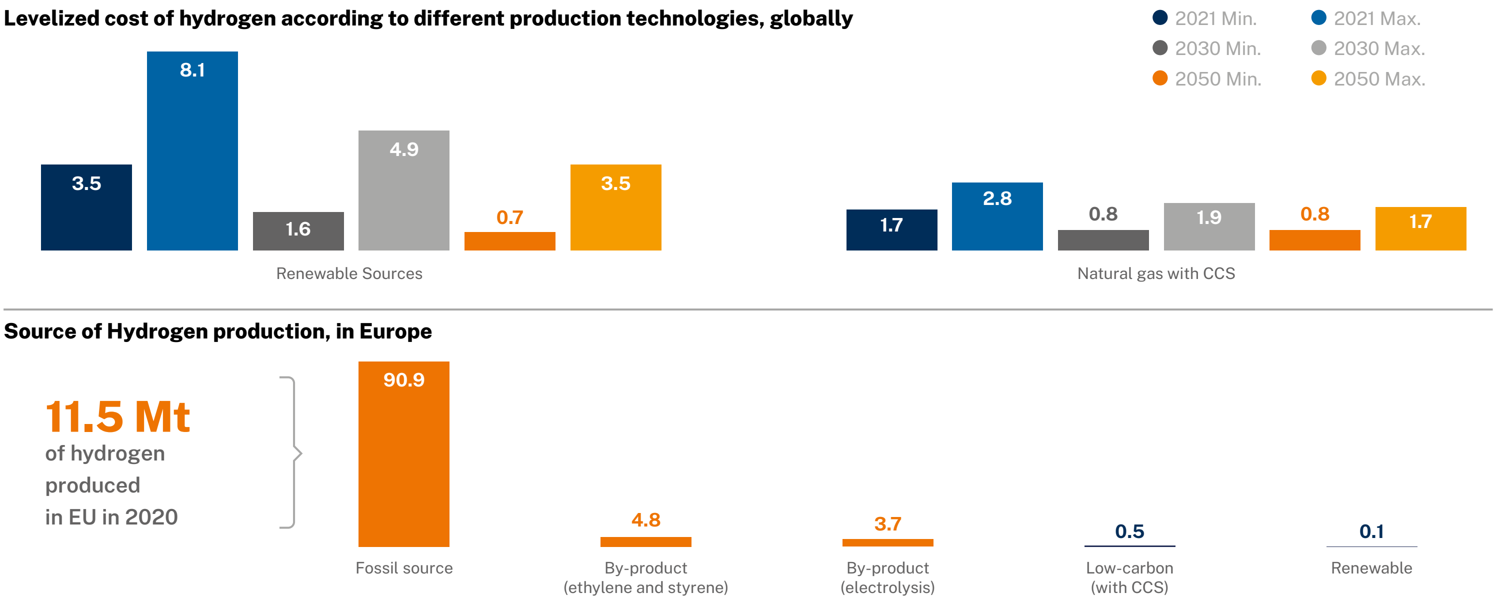
9 The Hard to Abate sectors considered include the petrol-chemical, iron and steel and non-metallic minerals industries.

The second area of CCS application investigated in this Strategic Study is **hydrogen**. In Europe today, 98% of hydrogen is produced from fossil sources, which can be decarbonised through CCS (so-called low-carbon hydrogen). This hydrogen production source is to be pursued in synergy with other forms of hydrogen production from renewables[10]; as such, it needs to be harnessed to make hydrogen from fossil sources sustainable and enable the production of large-scale and programmable volumes necessary for the development of the EU hydrogen market.

Figure 19

Hydrogen cost by different production technologies (EUR/Kg H_2), 2022. Hydrogen production by Source, in EU (%), 2020

Source: The European House - Ambrosetti on IEA and European Commission data, 2023.



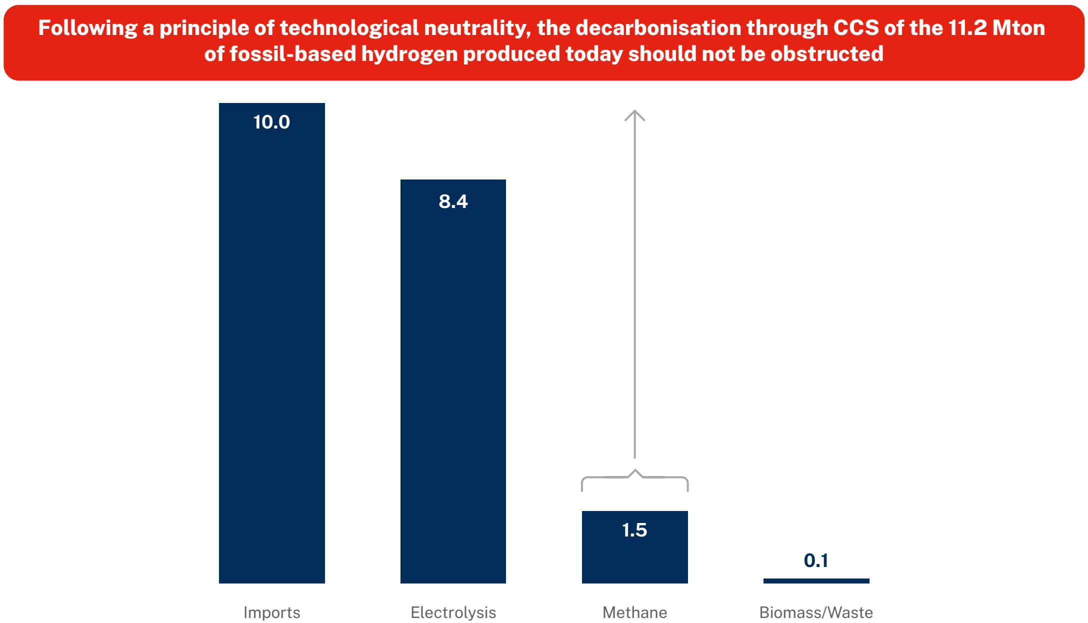
10 European regulations consider hydrogen to be "low-carbon," when its energy content energy is derived from non-renewable sources with a reduction in emissions greenhouse gas emissions of 70 percent. Pending developments in CCS technologies that would enable further improvements in abatement capabilities, following the principle of technology neutrality, it is already possible today to completely abate emissions from fossil fuel hydrogen production by combining direct CCS with CO_2 offsetting with carbon dioxide removal technologies from biomass (BECCS) or from the air (DACCS).

By 2030, the **REPowerEU Plan**, which envisages the import of 10 million tonnes of hydrogen and the production of the same amount in the EU, does not leverage the availability of hydrogen that will be possible to produce from fossil sources and decarbonized through CCS, thus risking to pass the opportunity to leverage the assets and know-hows associated with steam reforming. According to a principle of technology neutrality, the decarbonization through CCS of the 11.2 million tons of fossil-derived hydrogen produced today should not be hindered. Ultimately, **low-carbon hydrogen can be exploited in synergy with renewable hydrogen especially in geographies and not particularly favourable to the development of renewable sources** – both because of geographic characteristics, as well as for scarce land availability – and as a more programmable form of production to ensure energy security.

Figure 20

Sources of hydrogen production in the EU according to European Hydrogen Strategy (Mton of Hydrogen), 2030

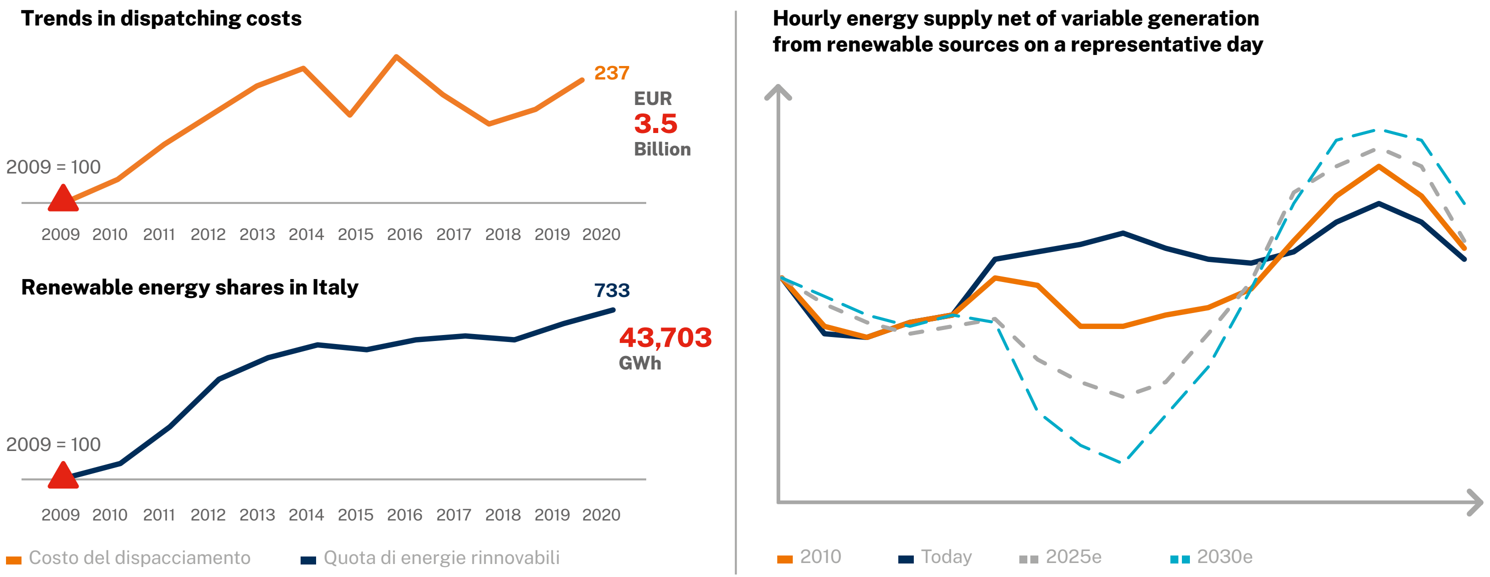
Source: The European House - Ambrosetti on European Commission, 2023.



It was assumed in the analyses that the 10 Mton hydrogen production target envisioned by REPowerEU will be achieved by leveraging the production sources outlined in the European Hydrogen Strategy.

CCS solutions will play a key role in the decarbonisation of **energy systems**. Indeed, although the share of energy generated from fossil sources will gradually decrease in the coming years, it will still be necessary to ensure the flexibility and stability of energy systems. Moreover, between 2009 and 2020, the share of energy production from non-programmable renewable sources[11] increased by 633% in Italy[12] ; in the same timeframe, the cost of energy dispatch increased by 137%[13]. Behind the shift toward renewables, in addition to an increase of energy management requirements (batteries and consumption scheduling) there is an increase in the costs borne by the system.

Figure 21
Dispatch cost trends (left top) and renewable energy shares (left bottom) in Italy (percentages, 2009=100), 2009-2020. Hourly energy supply net of variable generation from renewable sources on a representative day (right), 2010 vs. today, vs. forecast to 2025, vs. forecast to 2030
Source: The European House - Ambrosetti on ARERA, Eurostat and market data, 2023.



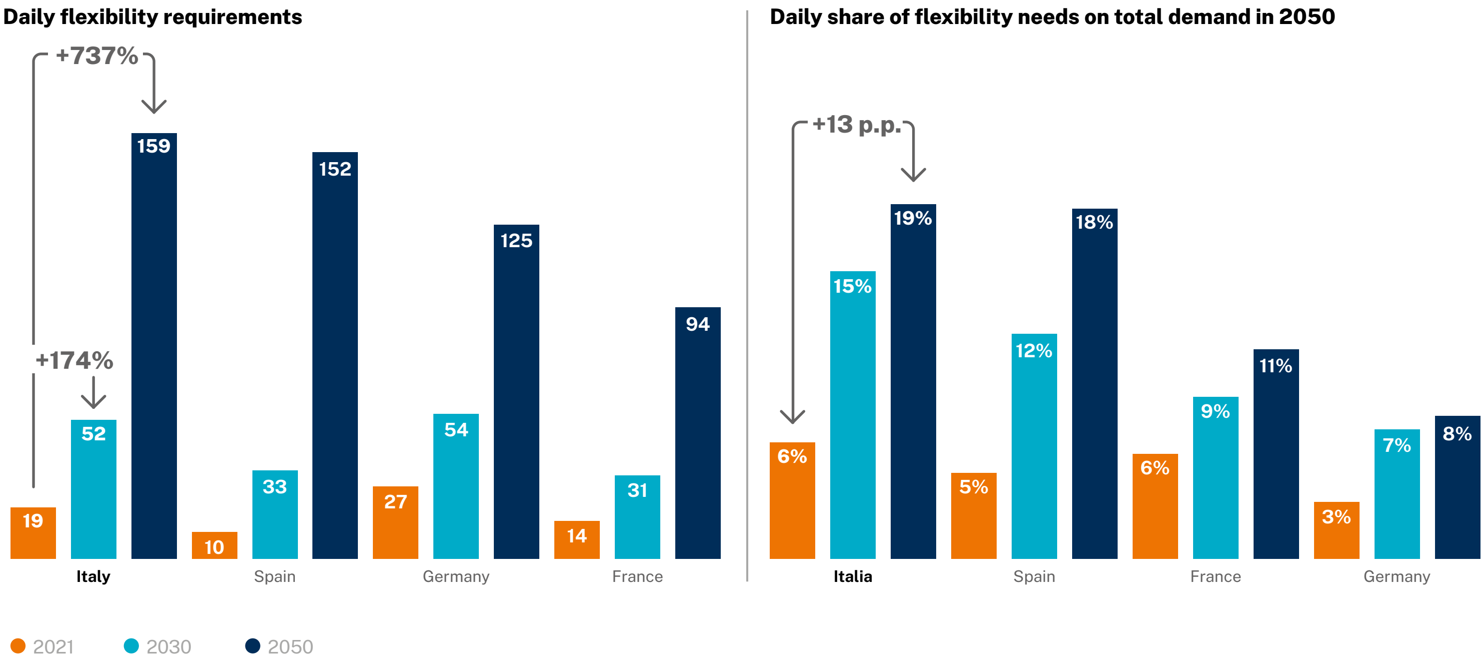
11 Wind and solar.
12 Source: The European House - Ambrosetti on Eurostat data, 2023.
13 Source: The European House - Ambrosetti on ARERA data, 2023.

In Italy, the **need for 'flexible energy'** is expected to **increase more than eightfold by 2050 and will amount to 19% of total electricity demand** (+13 p.p. compared to 2021). To be considered sustainable, the decarbonization strategy should consider the growing issues of intermittency and the flexibility requirements associated to renewables. Therefore, it is essential to identify the package of solutions to find the various sources of flexibility needed to ensure stability of the electricity system, even in view of the overall growth in electricity consumption.

Figure 22

Daily flexibility requirements (based on EU energy models, TWh/a), 2021, 2030 and 2050 and daily share of flexibility requirements in total demand in 2050 (based on EU energy models), 2021, 2030 and 2050

Source: The European House - Ambrosetti on Joint Research Center data, 2023.

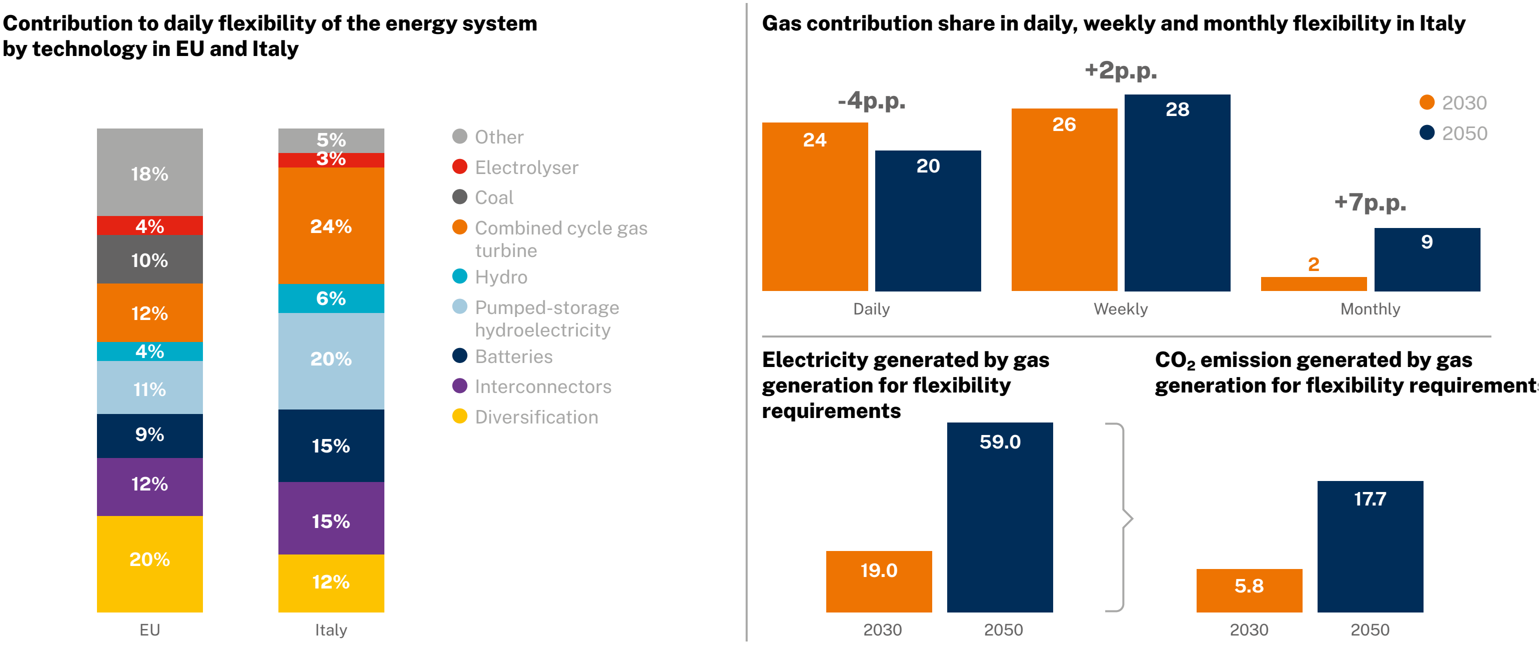


By 2030, almost 22% of the European electricity system's daily flexibility will still be provided by fossil fuels, including coal and natural gas. **Italy will base 24% of the daily flexibility of its electricity system on natural gas**. Overall, by 2050, natural gas will generate 59 TWh of electricity to ensure the flexibility of the power system, corresponding to about 17.7 million tonnes of CO_2, 3 times the value estimated in 2030. In this scenario, CCS can be harnessed to decarbonize emissions of the share of gas required for electricity production.

Figure 23

Contribution to daily flexibility of the energy system by technology in the EU and Italy (%), 2030. Share of gas in daily, weekly and monthly flexibility in Italy (% and p.p.), 2030 and 2050. Electricity generated by gas for flexibility needs (TWh) and CO_2 emissions from gas generation for flexibility needs (Mton CO_2), 2030 and 2050

Source: The European House - Ambrosetti on Ispra and JRC data, 2023.



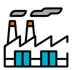
The last area of CCS application analysed concerns **negative emissions**. Among the different options available, BECCS (Bioenergy with CCS) and DACCS (Direct Air CCS) exploit engineered processes to 'generate' negative emissions by removing CO_2 from the atmosphere. **Such processes can be used to offset other non-avoidable emissions** (e.g., agriculture).

Figure 24
Technological solutions for achieving negative emissions
Source: Strategic Report 'Zero Carbon Technology Roadmap', The European House - Ambrosetti, 2023.

GEOLOGICAL SINK

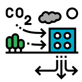
Bioenergy with CCS (BECCS)

Capturing and storing the carbon in the process of extracting energy from biomasses



Direct air capture (DACCS)

CO_2 extraction directly from atmospheric air



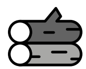
Underground CO_2 storage

CCS APPLIED TO BIOENERGY PRODUCTION AND DIRECTLY TO THE ATMOSPHERE MAKES IT POSSIBLE TO ACHIEVE NEGATIVE EMISSIONS

BIOGENIC SINK

Biochar

Pyrolysis or gasification of biomasses, the resulting char can be spread on arable fields, acting as a soil amendment technique



CO_2 permanently stored in the soil

Afforestation and reforestation

Afforestation and reforestation to store CO_2 within permanent trees' biomasses

Natural ability to capture and store CO_2

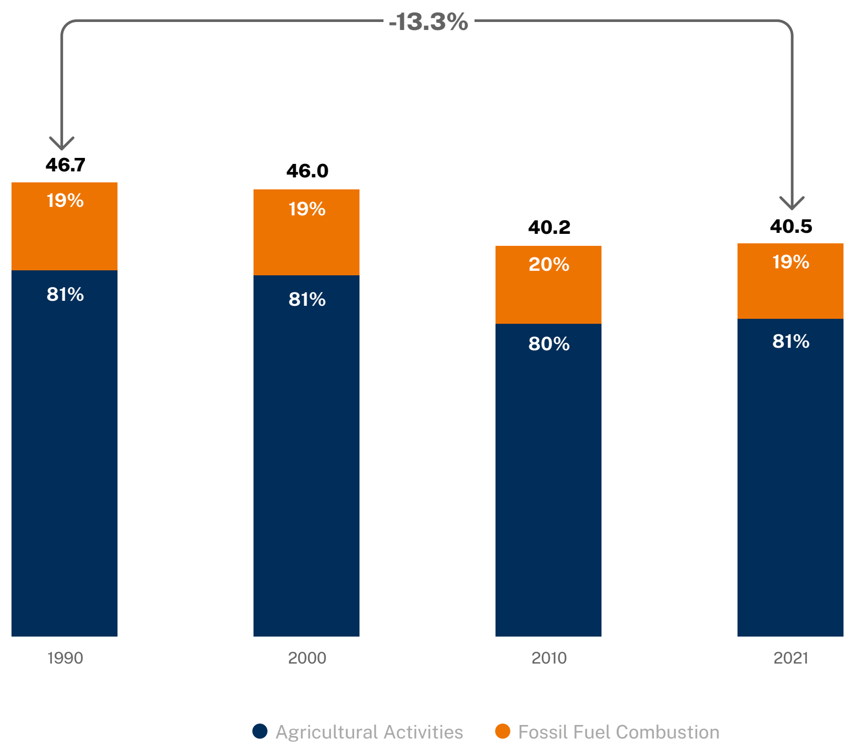
Macro-categories	Technologies	TRL
BECCS	CCS technologies can be exploited thanks to similar CO_2 concentration levels	9
DACCS	Liquid	6
	Solid	6

The **agricultural sector will require atmospheric CO_2 removal technologies** (BECCS and DACCS) to offset emissions that cannot be abated by other direct technological levers, as emissions not associated with the combustion of fossil fuels account for about 80% of the sector's emissions and are linked, for example, to enteric fermentation or other processes that have no other levers to reduce emissions than offsetting them.

Figure 25

CO_{2eq} emissions from the agricultural sector (Mton CO_{2eq}), 1990, 2000, 2010 and 2021

Source: The European House - Ambrosetti on Eurostat data, 2023.



In addition, **DACCUS (DACCS using CO_2) and BECCUS (BECCS using CO_2) will be able to actively contribute to the value chain of synthetic fuels**, but only in a long-term renewable electricity surplus scenario, in which synthetic fuels can be exploited as a source of flexibility where excess renewable electricity can be 'stored'.

Figure 26

Inputs and outputs to produce synthetic fuels and efficiency loss in the production of hydrogen from electrolysis and synthetic fuels, (%, TWh renewable electricity = 100)

Source: The European House - Ambrosetti, 2023.

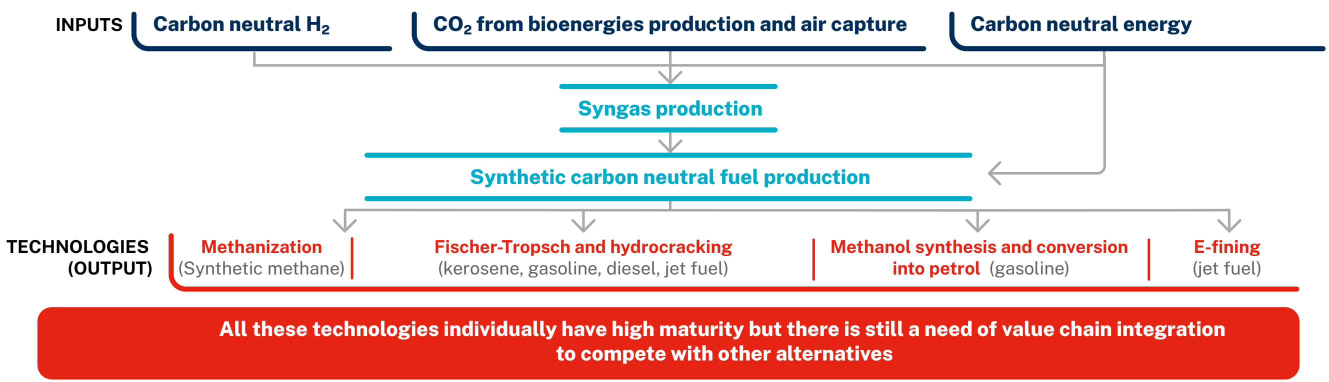
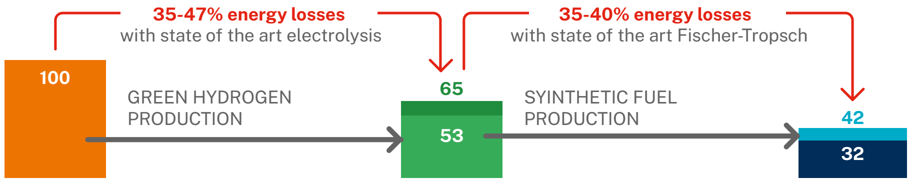


Figure 27

Technology efficiency losses in the production of green hydrogen and synthetic fuel from renewable electricity,
(%, TWh of renewable electricity = 100) - Light and dark colours indicate value ranges



KEY MESSAGE 3

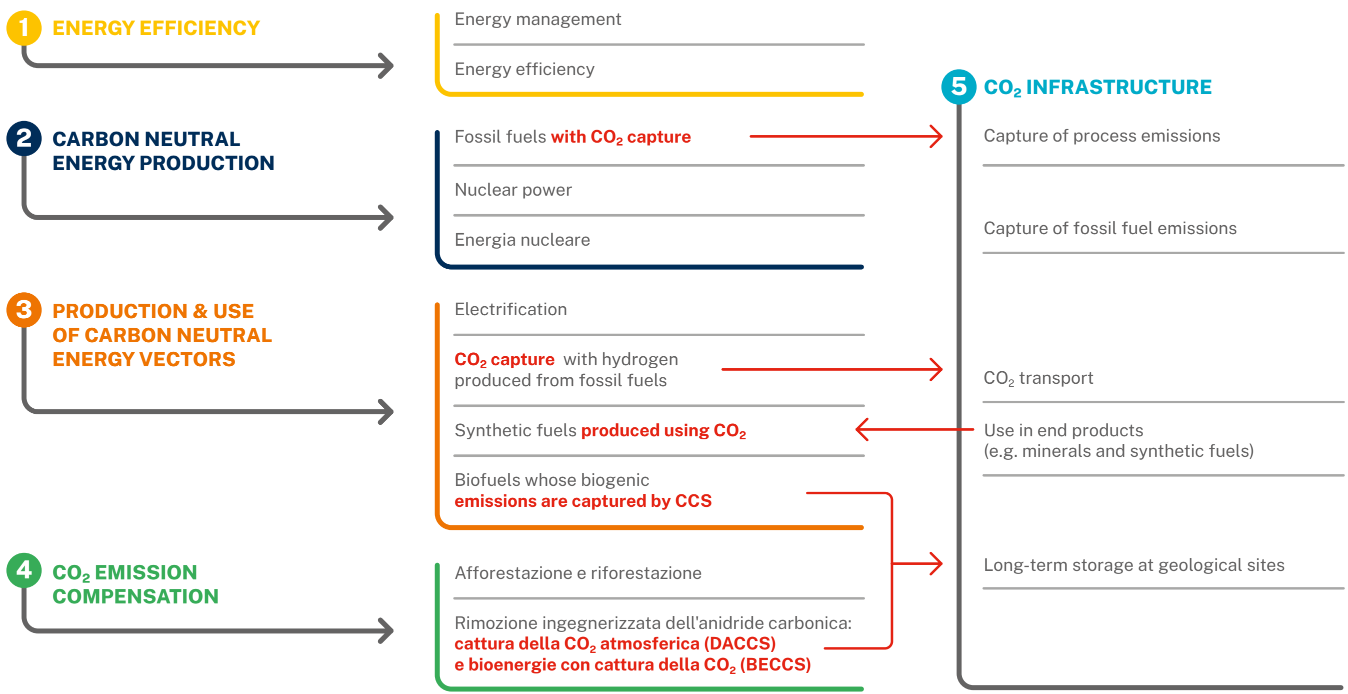
CCS is a **technological solution to accompany the green transition in synergy with other levers for decarbonisation** such as renewables, electrification, and energy efficiency.
There is **growing awareness among Italian and European institutions** of the need to exploit all possible levers for decarbonization, including CCS.
In view of the upcoming European electoral round and the time needed for the EU to stabilise and resume legislative activity, **Italy can play a central role in defining a competitive framework capable of attracting investment and facilitating the start-up of projects.**

In 2022, The European House - Ambrosetti has mapped 100 technologies to achieve decarbonisation targets, to be exploited synergistically, in different areas of use, according to a principle of **technology neutrality**. The technologies can be grouped into five technological levers: energy efficiency, low-carbon energy production, production and use of low-carbon energy carriers, emission offsetting and CO_2 infrastructure. As shown in the figure below, **technologies and infrastructures for the transport, use or storage of CO_2 have an enabling role in supporting other decarbonisation solutions**.

Figure 28

Decarbonisation levers

Source: Strategic Study 'Proposal for a Zero Carbon technology roadmap', The European House - Ambrosetti (2022), 2023.

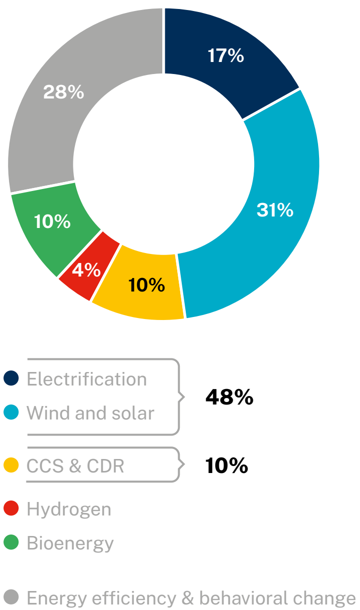


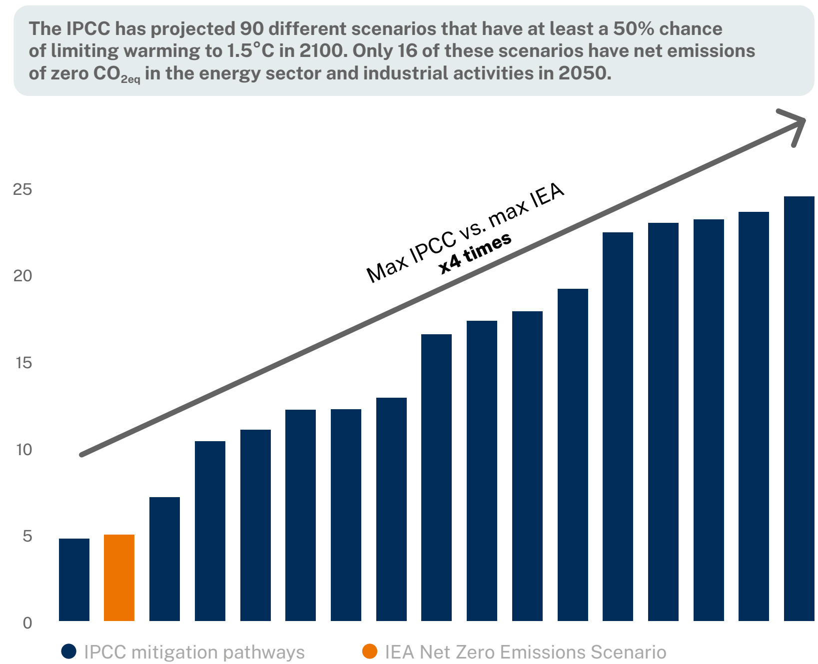
In the IEA scenarios, **Carbon Capture and Storage (CCS) and Carbon Dioxide Removal (CDR) are among the technological solutions needed to meet decarbonisation targets and will contribute to a 10% reduction of global CO_2 emissions between 2020 and 2050**. Some full decarbonisation scenarios developed by the IPCC predict a role for CCS and CDR up to 4 times greater than the IEA.

Figure 29

Share of contribution of each mitigation measure (% of total emissions reduction), 2020-2050 (left); CCS in zero emission scenarios by 2050 (Gton CO_2, 2050 forecast (right)

Source: The European House - Ambrosetti on IEA "Energy Technology Perspective" and IPCC data, 2023.





MYTHBUSTERS

CCS is not an effective way to abate CO_2, but an excuse to keep highly emissive industrial and energy supply processes going

FALSE

According to a portfolio and technology-neutral logic, CCS is one of the indispensable technologies for the decarbonisation of industrial systems and energy production, along with the reduction of fossil fuel use (as indicated by the IEA and IPCC scenarios)

TRUE

In the European context, but also on a global scale, Norway is the country at the forefront of CCS project implementation. To date, all commercially operating CCS projects in Europe are in Northern Europe. However, a further 60 projects are in the construction or planning stage, most of which are located in depleted gas fields or saline aquifers in the North Sea. In this context, **the Ravenna CCS project represents a unique opportunity to create a decarbonisation hub for Southern Europe**. When fully operational, the Ravenna project will be among the world's leading hubs and will be able to facilitate access to this technology in the wider Mediterranean area, as well as providing a significant **competitive advantage for the area's Hard to Abate industries**, which will also be able to use this tool to reduce their emissions. The Ravenna CCS project therefore represents a relevant opportunity to support Italy's positioning as a reference country for the decarbonisation of Southern Europe, thanks to its strategic location and storage capacity.

Figure 30
Distribution of CCS projects in Europe[14]
Source: The European House - Ambrosetti on IEA data, 2023.

3
Commercial CCS projects in Europe

- **Sleipner** – Norway
- **Snøhvit** – Norway
- **Orca** – Iceland

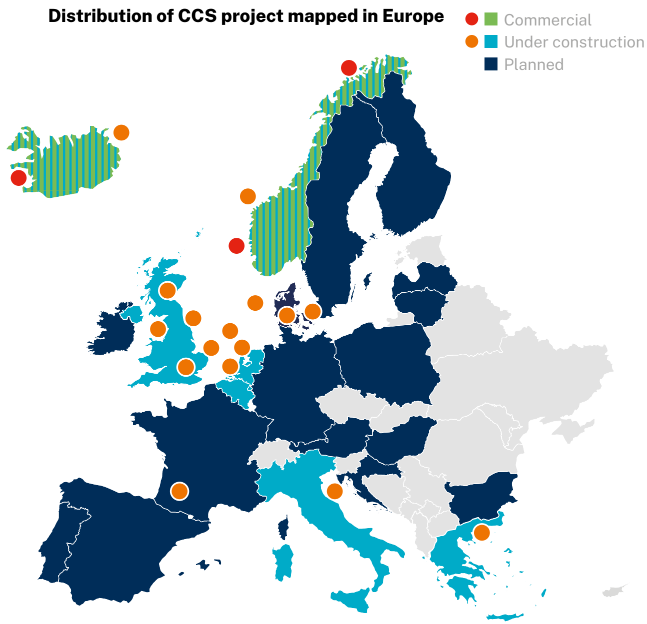
Storage Capacity
800,4 Mton CO_2

Investments
3.5 Billion Euros

16
Under-construction projects mapped in Europe

- **Aramis** – The Netherlands
- **Bacton Thames Net Zero** – UK
- **Bifrost** – Denmark
- **Carbfix Coda Terminal** – Iceland
- **East Coast Cluster** – UK
- **Greensand** – Denmark
- **HyNet North West** – UK
- **L10 Area** – The Netherlands
- **Northern Lights** – Norway
- **Porthos** – The Netherlands
- **Pycasso** – France
- **Prinos** – Greece
- **Ravenna CCS** – Italy
- **Scottish Cluster** – UK
- **Smeaheia** – Norway
- **Viking CCS** – UK

In total, there are other 44 projects in development in Europe



14 Of the 60 projects under development in Europe, the 16 highlighted were selected on the basis of examples given during stakeholder engagement activities (Working Tables and confidential interviews).

MYTHBUSTERS

CCS is adopted primarily because it allows the extraction of what is left in the oil and gas fields

FALSE

Even though Carbon Capture & Storage was created to increase the extraction capacity of fossil fuels in the operations of energy companies, to date active commercial projects in Europe, as well as CCUS Hubs under development, are exclusively devoted to geological storage of carbon dioxide for environmental purposes, effectively excluding the use of CCS to extract additional fossil fuels

TRUE

In addition to the growing interest of the business community, over the years, EU institutions have also become aware of the strategic relevance of CCS. After the first Directive for the geological storage of CO_2 adopted in 2009, CCS has gained increasing importance among EU and national institutions since 2019. The **Net Zero Industry Act** of March 2023 **mentions CCS as one of the strategic levers to increase the EU's industrial competitiveness**, with a target of 50 million tonnes per year of injection capacity by 2030. Recent draft updates of the National Energy and Climate Plans also underline the increased awareness of the importance of CCS, both in Italy and in other EU countries. Stakeholder Engagement activities conducted by The European House - Ambrosetti revealed the need to make CCS available as a solution for industrial decarbonization, since it can be adapted to existing plants without changing its production set-up, as well as the need to de-risk CCS from the costs incurred in adapting plants to capture and time to build infrastructure for transport and storage.

Figure 31

Evolution of CCS in the European regulatory context

Source: The European House - Ambrosetti on European Commission data, 2023.

"I believe CCS has incredible potential in our race towards climate neutrality. Without CCS and CCU, it will be virtually impossible to limit global warming."

Kadri Simson, ***European Commissioner for Energy*** **27th October 2022**

2009

Directive 2009/31/EC "CCS Directive"

Establishes a legal framework for the **environmentally safe geological storage of CO_2**

2021

CCUS Forum

The EC has set up a **consultation platform for stakeholders** (institutions, NGOs, business and academia) to facilitate the dissemination of CCS.
Four working groups operate under the auspices of the Forum:

- CO_2 infrastructure development
- Industrial partnerships
- Public Perception
- CCS Strategy

2022

Update of the TEN-E Regulation

The revision covers cross-border **CO_2 transport and storage networks between member countries and with neighbouring third countries.**

Eligible infrastructure includes pipelines, cross-border CO_2 transport and storage facilities and fixed installations for liquefaction and temporary storage

2022

Inclusion of 6 CO2 network projects in Projects of Common Interest (CPI)

CIPs connect the energy systems of EU countries and benefit from accelerated authorisation procedures and funding. In the list published in November 2021 and in force since April 2022, **6 out of 98 projects concerned the cross-border transport of CO_2**

2023

Net-Zero Industry Act

Still in the process of incorporating feedback from the open discussion, the document sets the EU target of achieving **an annual injection capacity of 50 Mton** in the EU **by 2030**

2023

Study on the possible future regulatory framework for CO_2 transport infrastructure

The EC commissioned this study to **define third-party access to CO_2 transport and storage, tariffs, network development plans and business models**

In addition, it is also planned to release an **update on the non-binding guidelines on CO_2 storage's Directive**

The results of the second study on the optimal approach for the development of **a Europe-wide CO_2 infrastructure** are expected by summer 2023

2023

Public consultation on industry-wide CO_2 management

The consultation opened on 9 June and will run for 12 weeks, with the aim of gathering input from stakeholders and citizens to prepare a **new EU strategy for CCUS**, which will be instrumental in providing a clear regulatory framework for interested emitters

2023

Review of Integrated National Energy and Climate Plans

In 2019, many EU countries, including Italy, had not included CCS in their Plans as a mean to achieve the 2030 targets.

However, the Commission recommended integrating CCS into the updated plans. In the new draft of the Italian Plan (2023), **CCS is an essential element to achieve the new climate targets in the ETS sectors**

In line with the evolving European regulatory environment, **several Member States have** also **defined strategies and instruments to foster the development of CCS projects**. Notable among these are Denmark, Germany, and the Netherlands in terms of clarity of national/regional strategy and allocated funds.

Figure 32
Main EU countries' strategies and instruments to support CCS
Source: The European House - Ambrosetti on various sources, 2023.

Regulatory instruments from EU countries at the forefront of CCS project support and creation

DENMARK

- **CCS Fund:** 2.14 billion Euros over 20 years to support CCS deployment
- **National Strategy for CCS:** dedicated to defining regulations and licensing procedures to support CCS deployment and how to allocate the CCS Fund
- **State aid of 1.1 billion Euros**

GERMANY

- **Long-term strategy for engineered CO_2 removal**, aimed at managing around 5% of national emissions considered 'unavoidable'
- **North Rhine-Westphalia Regional Strategy**: capture up to 7 million tons of CO_2 per year from local industries

THE NETHERLANDS

- **SDE++ scheme**: in the 2022 round, CCS projects received around 56% of the total allocated, it is the technological solution that captures the most CO_2 per year
- **CO_2 tax:** will gradually increase over the next decade and reach 125 Euros per ton of CO_2 emitted by 2030

Although interest in CCS solutions from European institutions, member state governments, and industry players is growing strongly, **developments in the international context, particularly in Australia, Canada, Norway, the United Kingdom, and the United States, must also be considered**. For example, the **Inflation Reduction Act** (USA) provides incentives in the form of tax credits for CCS projects, a highly simplified measure that could attract investment outside the EU.

Figure 33
International contexts favourable to CCS

Source: The European House - Ambrosetti on Report "EU regulation for the development of the market for CO_2 transport and storage", Bolscher H. et al, Energy Transition Expertise Center (2023) and Report "A European Strategy for Carbon Capture and Storage", Lockwood T., Clean Energy Task Force (2022), 2023.

Third-country regulatory instruments at the forefront of CCS project support and creation

AUSTRALIA

Greenhouse Gas Geological Sequestration Act: regulates certain aspects of CO_2 storage

National Strategy for CCS: will provide policy direction and prioritise CO_2 management centres

CANADA

CO_2 tax to reach 170 Candian Dollars per ton by 2030 and **tax credits** on investments in CCS projects of 20-30%

Carbon Management Strategy: federal vision document to support CCS projects

NORWAY

Climit: initiative launched in 2005, with the aim of contributing to the development of CCS technologies and solutions by providing financial support for projects

Longship: a project for which 1.6 Euros billion has been earmarked for 2020, for the construction of an offshore transport and storage site and two capture sites

UNITED KINGDOM

Action Plan: CCUS deployment pathway with clear indication of key actions, timeframes, milestones and stakeholders

Spring Budget 2023: 24 billion Euros earmarked for CCS deployment over the next 20 years

UNITED STATES

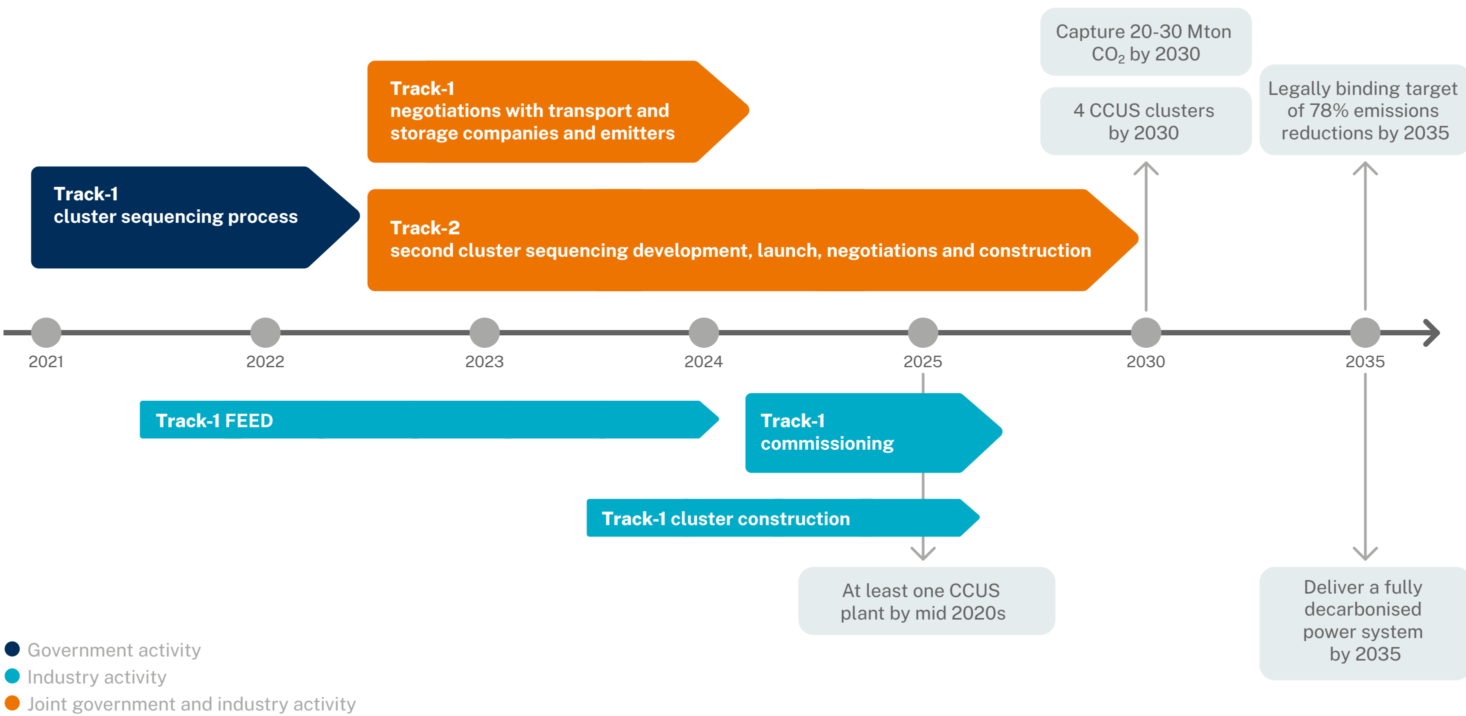
SCALE: $2.1 billion funding programme for infrastructure development

Inflation Reduction Act: tax credit up to $85/ton CO_2 stored and $60/ton CO_2 used for industrial applications, up to $180/ton CO_2 stored and $130/ton CO_2 used through DACCS

The **UK** also has **a very clear and effective strategy to support CCS**: it has allocated 24 billion Euros for CCS deployment and has set out an implementation plan where timelines and responsibilities are detailed.

Figure 34
UK plan for CCUS clusters

Source: The European House - Ambrosetti on Report 'EU regulation for the development of the market for CO_2 transport and storage', Bolscher H. et al, Energy Transition Expertise Centre (2023), 2023.



KEY MESSAGE 4

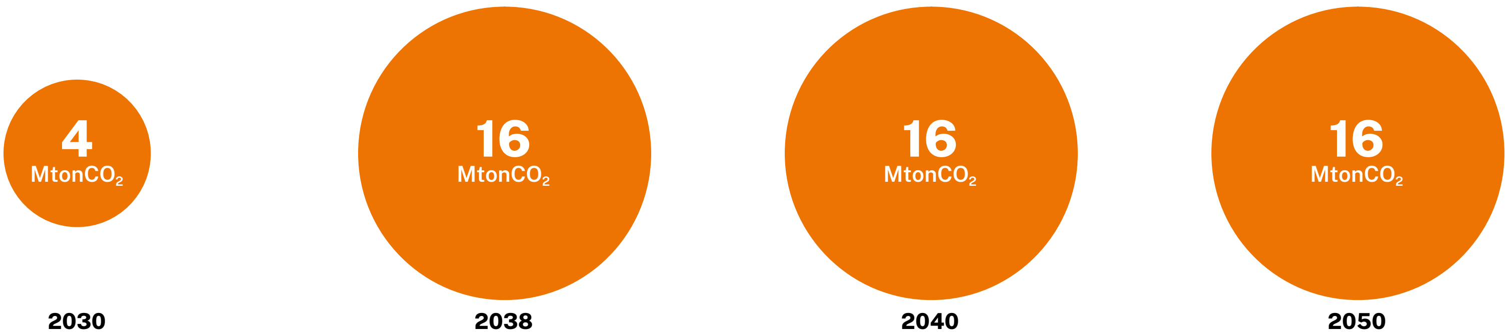
The European House - Ambrosetti developed a model to assess the **impacts of CCS on the decarbonisation and competitiveness of Italian Hard to Abate sectors.**
The model estimates storing around **300 million tonnes of CO_2 by 2050**, leveraging the construction of the Ravenna Hub and associated transport network.
This will support the competitiveness of industrial sectors that together generate **62.5 billion Euros in added value and 1.27 million jobs.**
Furthermore, the deployment of CCS will foster the creation of a value chain that will generate **Euros 1.55 billion in added value and over 17 thousand new jobs by 2050**.

The European House - Ambrosetti has developed a **theoretical model to estimate the potential environmental, economic, and social contribution of CCS solutions**, based on an intensive analysis of 160 academic and managerial papers and the involvement of 63 international stakeholders. The model assumes that the annual national capture capacity corresponds to the target CO_2 sequestered by the Ravenna plant, which from 2026 (the year it will enter the commercial phase) **will grow to store 4 million tonnes to 2030 and subsequently increase to 16 million tonnes of CO_2 per year to 2038**. In total, the theoretical model considered assumes to store about 300 million tons of CO_2 by 2050.

Figure 35

Annual storage capacity targets of the Ravenna Hub. 2030, 2038, 2040 e 2050

Source: The European House - Ambrosetti, 2023.

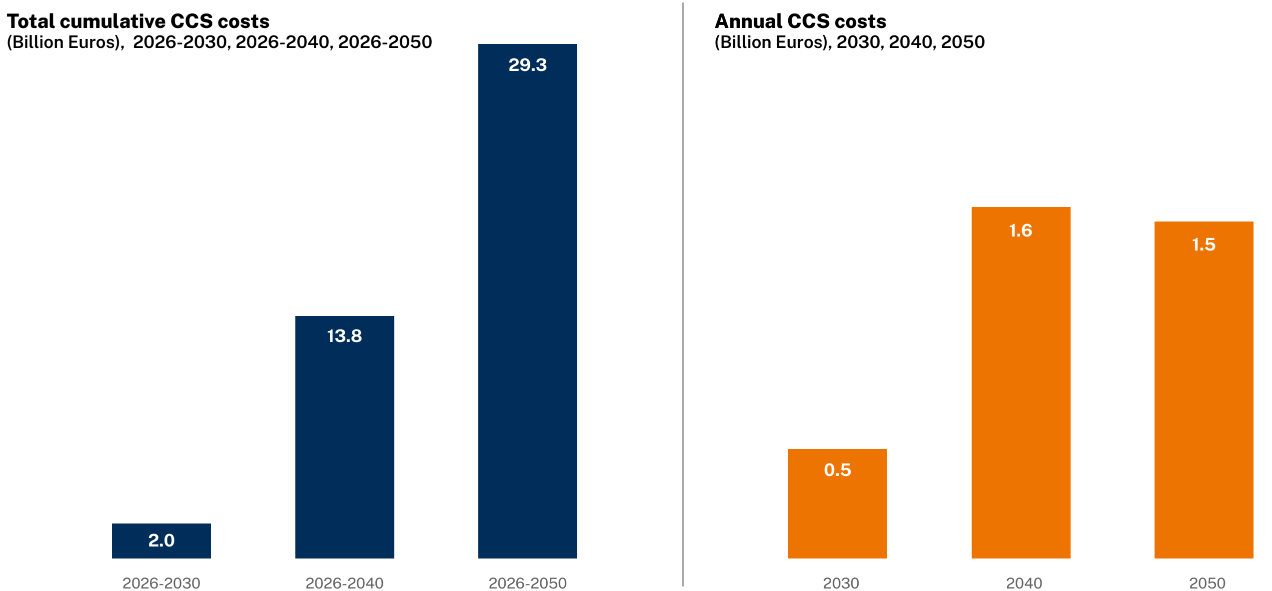


Based on literature data and considering the storage capacity assumed in the theoretical model, The European House - Ambrosetti estimated the **standard cumulative cost for capturing, transporting, and storing about 300 million tonnes of CO_2 between 2026 and 2050 to be about 30 billion Euros, with an annual cost to 2050 of about 1.5 billion Euros**.

Figure 36

Cumulative and annual costs of implementing the theoretical CCS model developed by The European House - Ambrosetti

Source: The European House - Ambrosetti on data from proprietary models and IEA, 2023.



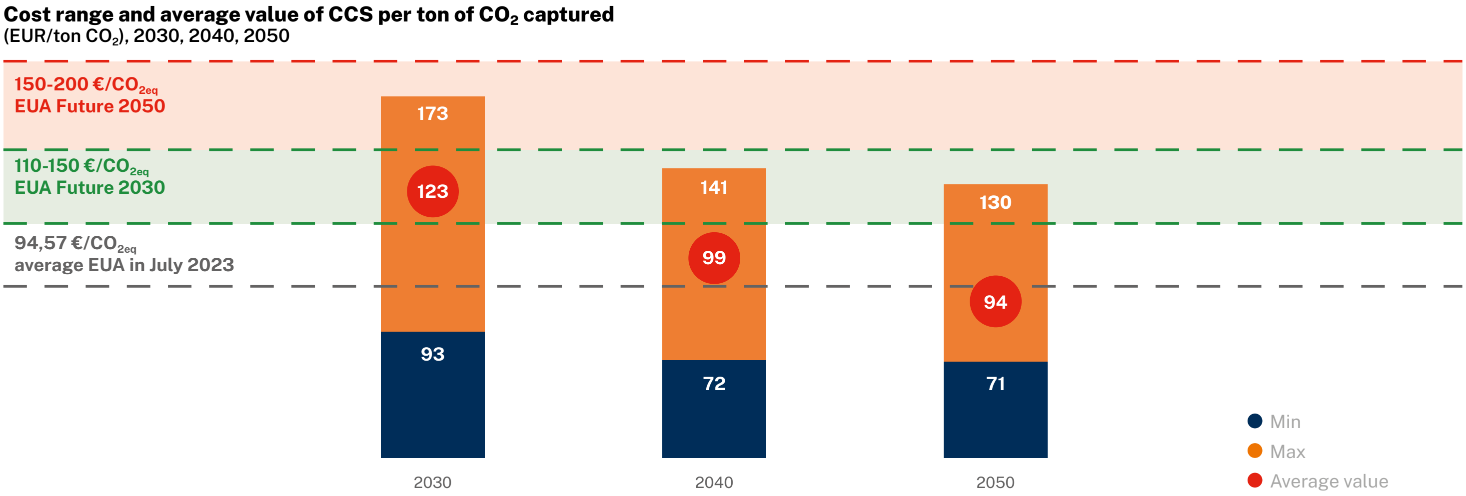
The data for the impact estimation model were collected by The European House - Ambrosetti on the basis of the analysis of more than 160 sources of academic-scientific literature.
The results of the analyses refer to the theoretical model developed by The European House - Ambrosetti.

At the same time, according to estimates by The European House - Ambrosetti, the **average costs of capture, transport and storage will decrease from 123 Euros/ton CO_2 in 2030 to 99 and 94 Euros/ton CO_2 in 2040 and 2050 respectively**. These costs are lower than the ETS price that Hard to Abate companies would face from 2026 onwards[15], estimated at between 110 and 150 Euros/ton CO_2 in 2030 and between 150 and 200 EUR/ton CO_2 in 2050.

Figure 37

Cost range and average value of CCS per tonne of CO_2 captured (EUR/ton of CO_2)

Source: The European House - Ambrosetti on proprietary model data and IEA, 2023.

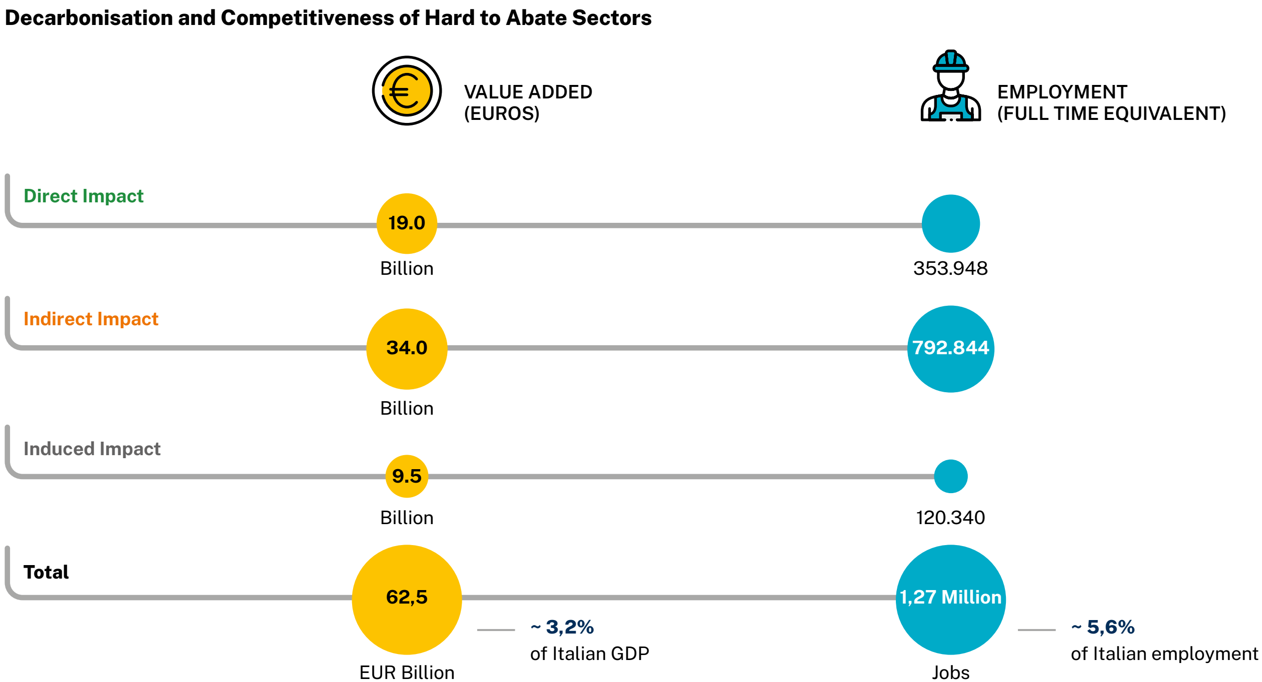


The cost values shown on this page were estimated by The European House - Ambrosetti based on data from academic-scientific literature.
The given cost ranges are related to capture, transport and storage and account for a large variability of emitter typologies, CO_2 volumes, transport distances and pre-existing infrastructures.
Specific project conditions can result in different costs, approaching the lower bound of the given range where synergies and economies of scale can be exploited.
Eni and Snam highlight that storage in depleted reservoirs and reuse of existing infrastructures are the key factors that allow a significant full-chain cost optimizations, enabling the deployment of competitive CCUS projects. Nevertheless, project configuration and the need to develop the infrastructure entail final actual costs which are higher at the beginning of the operative phase of new CCUS hubs, requiring appropriate incentives to start-up the activity. Economic sustainability of CCUS without any incentives will be possible in a later phase, once the full project configuration is achieved, also thanks to the contribution of technology innovation and market evolutions.

15 To protect the competitiveness of European companies subject to the ETS in the internal market, the phasing out of the free emission allowances from 2026 will be accompanied by the adoption of the Carbon Border Adjustment Mechanism (CBAM) to enable European industries to remain competitive worldwide and avoid relocation phenomena of production to other countries.

The full development of the model developed by The European House - Ambrosetti will have a **major economic, environmental, and social impact on the Hard to Abate sectors**. These will be able to achieve decarbonization goals in a sustainable manner, including economically, while safeguarding their competitiveness. Overall, the **application of CCS will make it possible to support the competitiveness of supply chains capable of generating EUR 62.5 billion in Added Value** (about 3.2% of Italian GDP) **and sustain the employment of 1.27 million people** (about 5.6% of Italian employment) between direct, indirect, and induced impacts.

Figure 38
Overall impact of CCS on Hard to Abate sectors
Source: The European House - Ambrosetti on proprietary model data, 2023.

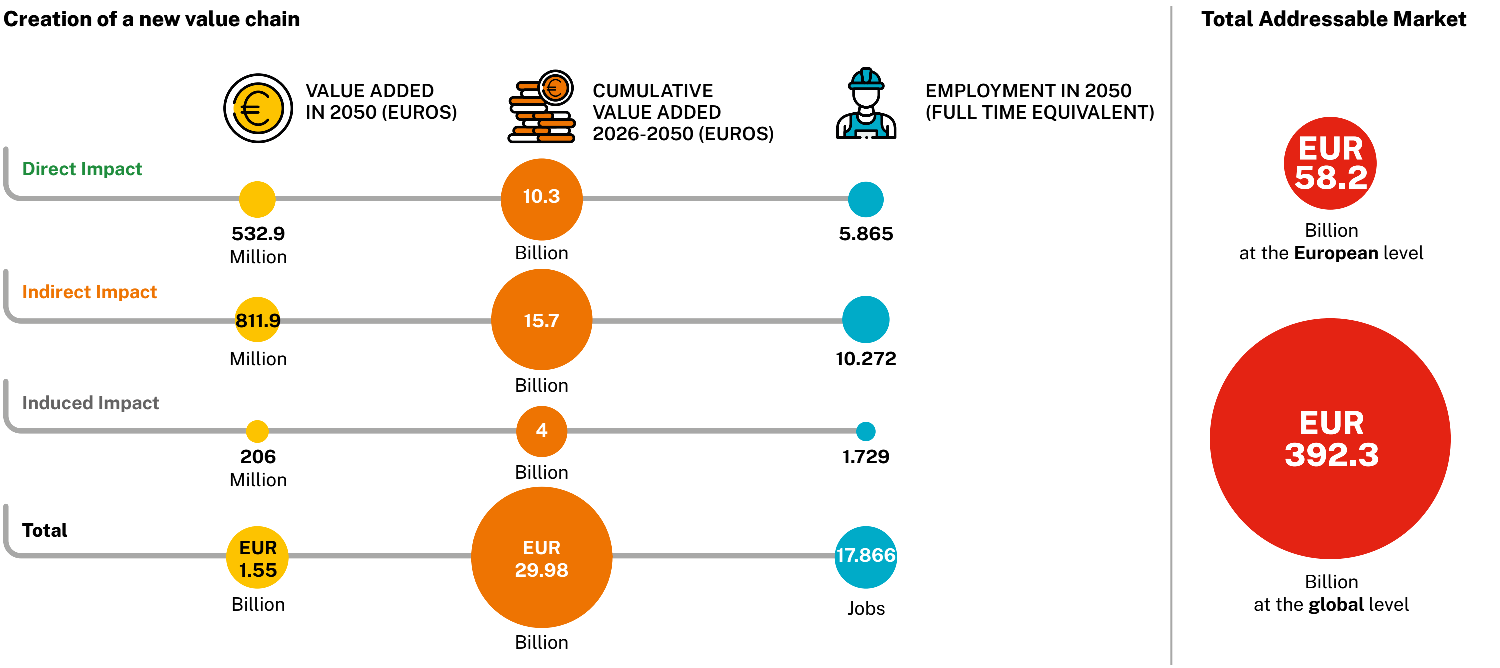


Moreover, the concretisation of the model developed by The European House - Ambrosetti will foster the develop a new supply chain in Italy, capable of generating between 2026 and 2050 **an added value in our economy equal to 30 billion Euros with the creation of more than 17 thousand jobs by 2050 between direct, indirect, and induced impacts**. Italy's ability to be a first mover in the development of a complete supply chain linked to CCS is functional to seize further opportunities that will be created in the international context. Based on the storage targets set by the European Union and at global level, it is possible to estimate that the Total Addressable Market for CCS in 2050 will be about 60 billion Euros at European level and about 400 billion Euros at global level.

Figure 39

Totals by added value and impact on employment in the whole CCS chain

Source: The European House - Ambrosetti on proprietary model data, 2023.



KEY MESSAGE 5

At the national level, it will be important to continue the development path of CCS solutions for the decarbonisation and competitiveness of the Hard to Abate sectors, **investing in the implementation of further initiatives based on the principle of technology neutrality** to maintain the competitiveness of sectors that generate an additional **57.7 billion Euros in Value Added with 1.19 million jobs.**

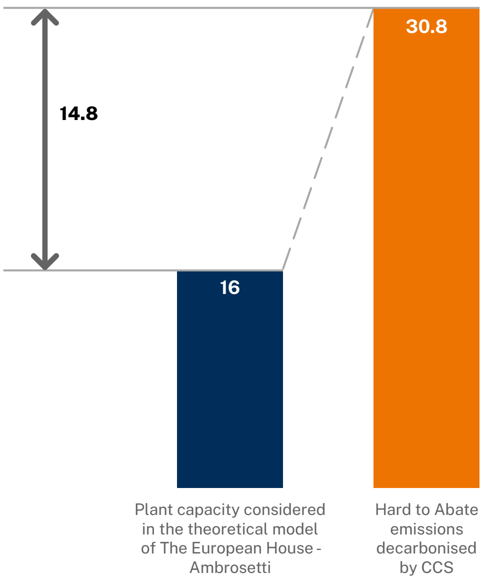
The Ravenna Hub will be able to contribute to the decarbonisation of 48% of the residual emissions[16] of the Italian Hard to Abate sectors. **The remaining 14.8 Mton CO_2 will have to be sequestered by investing in the development of new CCS projects.** The complete decarbonisation of Hard to Abate sectors through CCS will help sustain their competitiveness, supporting an additional **57.7 billion Euros in Value Added** and **more than 1.19 million jobs by 2050**.

Figure 40

Strategic levers to complete the decarbonisation of the ETS sectors in Italy[17]

Source: The European House - Ambrosetti on European Commission and IEA data, 2023.

Annual storage capacity of the plant considered in the theoretical model of The European House – Ambrosetti and overall market requirements
(Mton/y)



Strategic levers to ensure complete decarbonisation

NEW CCS PLANTS

The remaining 14.8 Mton CO_2 will have to be sequestered by **investing in the development of new CCS projects** investigating the residual potential of depleted fields in the Italian offshore*

The ability to address the additional 14.8 Mton of emissions by achieving full decarbonisation could support an **additional 57.7 billion in added value and 1.19 million jobs**

To these emissions must be added the share of emissions related to fossil fuel power generation needed to provide flexibility services to the electricity system and maximise the penetration of non-programmable renewables

* The storage capacity of depleted fields in the off-shore Adriatic sea has been estimated at 500 Mton CO_2, of which 300 are considered in the model elaborated by The European House - Ambrosetti. Additional storage possibilities in other areas need to be investigated.

16 Net of energy efficiency, electrification, bioenergy, hydrogen, and feedstock switching.
17 Hard to Abate net emissions indicate the share of emissions remaining after the application of other decarbonisation levers (electrification, bioenergy, hydrogen and the use of new feedstocks).

KEY MESSAGE 6

To enable the full development of CCS, according to a technology-neutral principle, and of its economic and social benefits, it is necessary to **identify effective regulatory schemes capable of reconciling decarbonisation and economic competitiveness through integrated planning and support mechanisms for de-risking.**

Stakeholder Engagement analysis and activities, conducted by The European House - Ambrosetti, highlighted several areas of focus to address challenges and priority areas for action and to maximize the development of CCS solutions in Europe and Italy. The European House-Ambrosetti formulated **10 policy proposals**, with reference to four areas of intervention, with the aim of supporting Policy Makers, industrial actors, and stakeholders in the CCS value chain in the creation of market conditions that would allow overcoming the obstacles that have emerged, to maximise the deployment of CO_2 capture, transport and storage solutions.

Legislation should focus on **enabling conditions for investments rather than on the imposition of cross-cutting obligations**, through the definition of a regulatory framework outlined in the forthcoming EU Communication ("Communication on an EU strategy to create a single market for CO_2 transport and storage services by 2030", scheduled for Q4 2023) and of planning tools that are certain and defined in consultation with industrial players according to specific contexts, and the deployment of support tools that enable the creation of market development conditions from the outset, at national and EU level.

Figure 39

Main evidence from stakeholder engagement activities on CCS policy gaps in Italy and Europe

Source: The European House - Ambrosetti on proprietary data, 2023.

35 Key Opinion Leaders were involved, representing 31 leading institutions, trade associations, research organisations and companies. Main points:

- **common standards:** common technical standards need to be defined among EU Member States to facilitate cross-border CCS projects;
- **public support:** based on what has been done in the Netherlands or the US, the most effective ways to support CCS projects are Contracts for Difference and subsidies in the form of tax credits;
- **de-risking:** CCS projects need to be accompanied by a clear political vision to reduce initial investment risks for the construction of key infrastructure needed to attract Hard to Abate industries.

Area of intervention #1

The first area of intervention is dedicated to the creation of the so-called 'soft infrastructure', i.e. the definition of a clear and stable regulatory and legislative framework, which is necessary to facilitate the full development of CCS by providing investment certainty.

#1 SOFT INFRASTRUCTURE

	POLICY PROPOSAL	KEY ELEMENTS TO CONSIDER
1	Ensure a clear **definition of responsibilities along the CCS value chain**, including separating the responsibilities of emitters from transport and storage.	• Clearly separating roles and related responsibilities will **optimise coordination within the system** • **Creating areas of competence/responsibility will relieve issuers of elements of uncertainty**
2	Establish a **robust regulatory system, both at national and European level, to enable capture, transport and storage activities**, rewarding states that favour the creation of common storage and transport infrastructure.	• Establishing **an agreement for the management of cross-border transport and storage in Europe** will facilitate the establishment of CCS projects f rom a European perspective • Reducing the technical timeframe for **granting CO_2 storage permits**
3	Define **common EU-wide technical standards for transport and storage** (to the extent necessary for cross-border projects, e.g. CO_2 transport characteristics, design and operation characteristics of CO_2 transport pipelines, etc.).	• The only technical reference standard at the Italian level is Legislative Decree No. 162 of 2011 on the **geological storage of CO_2** • Harmonising parameters will make it possible **to improve coordination between emitters and transport and storage systems**

Area of intervention #2

The second area of intervention refers to the application of CCS to different forms of emissions and different sectors. The deployment of CCS solutions (including DACCS and BECCS) will be able to accompany the decarbonisation pathway of Hard to Abate industries, in synergy with other technological solutions and according to a principle of technological neutrality and complementarity between the different options available. Furthermore, CCS will also be able to ensure the decarbonisation of power generation and accelerate the production of decarbonised energy carriers.

#2 APPLICATION ON DIFFERENT EMISSION SECTORS

	POLICY PROPOSAL	KEY ELEMENTS TO CONSIDER
1	Favor the a**pplication of the principle of technology neutrality** by considering the opportunity to leverage **complementarity** between mature decarbonisation solutions and those that will only be available in the medium to long term, including supporting the use of CCS for emissions offsetting through BECCS and DACCS.	• CCS enables the **rapid decarbonisation of almost all emissions** from many plants that would otherwise require longer time scales • CCS is expected to accelerate the decarbonisation pathway, **helping to reduce the total amount of emissions between now and 2050** • **Including negative emissions from BECCS and DACCS in the ETS** could be a further boost to support the development of these projects
2	**Natural gas**, as the fossil fuel source with the lowest emissions, **will have to accompany the transition to renewables by ensuring the flexibility and adequacy of energy systems. CCS can be exploited to decarbonise the emissions of the required share of gas** in power generation and high-efficiency, high-temperature steam production (through cogeneration) for the decarbonisation of industrial sectors.	• In a scenario of high penetration of renewables, together with electrochemical storage systems, it will be necessary **to maintain a flexible gas-fired power generation component** • **Combining CCS solutions with gas turbine power generation,** thus reducing CO_2 emissions from this source
3	Define **parity between decarbonised hydrogen and renewable hydrogen** in European regulations.	• Accelerating the development of the hydrogen supply chain by leveraging **the availability and higher cost-effectiveness of low-carbon hydrogen obtained from fossil sources with** CCS • Exploiting the significant production already present in Europe and existing industrial assets

Area of intervention #3

The third area of intervention relates to strategic planning, as the development and deployment of CCS solutions will need to be facilitated by the definition of a clear political vision, shared strategic planning and a roadmap for development at national level.

#3 STRATEGIC PLANNING

POLICY PROPOSAL	KEY ELEMENTS TO CONSIDER
1 As part of the national **NECP**, set CCS targets geared towards Hard to Abate economic activities, considering in the assessment their **geographic spread, levels of CO_2 concentration in emissions**, and how they **connect to available storage sites**.	• Planning will have to consider some **contextual aspects**, e.g. the distribution of industrial activities on the territory, the amount of CO_2 emissions, the presence of clusters, and other **aspects specific** to CCS solutions, e.g. the different options for transporting CO_2 • At least initially, the Ravenna Hub will be the only storage site on the national territory, but it will be necessary to **identify additional solutions to achieve full decarbonisation of residual emissions**
2 **Enhance the Institutions' role in involving key stakeholders** in defining a concrete and appropriate infrastructure development plan that meets industry expectations and leverages market initiatives.	• Institutions will have to initiate an active dialogue with national stakeholders, both emitters and promoters of transport and storage infrastructures, who will have to deal with the development and deployment of CCS solutions in order **to accelerate the strategic planning process and define a clear and concrete roadmap aimed at maximising the potential benefits for the country-system** • Considering that **decarbonisation is a challenge that will have to be tackled at the European level**, it will be crucial to identify relationship models that maximise the potential contribution of CCS solutions, also from a cross-border perspective, considering **Ravenna's role as a hub for decarbonisation in Southern Europe**

Area of intervention #4

The fourth and final area of focus addresses the need to reduce the financial risks associated with CCS projects, as support mechanisms are needed for the development of a CCS supply chain to provide certainty to industry players and enable the creation of important cross-sectoral economic and social benefits to society.

#4 DE-RISKING

	POLICY PROPOSAL	KEY ELEMENTS TO CONSIDER
1	Introduce **financial support mechanisms through Contracts for Difference (CfD) and direct subsidies** to support the deployment of capture projects.	• The definition of the incentive mechanisms will have to be shaped according to schemes that are easy to implement by companies, in order to be as **effective and direct an instrument as the tax incentives provided by the US Inflation Reduction Act**
2	**Define support models for T&S transport and storage infrastructure:** • **direct subsidies** to support initial infrastructure development; • **guarantee mechanisms** with respect to cost coverage and return on investment. Such models for T&S infrastructure development may evolve toward **RAB mechanisms**.	• **Ensure mechanisms for setting transport and storage tariffs that do not disincentivise the virtuous behaviour of first mover emitters** in implementing technology

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