



# Sustainable Energy Authority of Ireland

National Energy Research,  
Development & Demonstration  
Funding Programme

## FINAL REPORT TEMPLATE

### SECTION 1: PROJECT DETAILS – FOR PUBLICATION

<b>Project Title</b>	Feasibility of Carbon Capture Utilisation and Storage (CCUS) in Ireland
<b>Lead Grantee (Organisation)</b>	University of Galway
<b>Lead Grantee (Name)</b>	Professor Rory Monaghan
<b>Final Report Prepared By</b>	Professor Rory Monaghan, Haresankar Jayasankar, Jonathan Alexander, Dr David McNamara
<b>Report Submission Date</b>	15 April 2025

	<b>Name</b>	<b>Organisation</b>
<b>Project Partner(s)</b>	Dr Tiernan Henry Dr David McNamara	University of Galway University of Liverpool
<b>Collaborators</b>		

#### Project Summary (max 500 words)

This project performed a comprehensive feasibility study for CCUS deployment in Ireland. It was a collaboration between the University of Galway and the University of Liverpool and involved researchers from mechanical and energy systems engineering and geology. The study consisted of the following elements: (1) an assessment of all current and likely future fossil fuel derived CO<sub>2</sub> sources in Ireland, (2) a techno economic study of the costs of capture and transportation of CO<sub>2</sub> from these sources, (3) an assessment of the potential for conventional CO<sub>2</sub> storage in the Irish offshore setting based on currently available data, (4) a study on the potential for mineral carbonation as an alternative for onshore CO<sub>2</sub> storage, (5) a screening of options for CO<sub>2</sub> utilisation in long-lived materials, (6) a scenario-based assessment of the economic and environmental performance of complete CCUS supply chains for Ireland, and (7) recommendations for next steps in the deployment of CCUS for Ireland.

The project made the following findings: (1) the emissions sources most suitable for CO<sub>2</sub> capture are combined cycle (CCGT) power plants, despite their likely low capacity factors in future, cement plants, the Whitegate oil refinery, Aughinish Alumina, and large-scale food production plants; (2) the projected cost of capturing CO<sub>2</sub> was 50-200 €/tCO<sub>2</sub> for power plants, with capacity factor the main determinant of cost, and 55-70 €/tCO<sub>2</sub> for cement plants; (3) reservoirs under the Irish Sea showed promise for CO<sub>2</sub> storage but there was a significant lack of data, for example, borehole

image logs and geological mechanical data, that must be addressed for further work to continue; (4) five reservoirs (Antrim Lava Group, Connemara Metagabbro and Gneiss Formation, Carlingford Complex, Tyrone Plutonic Complex and Dawros-Currywongaun-Doughruagh Complex) showed potential for mineral carbonation and were recommended for future consideration; (5) options for CO<sub>2</sub> utilisation that avoids emission to the atmosphere in the long-term are extremely limited by CO<sub>2</sub> demand, with CO<sub>2</sub> concrete curing requiring less than 1% of total CO<sub>2</sub> emissions (note: despite their allowance under the EU's RFNBO scheme, use of fossil-derived CO<sub>2</sub> in fuels production was not considered as this delays but does not avoid eventual CO<sub>2</sub> release); and (6) the most economically and environmentally effective CO<sub>2</sub> supply chains are those that exclude the smallest, most dispersed emission sites, use truck transport for small-scale emitters, pipelines for large ones, centralised hubs for gathering CO<sub>2</sub> together for onward storage, and are planned such that CO<sub>2</sub> supplies are assured far into the economic life of the infrastructure.

The key recommendations of this project are: (1) the price of CO<sub>2</sub> emission must increase to reach a figure sufficiently high to incentivise investment in CCUS technologies; (2) A full assessment of the Irish offshore stress state using existing datasets is required to understand the existing stress state prior to any CO<sub>2</sub> injection for storage; (3) Depth-converted 3D fault models are required for all potential offshore CO<sub>2</sub> storage sites to fully analyse their potential behaviours under potential stress states during and after CO<sub>2</sub> injection; (4) more detailed follow-on studies of mineral carbonation should be performed rock-fluid reactivity studies and modelling, geochemical modelling, and a socio-economic and technical assessment; (5) stakeholders in Ireland should collaborate with UK CCS projects in progress, such as HyNET and Teesside Net Zero, and UK research efforts to better inform and derisk Irish activities; (6) building upon EU RFNBO regulations that increasingly support the use of CO<sub>2</sub> emissions from non-renewable sources, future research should examine viable CO<sub>2</sub> utilisation pathways, such as large-scale chemical or fuel production.

**Keywords (min 3 and max 10)**CCUS, sequestration, techno-economic, CO<sub>2</sub> utilisation, carbonation, geological, supply chain, cement, CCGT

**NB – Both Section 1 and Section 2 of this Final Report will be made publicly available in a Final Technical Report uploaded online to the National Energy Research Database.**

*In the following Section, please provide a clear overview of your project, including details of the key findings, outcomes and recommendations. The section headings below are provided as a guide, please update or add to these as best suits your project.*

*By submitting this project report to SEAI, you confirm you are happy for Section 1 and Section 2 of this report to be made publicly available. If you wish to request edits to this section in advance of publication, please contact SEAI at [EnergyResearch@seai.ie](mailto:EnergyResearch@seai.ie).*

## SECTION 2: FINAL TECHNICAL REPORT – FOR PUBLICATION

(max 10 pages)

### 2.1 Executive Summary

This project performed a comprehensive feasibility study for CCUS deployment in Ireland. It was a collaboration between the University of Galway and the University of Liverpool and involved researchers from mechanical and energy systems engineering and geology. The study consisted of the following elements: (1) an assessment of all current and likely future fossil fuel derived CO<sub>2</sub> sources in Ireland, (2) a techno economic study of the costs of capture and transportation of CO<sub>2</sub> from these sources, (3) an assessment of the potential for conventional CO<sub>2</sub> storage in the Irish offshore setting based on currently available data, (4) a study on the potential for mineral carbonation as an alternative for onshore CO<sub>2</sub> storage, (5) a screening of options for CO<sub>2</sub> utilisation in long-lived materials, (6) a scenario-based assessment of the economic and environmental performance of complete CCUS supply chains for Ireland, and (7) recommendations for next steps in the deployment of CCUS for Ireland.

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HyNET and Teesside Net Zero, and UK research efforts to better inform and derisk Irish activities; (6) building upon EU RFNBO regulations that increasingly support the use of CO<sub>2</sub> emissions from non-renewable sources, future research should examine viable CO<sub>2</sub> utilisation pathways, such as large-scale chemical or fuel production.

## 2.2 Introduction and Background to Project

Ireland has historically and is continuing to struggle to meet national targets set to reduce GHG emissions by 20% from 2005 levels by 2020 and further by 51% by 2030. The project's primary aim was to address this critical need of Ireland for reducing greenhouse gas (GHG) emissions. Decarbonisation efforts saw significant progress in the electricity sector, with over 40% of electricity coming from renewable sources. However, efforts to decarbonise hard-to-abate sectors like backup power plants that operate in high variable renewable energy (VRE) power systems like Ireland, cement, chemicals, and food production have lagged. This project explored the potential of CCUS technology to bridge this gap and assist Ireland in meeting its future climate targets. Its analysis encompassed all elements of the CCUS value chain, including capture, transportation, storage, utilisation and the supply chains to link them on the island of Ireland.

When considering hard-to-abate sectors, specially as the shift towards high VRE penetration progresses, natural gas power plants are still expected to be needed for uninterrupted power supply to ensure energy security. However, these power plants are expected to operate fewer hours than those in power systems that predominantly depend on non-renewable sources. It is expected that Ireland will have more installed capacity of natural gas power plants, but these will generate less electricity compared to today. Therefore, for the capture component of the project, a detailed techno economic analysis was conducted to determine the capture cost from these backup power plants. Additionally, cost analyses were conducted on CO<sub>2</sub> capture from other hard-to-abate sectors such as cement, chemical and food production.

The project's geological CO<sub>2</sub> storage component advanced understanding of two aspects of Ireland's CO<sub>2</sub> storage capacity. Earlier studies identified the Kinsale gas field as a prime location for CO<sub>2</sub> storage due to its existing infrastructure and proximity to CO<sub>2</sub> sources. This project expanded on those findings first by exploring additional geological settings in the Irish offshore environment, focusing on fault stability. Secondly, the research explored mineralization storage of CO<sub>2</sub>, which involves chemically interacting CO<sub>2</sub>-rich fluids with minerals in igneous and metamorphic rocks, offering greater storage capacities without leakage risks due to high pressure. Ireland's geological settings appear promising for this method. Additionally, the project investigated the Northern Lights CO<sub>2</sub> storage initiative in the North Sea as an option. This initiative is a viable alternative to indigenous CO<sub>2</sub> storage, enhancing the flexibility and scope of Ireland's CCUS strategies.

Focusing on the utilisation of CO<sub>2</sub>, this study focused solely on options for locking CO<sub>2</sub> away from the atmosphere permanently. This ruled out production of synthetic chemicals or fuels, which only temporarily prevent CO<sub>2</sub> release, despite their treatment under EU RFNBO regulations. Among permanent utilisation options, CO<sub>2</sub> concrete curing is a technically feasible near carbon-neutral option. However, the potential demand for CO<sub>2</sub> in concrete curing is estimated to be very low compared to total CO<sub>2</sub> emissions in Ireland, less than 1%, indicating that this utilisation would not significantly impact Ireland's overall emissions reduction targets.

To address the challenge of transporting and storing the CO<sub>2</sub> from the hard-to-abate sectors in Ireland, the project developed a supply chain model for CCUS. This model mapped and optimized the supply chains for CO<sub>2</sub> utilizing a case study approach using several scenarios, identifying capture costs, least cost transportation methods, and storage options.

The project aimed to have an impact by providing policymakers with a comprehensive techno-economic description of CO<sub>2</sub> capture, and supply chains for geological storage and CO<sub>2</sub> utilisation. It updated and built upon previous studies on CCS conducted between 2005 and 2008, enhancing the ability of policymakers to make informed decisions regarding major investments in the Irish energy sector. The project also focused on communication, dissemination, and exploitation plans to engage the international research community, the Irish public, and policymakers. Findings were shared in local and international conferences and through publications. The ultimate goal was to establish a framework that supported the deployment of CCUS, enabling Ireland to meet its GHG reduction targets and contribute to global climate change mitigation efforts.

## 2.3 Project Objectives

Table 1. Summary of Project Objectives

No:	Objective Description:
1.	An updated techno-economic model of the efficiencies and costs of CO <sub>2</sub> capture, transport and storage for Ireland with state-of-the-art technology descriptions.
2.	An assessment of the role of fault stability on CO <sub>2</sub> storage capacity.
3.	An assessment of Ireland's potential for mineral carbon capture.
4.	A design of a nationwide CO <sub>2</sub> supply chain.

## 2.4 Summary of Key Outcomes and Impacts

### *Outcome 1: TEA model for CO<sub>2</sub> capture with variable capacity factor*

The model outlined in Figure 1 identified the cost of CO<sub>2</sub> capture using MEA solvent from CCGT (Combined Cycle Gas Turbine) power plants with varying capacity factors or full load hours. This model combined a detailed thermodynamic representation of the CCGT power plant, including calculations of energy penalties from the capture plant, CO<sub>2</sub> emissions, and monoethanolamine (MEA) solvent usage, with a techno-economic analysis focusing on the calculation of the levelized cost of CO<sub>2</sub> capture (LCOC) and the levelized cost of electricity (LCOE) with CO<sub>2</sub> capture.

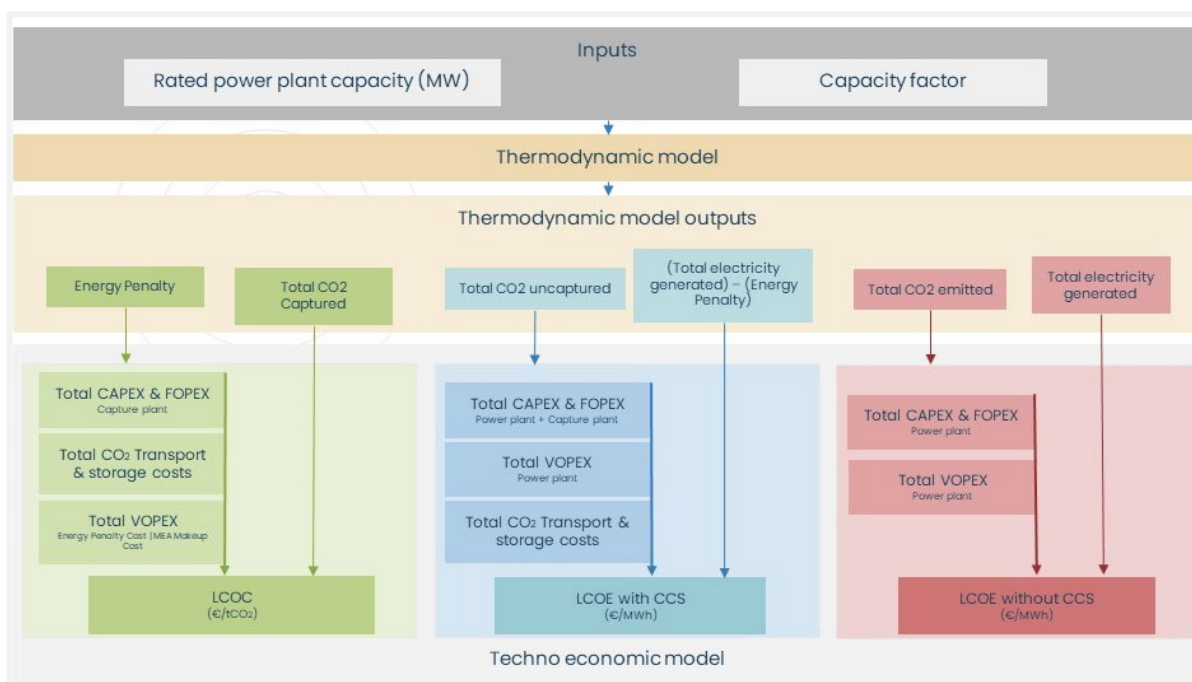


Figure 1: Flow diagram of CCUS techno-economic model

### Outcome 2: Dependence of CO<sub>2</sub> capture cost and electricity cost on CCGT capacity factor

The findings showed that as CCGT capacity factors decreased, due to VRE expansion, CO<sub>2</sub> capture costs rose significantly, as shown in Figure 2, which had a strong impact on the LCOE for the CCGT. For example, the model indicated that at 70% CCGT capacity factor and NG price of 50 €/MWh, a CO<sub>2</sub> emission price of around ~170 €/tCO<sub>2</sub> was needed for the LCOE with CCS to remain lower than without CCS. At 30% CCGT capacity factor, this figure was over 300 €/tCO<sub>2</sub>. Higher NG prices required even greater CO<sub>2</sub> prices to sustain cost-effectiveness.

**Impact:** It is evident from this outcome that decarbonizing natural gas power plants using CO<sub>2</sub> capture is economically unviable at lower operational hours. This outcome necessitates exploring alternative energy sources for powering backup power plants. These alternatives can include green hydrogen-powered CCGTs and hydro battery systems, where dedicated water reservoirs are used to manage fluctuating power demand in high VRE power systems.

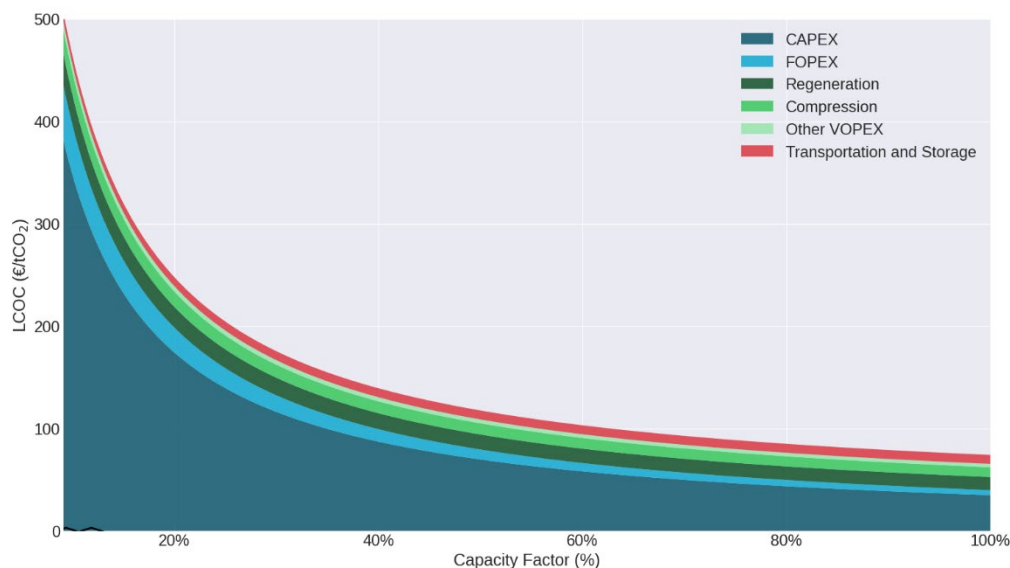


Figure 2: Levelised cost of CO<sub>2</sub> capture from a CCGT as a function of capacity factor

### Outcome 3: Need for more comprehensive datasets potential offshore storage reservoirs

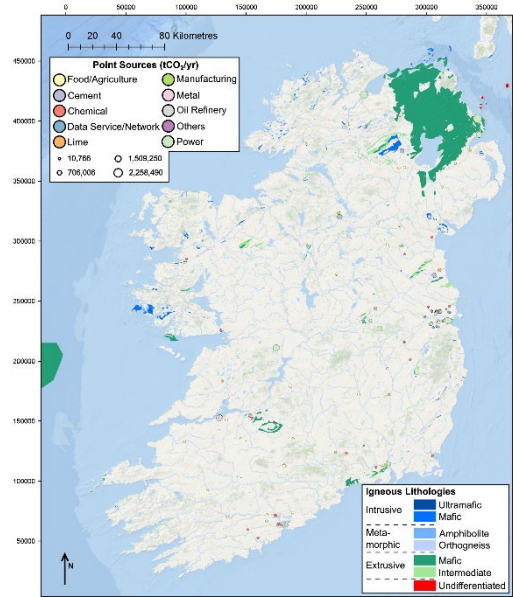
Research in WP2 revealed that fault stability for faults bounding potential offshore CO<sub>2</sub> storage sites in the Irish Sea will be very sensitive to any CO<sub>2</sub> injection that creates changes in the in-situ stress state. Specific fault orientations were found to be highly unstable across all tested potential stress states for the tested region of the Irish Sea. However, conducting this research has also revealed that existing Irish Sea offshore datasets are not adequate to refine such analyses further, and lack specific datasets such as borehole image logs, and geological mechanical data that would be required to reduce uncertainty around future CO<sub>2</sub> injection near faulted storage sites in the Irish Sea. Future CO<sub>2</sub> storage in the offshore Irish subsurface will require the careful acquisition of key datasets that will allow the derisking of any such industrial development of this technology.

**Impact:** This outcome should have significant impact on the future development of offshore CO<sub>2</sub> storage development in subsurface aquifers. The finding shows that faults are likely to be very sensitive to CO<sub>2</sub> injection, potentially moving because of CO<sub>2</sub> injection, increasing the risk of injected CO<sub>2</sub> leaking into shallower levels of the crust, away from the targeted storage site. Any development of Irish offshore storage sites by industry or government should conduct a robust fault stability analysis of the structures in and around their targeted storage sites to better constrain the amount of CO<sub>2</sub> that can be safely injected and stored, and what rates of injection as safe. Further impact from this outcome stems from the discovered scarcity of appropriate data with which to do adequate fault ability analyses, meaning any development of offshore CO<sub>2</sub> storage sites may need to perform new data collection to perform such studied prior to any injection. This may be a long and expensive process which could discourage industry development or investment in such endeavours.

**Outcome 4: The identification of potential reservoirs for mineral carbonation in Ireland**

Across the island of Ireland, 29 groups of geological formations were identified to have suitable lithologies for CO<sub>2</sub> storage via mineral carbonation, as shown in Figure 3. Of these, five reservoirs (Antrim Lava Group (ALG), Connemara Metagabbro and Gneiss Formation, Carlingford Complex, Tyrone Plutonic Complex and Dawros-Currywongaun-Doughruagh Complex) scored highly and are recommended for future consideration. The ALG is the largest and most suitable reservoir, capable of storing emissions from several utility-scale power plants.

Figure 3: map of feasible rocks for mineral carbonation



**Outcome 5: The importance of Ca-bearing zeolites in Irish basalt for CO<sub>2</sub> mineralisation**

Secondary mineralisation of zeolites has almost completely filled the pore space of basalt samples from the ALG in Northern Ireland. This will have a profound effect on the CO<sub>2</sub> storage capacity, unless the zeolites can be dissolved during injection. The primary zeolite phases were chabazite-Ca, chabazite-Na, and thomsonite. Because the identified zeolites are Ca-bearing, they might act as valuable reactants during mineral carbonation. Figure 4: shows a sample of EDS analysis results.

**Impact:** This outcome outlines the importance of zeolites for mineral carbonation reaction kinetics. Zeolites could be considered ‘make or break’ for the usage of the Antrim Lava Group for mineralisation of CO<sub>2</sub> as successful dissolution will provide important Ca<sup>2+</sup> for the reaction as well as create pore space for mineralisation. If zeolite dissolution does not occur, fluid pathways in the basalt might be limited, a major limitation for CO<sub>2</sub> mineralisation. Therefore, a separate PhD project was proposed to ascertain the outcome of fluid kinetics in a zeolite-rich basalt, with specific focus on the Antrim Lava Group, as this is the largest mafic reservoir in the British Isles. Whole-rock mineral dissolution experiments using multi-phase rock samples from the ALG (containing zeolites) are suggested to be a potential methodology for this. This PhD

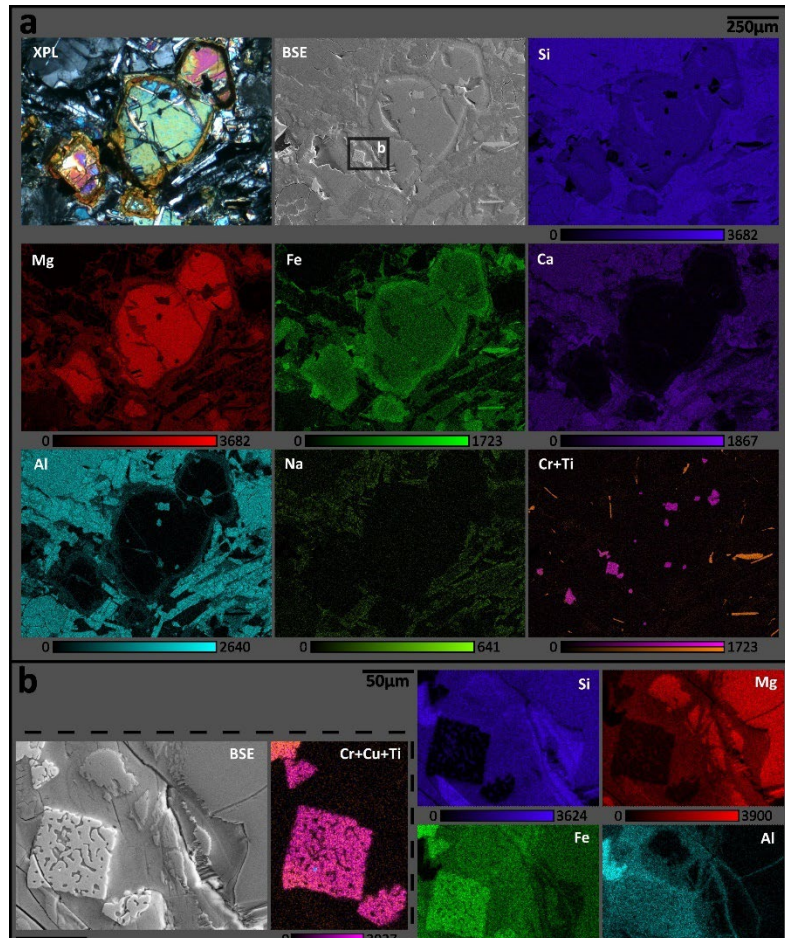


Figure 4: EDS analysis of candidate rock type.

has since been successfully funded via collaboration between the University of Liverpool and a new start-up company in Northern Ireland, Carbonation Ltd that will explore this impact further and expand the research on this potential carbon storage technology in Northern Ireland. The PhD began in Oct 2024, with Jonathan Alexander, the Geology MSc in the SEAI project as the candidate.

**Outcome 6: Options for long-term sequestration of CO<sub>2</sub> via utilisation are extremely limited**

When evaluating the options for utilization of CO<sub>2</sub>, the demand for CO<sub>2</sub> in concrete curing appears to be very low in comparison to total emissions. It was estimated that this quantity constitutes approximately 0.4% of total emissions. With around 50 concrete production sites on the island of Ireland, transporting small quantities of CO<sub>2</sub> to these sites incurs large costs and does not significantly impact emission reduction targets.

**Impact:** The low potential CO<sub>2</sub> demand in concrete production, at 0.4% of total emissions, highlighted its limited contribution to emission reduction targets. Transporting CO<sub>2</sub> to 50 dispersed sites in Ireland was found to be logistically inefficient, necessitating a focus on permanent storage.

**Outcome 7: Creation of a CCUS supply chain model for Ireland**

The project developed a supply chain model for CCUS to analyse the costs associated with transporting and storing CO<sub>2</sub> from Ireland's stationary emission sites, particularly those in hard-to-abate sectors. This model mapped and optimized the supply chains for CO<sub>2</sub> through case studies for the island of Ireland, exploring several scenarios. It identified capture costs, the most effective transportation methods, and storage options. The supply chain model incorporated several techno-economic sub-models, including CO<sub>2</sub> capture cost models, onshore transportation sub-models for both trucking and piping, and offshore transportation models for both piping and shipping.

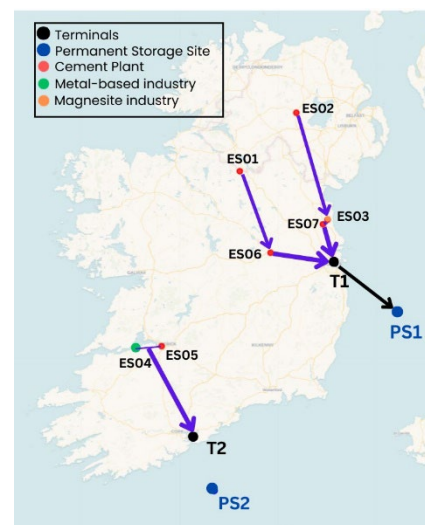


Figure 5: Optimal CCUS supply chain for Ireland.

**Outcome 8: Importance of planned and informed infrastructural deployment**

The findings emphasised the importance of carefully selecting capture sites before developing full-scale CCUS infrastructure. For instance, in a case study for a cement plant, a 26% reduction in shared infrastructure costs and an overall 5% reduction in the operating costs were achieved when shared infrastructure, such as terminal conditioning system, offshore piping, and storage was built at a single location (Scenario 6) for large-scale emitters with long-term CO<sub>2</sub> supply certainty (x.3 sub-scenarios). This contrasted with infrastructure initially built to include CO<sub>2</sub> from power plants, from which CO<sub>2</sub> supply eventually ceased (x.1 sub-scenarios).

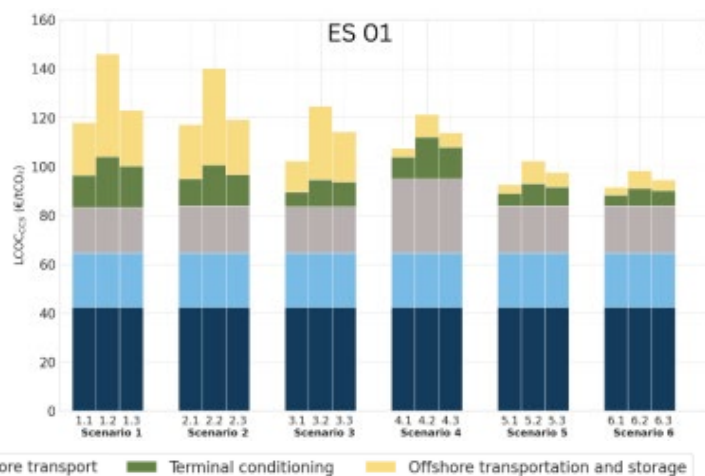


Figure 6: Full cost of CCUS for a cement plant with different assumptions for supply chain design

**Impact:** The key impact of this outcome is that it demonstrates how careful, strategic selection of CO<sub>2</sub> capture sites can lead to substantial cost savings and improved long-term efficiency of CCS infrastructure. It advocates for a more targeted approach in developing CCS systems.

## 2.5 Recommendations

1. An interdepartmental Governmental Working Group on CCUS should be established to begin the process of institutional learning necessary to fully understand the potential roles of CCUS in the future energy system of Ireland.
2. To enable cost-effective CO<sub>2</sub> capture at dispatchable fossil fuel power plants with low capacity factors, it is important to ensure a sufficiently high price on unabated CO<sub>2</sub> emission to make CCS competitive. Furthermore, low natural gas prices, reductions in capture plants capital costs, and improvements in capture system efficiency play important roles in enhancing the economic viability of CCS.
3. Offshore CO<sub>2</sub> storage in Ireland needs to be derisked beyond the calculation of potential storage properties and volumes of target reservoirs. Research from this project highlights significant risk to fault stability in an area of the Irish offshore that has implications for how much and how fast CO<sub>2</sub> can be injected for storage there. Such research is needed for all existing potential Irish offshore CCS sites, which currently has not been done. Specific aspects of this recommendation are:
  - 3.1. A full assessment of the Irish offshore stress state using existing datasets is required to understand the existing stress state prior to any CO<sub>2</sub> injection for storage, and to highlight gaps in data needed, relevant to prospective storage sites.
  - 3.2. Depth-converted 3D fault models are required for all potential offshore CO<sub>2</sub> storage sites to fully analyse their potential behaviours under potential stress states during and after CO<sub>2</sub> injection.
4. Build on initial findings on CO<sub>2</sub> storage by carbonation. Following the preliminary petrological and chemical characterisation, which is classified as stages L1 and L2 by CarbFix, a more in-depth study of the ALG is recommended as WP3 identified potential feasibility for this rock reservoir. An L3 feasibility study should be implemented, including in-depth rock-fluid reactivity studies and modelling, geochemical modelling, and a socio-economic and technical assessment.
5. Cooperate with UK CCS projects in progress and UK research efforts to better inform and derisk Irish storage potential, both offshore and onshore. Irish stakeholders should partner with advanced UK CCUS projects, including the HyNET and Teesside Net Zero projects.
6. Building upon EU RFNBO regulations that increasingly support the use of CO<sub>2</sub> emissions from non-renewable sources, future research should examine viable CO<sub>2</sub> utilisation pathways, such as large-scale chemical or fuel production. It should be noted, however, that such short-term utilisation of CO<sub>2</sub> does not avoid its emission to the atmosphere, but it does help early-stage sectoral development by creating a high-value demand for captured CO<sub>2</sub>.

## 2.6 Conclusions and Next Steps

The conclusions of this study are: (1) CCUS has a role to play in moving from the 51% emissions reduction target of 2030 to the 2050 net-zero vision, especially in the hard-to-abate sectors of dispatchable backup power generation, cement, alumina and oil refining, and food production; (2) CO<sub>2</sub> capture at power plants in Ireland will be more expensive than literature indicates due to the low capacity factors expected in an electricity system dominated by variable renewable electricity; (3) there is a lack of measured data on the suitability of geological structures in the Irish offshore setting; (4) early

indications are that there are suitable geological structures for mineral carbonation storage of CO<sub>2</sub> on the island of Ireland, but much work is needed to quantify this potential; (5) export of CO<sub>2</sub> for storage in other countries adds significantly to the cost of CCUS; (6) limited opportunities exist for cost-effective utilisation of fossil-derived CO<sub>2</sub> in long-lived materials in Ireland; and (7) planned and data-informed design of truck- and pipeline-based CO<sub>2</sub> supply chains is extremely important given Ireland's generally small scale and geographic spread of emitters. The next steps advised for assessing the feasibility of CCUS in Ireland are outlined in the Recommendations section above.