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Markets & Mandates

Policy Scenarios for UK CCS Deployment & Exploring the Role of a Carbon Takeback Obligation

Carbon Balance Initiative

CCSA

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About this Report

This report is the output of a collaboration between the Carbon Balance Initiative, Oxford Net Zero and the Carbon Capture and Storage Association (CCSA). The report was published on 21 January 2025.

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Project Partners

Oxford Net Zero (ONZ)

Oxford Net Zero is an interdisciplinary research initiative based on the University of Oxford's fifteen years of research on climate neutrality. Our research fellows are working to track progress, align standards and inform effective solutions in climate science, law, policy, economics, clean energy, transport, land and food systems and Carbon Dioxide Removal.

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Carbon Balance Initiative is an NGO initiative born out of the University of Oxford. We strive to put conditions on fossil fuel extraction to protect the climate from any remaining fossil fuel use. We work with the climate movement, academia and policymakers to achieve 1.5°C, store carbon, and protect nature.

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The CCSA is the leading European association accelerating the commercial deployment of carbon capture, utilisation, and storage (CCUS). The CCSA represents the interests of their members and works with members, governments, and other organisations to ensure CCUS is developed and deployed at the pace and scale necessary to meet net zero goals and deliver sustainable growth across Europe.

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Executive Summary

The 'Markets & Mandates' project was initiated in response to calls from government and industry, including the Department of Energy Security and Net Zero (DESNZ)[1] and the CCUS Council[2] to explore long-term policy options for catalysing investments in carbon storage.

In particular, this project responds to an interest in exploring carbon storage mandates such as a Carbon Takeback Obligation (CTBO)[2]. It considers current government policy for carbon storage deployment, as well as potential long-term policy options that include a carbon storage mandate. It does not seek to evaluate the effectiveness of CTBO in comparison to alternative additional policy tools.

Achieving the UK's net zero emissions target by 2050 is crucial for mitigating climate change and meeting our Paris Agreement commitments. As demonstrated by the IPCC and the UK Climate Change Committee scenarios, alongside rapidly reducing fossil fuel use, permanent geological carbon storage – using carbon capture and storage (CCS) and greenhouse gas removal (GGR) technologies – will be required for any remaining CO_2 emissions at the time of net zero[3,4]. The UK has declared ambitions to store at least 50 megatonnes of carbon dioxide annually by the mid-2030s, positioning itself as a global leader in carbon storage[1]. To achieve this, the Department for Energy Security and Net Zero (DESNZ) has committed £21.7 billion to CCS[5] and outlined a comprehensive vision for Carbon Capture, Usage, and Storage (CCUS)[1]. This vision is anchored in establishing a commercial and competitive UK CCS market, with a focus on reducing the degree of government support needed. Achieving the UK's carbon storage ambitions will require a well-designed policy mix that can operate in and adapt to a rapidly changing global environment.

This 'Markets & Mandates' report examines the benefits and risks of selected policy scenarios for stimulating CCS deployment in the UK, grounded in a scenario analysis and extensive stakeholder input. This includes evaluation of a scenario predominantly centred around the current government-led revenue support package for CCUS and the UK Emissions Trading Scheme (ETS), inspired by the DESNZ CCUS Vision[1]. The report then introduces a scenario that includes a carbon storage mandate, specifically a Carbon Takeback Obligation (CTBO), in addition to the current policy suite. A CTBO would require obligated entities, such as fossil fuel producers and importers, to store (or pay third parties to store) a rising percentage of the CO_2 embedded in their fossil fuel products. Such a mandate could be designed to complement existing policy instruments to help drive investment in carbon storage and transition to a long-term mature and subsidy-free CCS market.

The report also explores different potential carbon mandate implementation options. It provides an extensive overview of CTBO policy design choices and potential interaction effects with other policies, including a discussion of potential impacts of a unilateral application.

This project does not represent CTBO as a 'magic bullet' solution and emphasises that a comprehensive policy approach is key to achieving decarbonisation. The research identifies potential benefits and risks of relying only on the current policy suite, and of implementing a CTBO alongside current polices. While not an exhaustive study, it provides an initial assessment based on a scenario analysis and stakeholder input, and highlights where additional research and analysis is required.

Recommendations for Policymakers

Although further quantitative work is needed, the analysis suggests that the current ETS system alone is unlikely to drive sufficient carbon storage development in the UK in the medium to long term. Furthermore, it suggests that supplementing market-based mechanisms with a potential carbon storage mandate could enhance the UK's ability to meet its carbon storage ambitions and strengthen its global leadership in achieving net zero, provided this would be designed to avoid potential risks to developing a self-sustaining CCS market, such as declining UK competitiveness and carbon leakage.

This analysis should be supported by further stakeholder engagement and research, including an exploration of all potential consequences of implementation and additional policies that could be implemented alongside the current policy suite.

As next steps, this report recommends that government should:

1. **Define clear objectives and metrics:** Further develop the DESNZ CCUS Vision by establishing success criteria with clear metrics for any future CCS policy mixes to objectively track progress towards the Vision.
2. **Identify gaps in the current policy mix:** Build on existing research to identify potential gaps in the ability of the current UK CCS policy suite to meet the identified objectives, and discern what supplementary policy instruments should aim to achieve in the short-, medium- and long-term.
3. **Conduct a quantitative assessment:** Evaluate the potential climate, economic, and social implications of different policy mixes, including scenarios implementing a CTBO or other mandates, through a quantitative assessment. This assessment should make clear and credible assumptions on scenario timelines and policy design choices. It should stress-test policy mixes under various exogenous and endogenous conditions, as well as look at factors that include UK competitiveness, carbon leakage effects, and potential interaction effects between different policies.
4. **Engage stakeholders:** Maintain continual dialogue with stakeholders to refine policy design and address outstanding questions and concerns.

Report Outline

The report is divided into two parts. **Part 1** assesses two core CCS policy mix scenarios, while **Part 2** provides an in-depth analysis of the options for carbon storage mandate implementation and design.

Part 1: Policy Scenarios

Based on stakeholder input, **Part 1** evaluates benefits and risks of different CCS policy scenarios. In line with the DESNZ CCUS Vision[1] and inspired by the CCSA Delivery Plan[6], each scenario considers a policy suite that transitions across three phases from 'market creation' (2020-2030), to 'market transition' (2030-2035) to a 'self-sustaining market' (2035 onwards). The evaluation of each scenario was grounded in the DESNZ success criteria outlined in the Vision document, stakeholder input from workshops and interviews, and an original analysis of potential policy outcomes based on previous research.

1. 'Base Case' Scenario

The 'Base Case' scenario is defined as a transition from a government-led subsidy regime utilising multiple sectoral business models under the CCUS Cluster Sequencing Programme to a market-led regime under the UK Emissions Trading Scheme (ETS).

Scenario analysis and stakeholder input suggest that, while this should kickstart the CCS market and offer potential economic opportunities, relying solely on an ETS could carry significant risks to long-term deployment. The analysis indicates that a market-led ETS alone may not be sufficient to drive timely storage capacity development, risking a failure to achieve the UK's net zero targets, carbon price surges, or a continuing requirement of government subsidies for longer than intended.

2. 'Base Case+' Scenario

The 'Base Case+' scenario goes beyond the 'Base Case' scenario by introducing a carbon storage mandate, specifically a form of a CTBO, alongside the ETS. In this scenario, a carbon storage mandate would be implemented in parallel with government revenue support packages (such as contracts-for-difference) and the ETS, between 2030-2035.

This is envisioned to start with a small storage fraction to foster investor confidence, enabling government and industry to progressively adapt and iterate as the stored fraction rises.

The Base Case+ scenario also briefly considers the potential impact of implementing a low-carbon product standard (LCPS) or low-carbon fuel standard (LCFS).

Results of the research suggest that a CTBO and ETS could work in tandem to boost CCS investor confidence, ensure storage development aligns with net zero requirements, and accelerate the energy transition. The overall impact on the investor climate needs further investigation. Many stakeholders appreciated the potential stability and robustness of this mixed approach. Risks were also identified, with some stakeholders expressing concern about an over-reliance on abated fossil fuels and unintended consequences of a mismatch between supply and demand. Other stakeholders underscored the risk of adverse economic impacts on consumers and producers, citing competitiveness and carbon leakage concerns. These risks would need to be addressed through careful consideration of policy design choices and design and a consideration of the broader domestic and global climate policy landscape.

Part 2: Implementation of Carbon Storage Mandates

Part 2 explores the operationalisation of carbon storage mandates, particularly the CTBO. It introduces a novel typology for carbon storage mandates and outlines three core principles that underpin the CTBO in the scientific literature – a progressive transition to permanent storage, the principle of 'producer responsibility', and the need for a comprehensive climate policy suite to achieve net zero.

Part 2 also discusses the five policy design decisions that would need to be made for a CTBO to be implemented: the stored fraction design, obligation placement, technology and location accreditation, governance mechanisms, and interactions with other climate policies, including with the ETS, government revenue support packages, and other climate regulations.

Scope of the Research

The report focuses on carbon storage mandates, particularly the CTBO, as one option in the CCS policy toolkit. It does not dismiss other market or mandate mechanisms that could be used to supplement the CCS policy mix, including reforms to the ETS. Limitations include a lack of detailed analysis on voluntary carbon markets, as well as on international dimensions, such as interactions with the global climate policy landscape, cross-border CO_2 transport, and export-import dynamics. The study does not fully examine the economic implications of unilateral implementation of a UK-specific policy framework, including potential effects on UK industry competitiveness (both domestically and on export markets) and the investment climate. The assessments are qualitative, recognising the need for further quantitative research. UK-specific policies must account for the role of industrial decarbonisation strategies in achieving net zero goals whilst considering impacts on competitiveness, carbon leakage risks, energy costs, and energy security.

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Abbreviations

BECCS	Bioenergy with Carbon Capture and Storage
CBAM	Carbon Border Adjustment Mechanism
CCC	The Climate Change Committee
CCS	Carbon Capture and Storage
CCSA	Carbon Capture and Storage Association
CCUS	Carbon Capture, Utilisation and Storage
CfD	Contracts-for-Difference
CO_2	Carbon Dioxide
CRO	Carbon Removal Obligation
CSUs	Carbon Storage Units
CTBO	Carbon Takeback Obligation
DACCS	Direct Air Capture (DAC) and Carbon Storage
DESNZ	Department of Energy Security and Net Zero
EPR	Extended Producer Responsibility
ETS	Emission Trading Scheme
EU	European Union
GHG	Greenhouse Gases
GGR	Greenhouse Gas Removal
GNZ	Geological Net Zero
IAM	Integrated Assessment Model
ICO	Injection Capacity Obligation
IPCC	Intergovernmental Panel on Climate Change
LCFS	Low-Carbon Fuel Standard
LCPS	Low-Carbon Product Standard
$MtCO_2$	Megatonnes of CO_2
MRV	Monitoring, Reporting and Verification
NGO	Non-Government Organisation
NSTA	North Sea Transition Authority
NZIA	Net Zero Industry Act
Ofgem	Office of Gas And Electricity Markets
R&D	Research and Development
R&I	Research and Innovation
SAF	Sustainable Aviation Fuel
SDE++	Stimulation of Sustainable Energy Production and Climate Transition (Dutch CfD)
T&S	Transport and Storage

1. Introduction

1.1. Pioneering CCS: UK Policy Options to Reach Net Zero

Addressing the climate crisis is an urgent priority for the United Kingdom and requires reaching net zero CO_2 emissions by 2050. The Paris Agreement commits the UK to contribute to limiting global warming to below 2.0°C while pursuing efforts to limit warming to 1.5°C. Domestically, the legally binding Climate Change Act mandates reaching net zero by 2050[7]. Achieving this goal necessitates significant emission reductions across all sectors of the economy, including a rapid transition away from fossil fuel production and consumption towards low-carbon energy sources[3,8]. Safeguarding UK competitiveness and energy security whilst driving domestic emission reduction and a rapid energy transition will be crucial.

Permanent capture and storage of CO_2 is deemed essential to achieving net zero by 2050, as emphasised by both the UK's Climate Change Committee (CCC) and the Intergovernmental Panel on Climate Change (IPCC)[3,8]. Even with aggressive mitigation efforts, reaching net zero by 2050 will require scaling up geological carbon storage – using point-source carbon capture and storage (CCS) and greenhouse gas removal (GGR) technologies – for any remaining residual emissions. Although the exact amount of CCS and GGR that will be needed is uncertain and depends on wider fossil fuel demand reductions[9], the CCC's sixth carbon budget underscores that CCS is a "necessity, not an option" for reaching net zero by 2050[4].

The UK has demonstrated global leadership in climate policy and setting carbon storage targets. The UK was the first country to legislate a legally binding net zero target and publish a dedicated Industrial Decarbonisation Strategy[10]. Guided by CCC figures, the strategy sets out CCS ambitions to capture 20-30 $MtCO_2$ per year by 2030 and store at least 50 $MtCO_2$ per year by the mid-2030s[1,11]. To put this in perspective, total emissions from UK power stations in 2020 were also around 50 $MtCO_2$[12], implying that the UK must establish an entirely new industry, comparable in carbon terms to the current power sector, in less than two decades[13].

The growth of the CCS sector also presents economic opportunities for the UK. Analysis by the CCSA shows that, by realising an estimated storage capacity of 78 billion tonnes of CO_2 in the North Sea[1], the UK could create around 70,000 new jobs and retain 77,000 existing ones, as well as drive investment into industrial heartlands[6]. This can be seen in the £1 billion of private capital invested in industrial clusters so far, with a further £40 billion of investment projected by 2030[6].

To catalyse this growth and meet storage ambitions, the government has committed at least £21.7 billion in subsidy support. To kick-start the CCS industry in the UK, the Labour government committed £21.7 billion of government support for the two 'Track-1' clusters – East Coast and Hynet – in October 2024[5]. This aligns with the DESNZ CCUS Vision, which lays out the ambition of deploying two 'Track-1' and two 'Track-2' industrial cluster locations by 2030[2,6]. Funding for CO_2 capture is expected to be provided through business models developed with industry based on a contracts-for-difference (CfD) structure, as well as other support mechanisms for de-risking capital investment into transport and storage[2,6].

However, the rapidly evolving economic and policy landscape limits the scope for further government subsidy. Global competition for CCS investments, fiscal constraints, and economic uncertainty limit the government's ability to provide long-term support for the CCS industry. To maintain momentum and meet UK storage ambitions, policymakers and industry must create a self-sustaining CCS market. This requires urgent private investment, with some estimates suggesting a need for a minimum of £30 billion by 2030[14]. The creation of this self-sufficient sector must align with the economy-wide transition to net zero, taking into account concerns of mitigation deterrence, costs to UK industry and consumers, industrial competitiveness, carbon leakage, and energy security issues.

Concerns have emerged about the ability of existing market-led mechanisms to create a self-sustaining sector[2,15]. The DESNZ Vision for CCUS, published in December 2023, outlines the ambition of establishing a long-term "commercial and competitive" market for carbon storage based on the Emission Trading Scheme (ETS) mechanism[1]. As the CCUS market develops, the government expects a number of policies to play an increasingly important role in supporting CCUS investment. In the event of the ETS acting as the main driving factor for CCUS deployment, however, the sector is likely to be exposed to various risks, including low confidence in the ETS. For example, a 2023 survey found that three-quarters of CO_2 capture project developers do not foresee deploying CCS if incentivised solely by the ETS[6,16].

This underscores the urgent need to explore additional policy tools to complement existing strategies, including carbon storage mandates. To supplement the existing policy mix, carbon storage mandates, such as a Carbon Takeback Obligation (CTBO) - which would require obligated entities such as fossil fuel producers and importers to permanently store the CO_2 emissions associated with their operations and products - have emerged as potential mechanisms to support the creation of a self-sustaining carbon storage market and meet net zero goals.

1.2. The Markets & Mandates Project

The 'Markets & Mandates' project commenced in September 2023 and is a collaboration between the Carbon Capture and Storage Association (CCSA), Oxford Net Zero at the University of Oxford, and the Carbon Balance Initiative. The project was initiated in response to various government and industry bodies calling for the policy development of long-term deployment mechanisms for CCS, and particularly for further investigation into the potential of a carbon storage mandate[1,2,17].

As a first-of-its-kind project on carbon storage mandates in the UK, the project consisted of a scenario analysis and two workshops - one in the UK (February 2024) and one at COP28 (November 2023) - which resulted in a short policy brief. The workshops brought together a diverse group of stakeholders from government, regulators, industry, and NGOs. This report represents the flagship deliverable of the project, providing a comprehensive summary of findings and recommendations to UK policymakers.

Net Zero and Geological Net Zero

0.1%

Current Geological Stored Fraction

The UK's Independent Review of Net Zero[17] highlights the necessity of reaching not just 'net zero' emissions, but achieving "Geo Zero", or geological net zero. This is a state in which any residual carbon emissions from fossil fuel sources are balanced by permanent geological carbon storage, rather than solely relying on less permanent nature-based carbon offsets[18-20].

Research by Oxford Net Zero highlights reaching geological net zero is essential for durably stabilising temperatures[18-21]. Reaching geological net zero requires storing a rising fraction of CO_2 produced from fossil sources. Current geological storage is only 0.1% of global CO_2 production, whereas models indicate this will need to reach a minimum of 100% by mid-century[22].

1.2.1 Context & aims

This project responds to a growing interest in carbon storage mandates within the UK and the EU, including the recommendation in the Independent Review of Net Zero[17] and the landmark carbon storage injection capacity obligation (ICO) on EU oil and gas production licence holders enacted in the EU's Net Zero Industry Act in 2024[23]. It builds on recent research from the University of Oxford and others that highlight the potential of a Carbon Takeback Obligation to address gaps in current climate policy by stimulating storage demand in the short term and acting as a 'backstop' to other net zero policies in the long term while shifting CCS costs from government to industry and fossil fuel consumers[22].

This project aims to drive further policy development on future CCS policy mixes, particularly carbon storage mandates. By combining desk-based research, analysis, and diverse stakeholder input, it explores the potential benefits and risks of two future policy scenarios for scaling CCS in the UK, with an additional focus on design choices around carbon storage mandates, specifically the CTBO. It also intends to lay the groundwork for a quantitative study in 2025 on mixed market-mandate policy scenarios.

1.2.2 Research questions & methodology

The project was guided by three research questions:

1. What are the key themes and desired outcomes for evaluating a CTBO in the context of future fossil fuel decarbonisation and CCS policies?
2. How could mandate policies such as the CTBO interact with and compare to other relevant policies and market drivers in different future policy scenarios?
3. How could mandate policies be practically implemented in the UK?

These questions were assessed using a combination of qualitative research methods, including a literature review and analysis, stakeholder workshops, and one-on-one interviews. For the purposes of the research, several stakeholders were interviewed at length, including representatives from the Department of Energy Security and Net Zero, the North Sea Transition Authority, the Climate Change Committee, the Crown Estate, industry actors, and NGOs. Further details on the methodology and organisations involved in this project can be found in **Annex A**.

1.2.3 Scope & limitations

This study has several limitations. It focuses primarily on policy mechanisms for scaling carbon capture and geological carbon storage, particularly for those emissions captured by point-source technologies and greenhouse gas removal (GGR) technologies relying on CCS infrastructure, such as direct air capture and storage (DACCS). It does not assess other permanent carbon sequestration technologies such as remineralisation or their supply chains. The report predominantly addresses the development of a self-sustaining CCS value chain within the UK, with international aspects only considered where relevant to UK policy. It therefore does not provide a detailed analysis of carbon leakage, export-import dynamics, or cross-border CO_2 transport. Details on the international component of this project can be found in the COP28 briefing and COP28 roundtable review.

The report explores carbon storage mandates, focusing on the CTBO as one option in the CCS policy toolkit. It does not suggest that CTBO is the only mandate policy that should be considered, nor that market mechanisms should be disregarded in favour of a CTBO. The report does not consider all policy tools available, nor seek to compare the CTBO to other policies not discussed in the report, such as a carbon tax or other forms of carbon pricing. It also does not address the role of voluntary carbon markets.

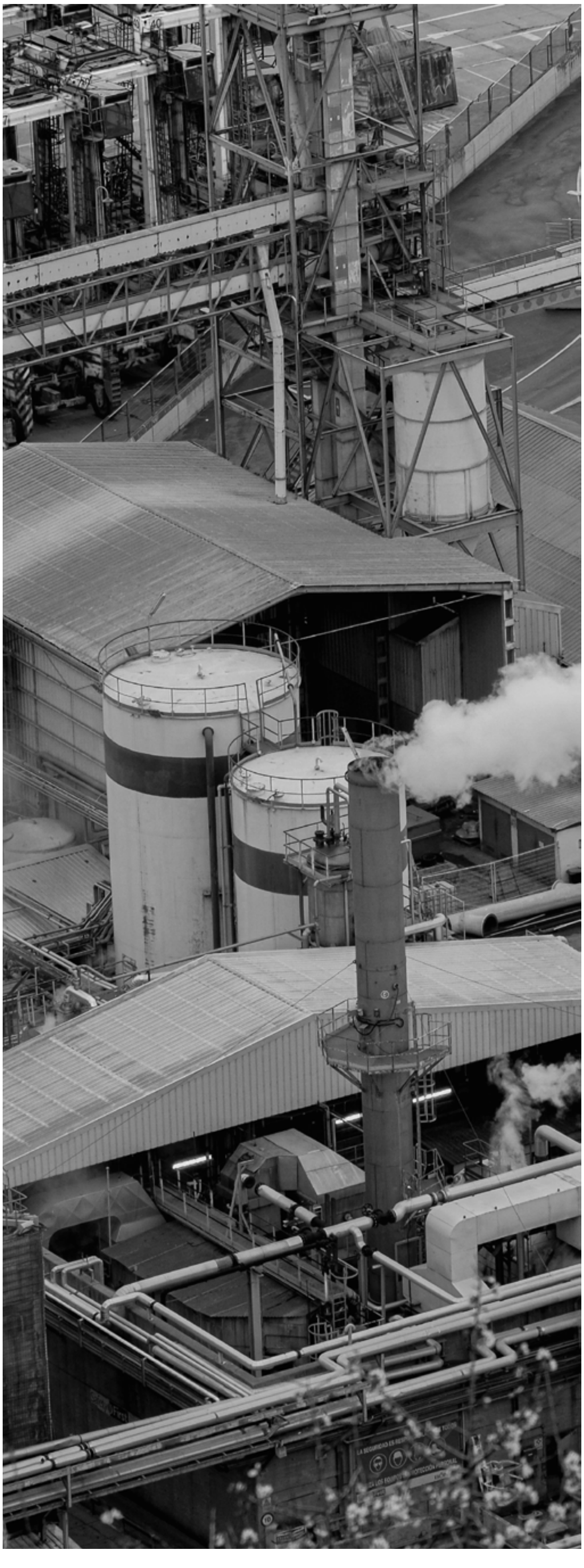
The report acknowledges that policy and research gaps on the CTBO and similar instruments exist, and thus it identifies areas where future work is needed. The assessments in the 'Markets & Mandates' report are qualitative. Quantitative evaluations of the impact of different policy mixes are beyond its scope, and will be addressed in future work.

1.2.4 Outline

This report is structured in two parts.

Part 1 focuses on a scenario evaluation of different future policy mixes. Section 2 introduces a typology of policy mixes available for stimulating CCS, and outlines the three core policy mechanisms utilised in the UK context. Section 3 details the criteria and methodology for evaluating different policy mixes. Sections 4 and 5 assess the benefits and risks of two potential policy scenarios: Section 4 covers the current ‘Base Case’ scenario, which transitions from a government-led to market-led approach, and Section 5 covers the ‘Base Case+’ scenario in which the ‘Base Case’ policy scenario is supplemented with an economy-wide CTBO. Additionally, a variant of the ‘Base Case+’ scenario – in which the ‘Base Case’ is supplemented with a sector-specific CTBO akin to a Low Carbon Product Standard (LCPS) or Low Carbon Fuel Standard (LCFS) - is briefly discussed in Section 5.3.

Part 2 dives deeper into carbon storage mandates and key implementation considerations. Section 6 provides an overview of carbon storage mandates in the context of climate policy, as well as the key principles, building blocks, and outcomes of a CTBO. Section 7 provides a comprehensive overview of design choices for CTBO implementation. Finally, Section 8 offers recommendations for future work.



Part 1

Policy Scenario Evaluation

Assessing policy options to scale CCS deployment in the UK

2. Policies to Drive CCS Deployment

2.1. Overview of CCS Policy Tools

A broad range of policies can be used to stimulate the deployment of carbon storage. This report introduces a novel 'triangle' typology to categorise these policy options. As illustrated in **Figure 2.1** and **Table 2.1**, we categorise policies based on their primary driving force: **Government-led policy** (shown in orange); **Demand-side market-led policy** (shown in green); and **Supply-side mandate-led policy** (shown in blue). Examples of each category, such as a market-led Emissions Trading Scheme (ETS)[24] or a mandate-led low-carbon fuel standard (LCFS)[25], are indicated on the diagram. Although other policy taxonomies exist[26–29], we focus on this typology to help simplify the complex policy landscape surrounding CCS deployment.

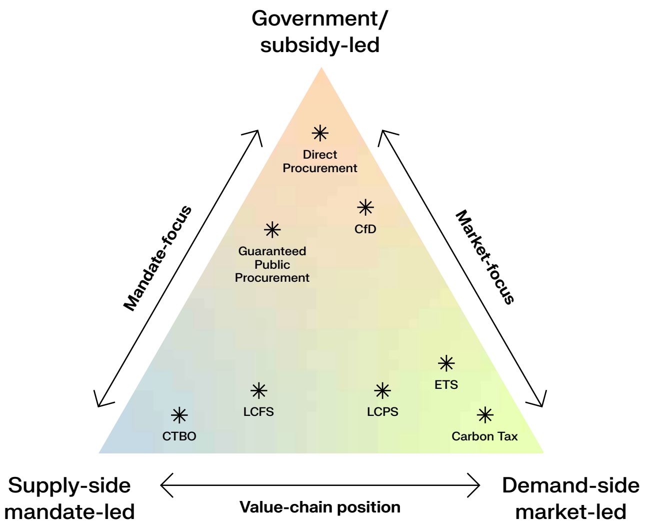


Figure 2.1. Schematic visualising CCS policy space. Corners represent policy categorisations: Government (subsidy-led) policy in orange, Demand-side (market-led) policy in green, and Supply-side (mandate-led) policy in blue. Examples of individual policies are represented by stars.

The three sides of the triangle schematic highlight the three broad axes of the policy space:

→ Market-focus axis: Policies near this axis (i.e. those furthest from the blue mandate-led corner) are designed principally to boost demand for CO_2 storage. These policies range from private sector demand creation policies (e.g. carbon pricing, ETS) to government-led interventions to create a market (orange corner; e.g. direct public procurement[i], tax relief or other subsidy mechanisms, such as contracts for difference).

→ Mandate-focus axis: Policies near this axis (i.e. those furthest from the green market-led corner) primarily aim to increase supply of CO_2 storage through obligations. These range from public sector mandates (e.g. net zero conditions on public procurement) to private sector supply-side mandates (e.g. CTBO, LCFS).

→ Value-chain position axis: Policies near this axis (i.e. those furthest from the orange government-led corner) focus on creating a self-sustaining private-investor-led CO_2 storage sector. The position along this axis indicates the relative placement between the upstream supply-side (left; blue corner) and downstream demand-side (right; green corner).

In practice, these categories often overlap and intersect. For example, mandates can create markets for tradeable Carbon Storage Units (CSUs), while subsidy regimes can operate within competitive frameworks such as timed auctions of contracts or certificates. Examples of such 'hybrid' policies to support CCS are illustratively positioned along the bottom axis of **Figure 2.1**. For instance, the ETS employs a mandated cap on allocated emissions allowances but offers flexibility in compliance methods (e.g. increasing energy efficiency, decreasing fossil fuel use, capturing CO_2, or purchasing additional ETS permits). Thus, it is predominantly a demand-side, market-led mechanism. Low-carbon product/fuel standards (LCPS, LCFS)[ii] are positioned toward the centre,

[i] Direct procurement refers to direct government purchases of CCS and GGR capacity to incentivise market growth and/or align with the UK domestic net zero targets. We note that governments can use methods such as auctions to incorporate an element of market competition.

[ii] LCPS are slightly inclined toward the demand-side market-led axis because mid- and downstream product manufacturers typically do not own or operate CO_2 storage facilities, creating additional demand for storage over time. Conversely, LCFS are slightly inclined towards the supply-side mandate-led axis because fuel suppliers often own and/or operate fuel production and storage infrastructure, thus mandating CO_2 storage deployment as a condition for supplying fuels.

as they set minimum standards for products sold within a jurisdiction, affecting both supply and demand for CO_2 capture and storage. The CTBO is predominantly a supply-side mandate-led mechanism, functioning as a 'licence-to-operate' condition for fossil fuel suppliers within a jurisdiction, while also potentially creating a market for tradeable carbon storage units.

An effective CCS policy that meets decarbonisation goals is likely to utilise different mechanisms at various stages. Initially, market creation may require substantial government support, while a maturing market might benefit from a mix of supply and demand mechanisms to ensure storage delivery. Further descriptions of the key policies in the UK policy mix are presented next in **Section 2.2**.

Table 2.1. Three policy categories to stimulate the CCS market

Category	Description	Examples
Government/ subsidy-led	Direct government intervention providing fiscal or financial incentives to develop CCS facilities or technology.	Direct or indirect government subsidy packages (e.g. Contracts-for-Difference, tax breaks) or government procurement.
Demand-side market-led	Stimulating CCS markets and investment by increasing the demand for CCS technologies and services. These policies target individual sectors or apply economy-wide, either by increasing the price of high-carbon products/ services or by guaranteeing demand for CCS.	Carbon tax or pricing, cap-and-trade structures such as ETS, public and private sector procurement contracts, low-carbon product standards (if set as industry-wide standards on the demand-side of products or services).
Supply-side mandate-led	Stimulating CCS markets by mandating upstream suppliers of high-carbon products to demonstrate investment in/procurement of CCS technologies, to compensate for the carbon generated by their activities and products.	Low-carbon fuel standards, extended producer responsibility frameworks (e.g. CTBO), injection capacity obligations (e.g. EU's NZIA Article 23[23]), low-carbon product standards (if set as industry-wide standards on suppliers of high-carbon products or services).

Notes: Supply-side and demand-side policies are used in this context to separate policies which operate on upstream vs. mid- and downstream companies in the fossil fuel value chain.

2.2. Application of CCS Policy Tools in the UK Context

While acknowledging the wide array of policies available to stimulate CCS, this report focuses on one policy mechanism for each triangle axis that underpin the UK CCS policy landscape: Contracts-for-Difference (government-led); the Emissions Trading Scheme (market-led), and the Carbon Takeback Obligation (mandate-led). An explanation of how these mechanisms function in the UK context is provided below.

2.2.1. Government-led: Contracts-for-Difference (CfD)

The UK government is actively promoting CCS deployment through various subsidy and funding mechanisms designed to mitigate financial risks and attract private investments. Research and innovation (R&I) and research and development (R&D) funding for CCS and GGR are provided through dedicated programs, such as the UKCCS Research Centre[30], the Net Zero Innovation Portfolio[31] and the Industrial Hydrogen Accelerator[32]. Deployment of CCUS projects utilises multiple sectoral business models in the UK[33], with specific UK subsidy schemes for CCS including the Carbon Capture and Storage Infrastructure Fund[34], which supports transport and storage network development, and targeted funding for low-carbon hydrogen production through the Net Zero Hydrogen Fund[35].

The flagship policy framework for incentivising large-scale CCS deployment is the Economic Licence for CO_2 transport and storage operators combined with the Contracts-for-Difference (CfD) mechanism for CO_2 capture site operators. CfDs are designed to incentivise investments in new technologies by providing price stability and predictability[36]. In the context of the UK's CCS policy, CfDs represent a government-led two-way contract between a CO_2 capture plant operator and the government. The government defines the regulatory framework, negotiates a strike price for the cost of capturing and storing a tonne of CO_2, and ensures the financial processes are in place to support the CfD mechanism[37]. If the market price for CO_2 reductions (e.g. carbon credits or CO_2 emission allowances in the UK ETS) is lower than the strike price, the government compensates the CCS operator for the difference. Conversely, if the market price exceeds the strike price, the operator pays the difference back to the government.
One example of a CfD policy mechanism is the Dispatchable Power Agreement, which provides a contractual framework through a dual-payment system with an 'availability payment' (providing payment certainty) and a 'variable payment' (providing price levelling) for power carbon capture, utilisation and storage (CCUS) projects[37–39]. This example demonstrates the CfD's precedent for ensuring stable revenue streams. This enables a reduction of financial risks for investors, as evidenced by the East Coast Cluster reaching financial close in December 2024[40].

2.2.2. Market-led: Emissions Trading Scheme (ETS)

The UK Emissions Trading Scheme (ETS), launched on January 1, 2021, replaced the EU ETS as the cornerstone of the UK's climate policy[41]. The UK ETS currently applies to energy-intensive industries (e.g. manufacturing, metal production), the power generation sector, offshore oil and gas extractive and operational emissions, and domestic and EU bound aviation, covering around 25% of the UK's domestic emissions[42]. Plans are underway to expand ETS coverage to include emissions from maritime transport and waste incineration[43]. Additionally, public consultations are currently exploring the GGR integration in the UK ETS[44].

The ETS operates by creating a market for emission allowances. Companies procure emission allowances through competitive auctions, free allocations, or secondary markets[41]. This takes place in a framework of a cap on total emissions that declines over time, in line with a pre-determined national carbon budget. As the government's allowance cap decreases over time, the price of emission allowances rises, incentivising emitters to invest in decarbonisation measures such as low-emission technology switching, energy efficiency improvements, and CCS, in order to avoid the higher costs of purchasing additional allowances. Thus, the ETS provides a strong economic signal for emission reduction.

The ETS is supported by wider regulatory frameworks, including annual reporting of emissions, penalties for non-compliance[41], a Cost Containment Mechanism that releases additional allowances if prices increase too rapidly, and an Auction Reserve Price to prevent sudden and significant price drops[43]. The Government is also considering the introduction of a Supply Adjustment Mechanism to withdraw allowances in the event of oversupply[43].

A challenge for the ETS is the risk of carbon leakage. Carbon leakage occurs when stringent climate policies drive companies to relocate to jurisdictions with more lenient policies, undermining the efficacy of climate policy and ultimately increasing global abatement costs[45]. This risk is currently mitigated by a system of free allocations under the UK ETS (i.e. an oversupply of emission allowances), but these are set to decrease from 2026 onwards[46]. With future exposure to carbon leakage risks uncertain[47–49], influenced by factors such as the competitiveness of the UK economy and international carbon price differentials[46], the UK plans to introduce a Carbon Border Adjustment Mechanism (CBAM). The CBAM aims to link the price of imported goods with the UK ETS price level at the time of import, levelling the playing field for domestic industries against international competition.

While the UK ETS plays a crucial role in reducing emissions and driving decarbonisation in the UK, its future effectiveness depends on continuous adjustments and additional measures to address challenges such as carbon leakage, full economy coverage and the inclusion of GGR technologies. As these uncertainties persist, additional policy tools could be necessary.

2.2.3. Mandate-led: Carbon Takeback Obligation (CTBO)

A supplement to government-led and market-led approaches is a mandate-led approach. Mandates, or regulatory obligations, are imposed by the government to regulate entities within their jurisdiction, influencing their 'licence-to-operate' or 'licence-to-sell'. The primary aim of mandates and regulation-based policy tools is to prescribe outcomes, such as minimum product standards at the point of sale, to accelerate the net zero transition. Mandates are often differentiated into product/facility level mandates (explicit requirements for individual products or facilities) and sector/regional level mandates (regulatory obligations for economic sectors or economy-wide mandates). Mandates with tradeable compliance credits[50] represent a hybrid approach that combines mandate and market principles to ensure compliance.

In recent years, mandates have gained traction as policy tools that can accelerate climate mitigation by setting minimum product standards or prescribing actions for polluters. Examples include the standards on transport fuel[51], aviation fuel[52] and car efficiency standards[53]. **Table 2.2** presents an overview of enacted and proposed mandates for climate mitigation in the UK.

Mandates have been shown to stimulate low-carbon production, cleaner supply-chain processes and innovation, and to incentivise waste management or recycling programs[54–57]. However, compliance schemes, such as sector-specific mandates, have also faced criticism for potentially reducing market liquidity, decreasing market efficiency, and crowding out nascent technology[58–61].

Table 2.2. Select examples of mandates in the UK energy sector

Policy name	Year(s)	Regulator	Obligated Entity	Type of mandate
Streamlined Energy and Carbon Reporting (SECR)	2018 - ongoing	DESNZ	Quoted companies, large unquoted companies and large limited liability partnerships	Reporting requirement
Energy Company Obligation (ECO)	2013 - ongoing	Ofgem	Medium to large energy supplier	Mandatory action and investment
Renewable Obligation (RO) Scheme	2002 - 2017	Ofgem	Electricity suppliers	Obligation to acquire
Renewable Transport Fuel Obligation (RTFO)	2008 - ongoing	DfT	Transport fuel suppliers of petrol, diesel, gas, oil or renewable fuel	Obligation to acquire
Low Carbon Hydrogen Standard	2023 - ongoing	DESNZ, Ofgem	Hydrogen producers	Minimum product standard
Emissions Performance Standards (EPS)	2013 - ongoing	Environmental Agency	Fossil fuel plant operators	Minimum operational standard
UK SAF Mandate	2025 - ongoing	DfT	Aviation fuel suppliers of fossil aviation turbine fuels	Obligation to acquire

Notes: This is not an exhaustive list, but should be read as illustrative examples.

Table 2.2 presents select examples of mandates in the UK energy sector.

A sub-category of mandates are carbon storage mandates[22,62–67], aimed at promoting geological carbon storage and durable GGR technologies. Carbon storage mandates can set storage targets at a specified quantity level (e.g. $MtCO_2$ per year stored by 2030) or as a percentage of produced CO_2 emissions (e.g. 10% of all-scope emissions stored by 2030). Examples include a Carbon Takeback Obligation (CTBO), Article 23 in the EU Net Zero Industry Act (referred to as an Injection Capacity Obligation in this report), Low Carbon Product Standards (e.g. LCFS), and Carbon Removal Obligations (CRO). More examples and design choices are explored in **Section 6**.

This report focuses on the carbon takeback obligation (CTBO), a specific proposal for a carbon storage mandate. It also briefly explores the concept of a sector-specific carbon storage mandate, such as a low-carbon product or fuel standard, in **Section 5**. Like other mandate schemes, a CTBO is a potential regulatory compliance mechanism. It is designed to be imposed on fossil fuel producers and importers by integrating a CO_2 storage mandate into their ‘licence-to-operate’ or ‘licence-to-sell’. The CTBO requires these entities to permanently store a rising fraction of the CO_2 emissions associated with their products and operations, rising to 100% by 2050. The CTBO aims to target upstream entities, rather than the existing and congested regulatory space aimed at downstream entities in the value chain[65]. This is due to factors such as the financial and technological ability of upstream entities and principles of producer responsibility (elaborated further in **Section 6**). Similar to the certificate function of the Renewable Obligation in the UK[68,69], fossil suppliers would be required to purchase compliance certificates (which would be tradeable to ensure market efficiency) demonstrating permanent CO_2 storage[66].

The proposed CTBO has several intended outcomes, which are explored in more detail in **Section 6**. These intended outcomes include, but are not limited to:

→ Creating long-term market stability by establishing a predictable investment pathway, ensuring sufficient storage is ready when it is needed to meet net zero targets;

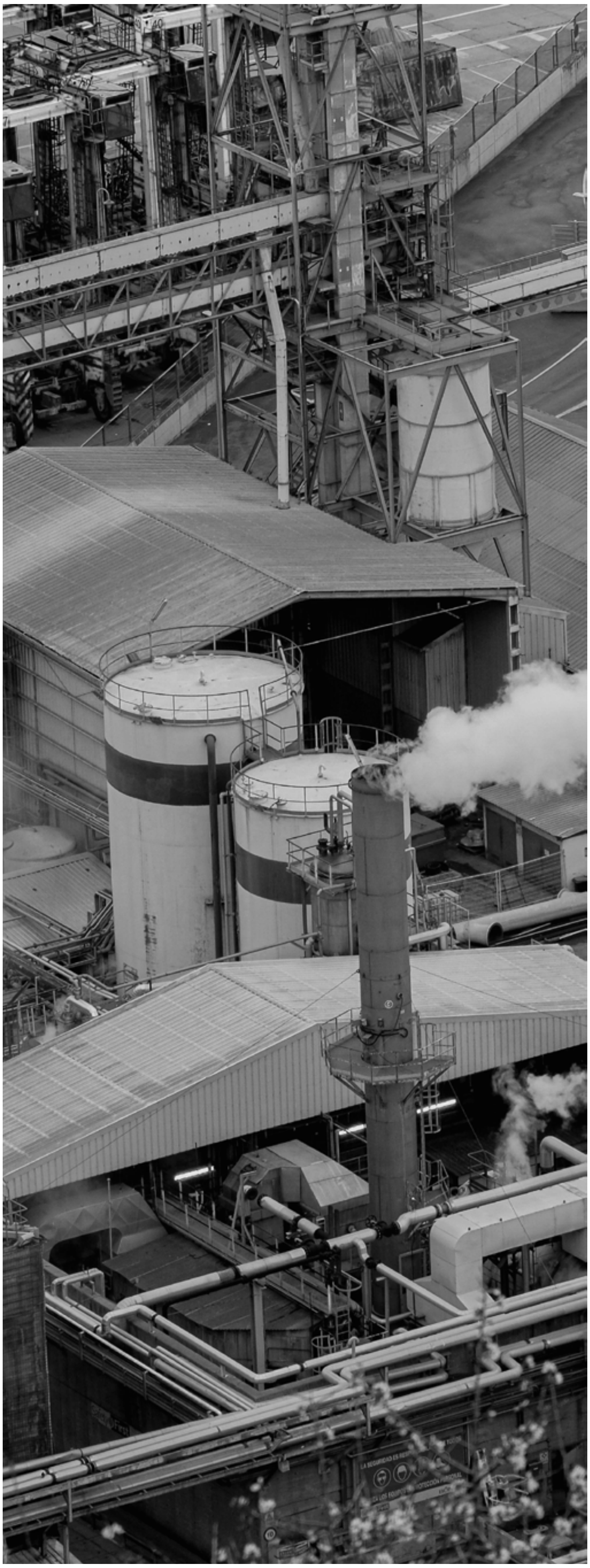
→ Bringing forward the point at which government subsidies for capture and storage projects can be significantly reduced;

→ Flexibly aligning with net zero goals under any future energy scenario, including changes in fossil fuel prices, providing a 'backstop' to other policies that reduce fossil fuel emissions;

→ Stimulating a competitive market through cost distribution across the value chain;

→ Facilitating active carbon management by increasing the price of fossil fuels and introducing regulatory penalties for fossil fuel supply without commensurate CO_2 storage[64].

The interaction of a CTBO with other policies is only partly considered in this report; however, it is envisaged that it would need to work alongside policies incentivising sectoral decarbonisation and therefore demand for CO_2 storage, particularly in hard-to-abate sectors. These intended outcomes as well as possible unintended consequences of a CTBO are explored further in the scenarios below.



3. Evaluating CCS Policy Scenarios

3.1. Framework for Scenario Evaluation: Methodology

The policies outlined above form the basis of two[iii] potential policy mix scenarios in the UK that will be evaluated in this report: the 'Base Case' scenario and the 'Base Case+' scenario. We also consider a sector-specific variant on the Base Case+ scenario. The potential benefits and risks of each scenario are assessed through a combination of qualitative analysis and wide ranging stakeholder input from workshops and interviews. More details on the methodology can be found in **Annex A**.

Exogenous factors for evaluating CCS policy mix scenarios

It is important to note that all policy mix scenarios are subject to exogenous factors that influence policy outcomes, including macro-economic, technological, and socio-political conditions. Examples include, but are not limited to: the price and volatility of fossil fuel supply, the costs of CCS technologies, the rate of innovation and cost reduction in CCS technologies, transport and storage availability, and broader economic conditions in the UK, EU, and globally. The effect of these variables should be assessed quantitatively in future work. This is explored further in **Section 8** (future work).

3.2. Scenario Evaluation: Success Criteria

The selected policy scenarios are evaluated based on several success criteria. This report defines four primary success criteria for CCS policy in the UK, drawn from recent DESNZ policy documents on CCS, particularly the CCUS Vision document[1].

The four success criteria can be described as:

→ Fast and deep decarbonisation that achieves net zero targets

→ A self-sustaining CCS sector free of government support

→ Economic growth and social benefits

→ Global leadership

Potential elements of the success criteria for future CCS policy mixes are outlined in **Table 3.1**. on the following page. Note that both the rationale and potential elements are based on an analysis by the authors, drawing on DESNZ CCS policy documents and the input of stakeholders, including academia, industry, and NGOs. They therefore do not represent DESNZ's CCUS Vision.

[iii] The 'Markets & Mandates' project also examined the impact of 'pure' policy scenarios, including a purely mandate-led approach and a purely government-led approach. Further details on these scenarios, as well as the reasons they are considered sub-optimal and thus excluded from the main analysis, can be found in **Annex D**.

Table 3.1. Success criteria for future CCS policy mixes

DESNZ Vision criteria	Description	Rationale	Potential elements*
1. Decarbonising for future generations ("Achieving Net Zero")	Aligning to an abatement pathway that is compliant with carbon budgets and net zero goals.	The effectiveness of climate change mitigation policy should be assessed primarily by its contribution to achieving net zero targets.	→ Progress on achieving storage targets (set by the CCC), with potential metrics including storage capacity or injection rates per annum. → Resilience to external factors (e.g. price shocks) over decade-long timescales. → Avoidance of an overreliance on fossil fuels and facilitation of a net zero transition.
2. Creating a self-sustaining CCS sector ("Self-sustaining Sector")	Increasing private sector confidence in the CCS market, to enable a reduction in government financial support.	A self-sustaining CCS sector, underpinned by strong private capital mobilisation and allowing for a reduced reliance on government financial support, is crucial[1,6].	→ Level of commercial certainty. → Long-term deployment plan. → Regulatory framework addressing de-risking of investment, demand-supply linkages, and carbon leakage risks[6,70]. → Level playing field for CCS investors. → Competitive market that lowers technology and financial cost[1,6,71].
3. Creating growth and levelling up ("Economic & Social Impacts")	Creating economic opportunities through low carbon investment across the whole of the UK, aimed at 'levelling up' regions economically.	CCS should benefit the UK economy, with the sector potentially boosting the economy by £5 billion per year by 2050[71]. Academic literature also highlights that social factors should be carefully considered, with recent studies highlighting the fragility of the social licence and support for net zero technologies[72,73].	→ Inwards investment (£m), particularly in industrial areas[6]. → Existing manufacturing jobs safeguarded, and maximising job growth secured through a skilled workforce programme for the net zero transition[6]. → Maintenance of UK industry competitiveness in domestic and export markets**. → Enabling public engagement and education on CCS; involving communities, addressing community concerns. → Incorporation of fairness principles like the 'polluter pays' principle**. → Minimisation of impacts on consumer bills[70].
4. Creating global leadership ("Global Leadership")	Exporting domestic expertise and infrastructure to support other countries to build CCUS, and offering UK CO_2 stores to sequester other countries' CO_2 emissions.	Building capacity to export the UK's CCS supply chain, including storage sites, to aid other countries in their decarbonisation efforts.	→ Compatible regulatory and commercial frameworks with international carbon markets, facilitating 'export' of storage capacity[1,6,70]. → Bi-lateral deals with other countries to allow storage of international emissions. → High percentage share of global CCS market. → Ambitious UK decarbonisation rate compared to other countries whilst maintaining UK competitiveness[1,70].

Notes: *The four criteria are based on the DESNZ CCUS Vision. The potential elements for each criteria are suggested by the authors of the report, based on an analysis of DESNZ CCS policy documents and the input of stakeholders, including academia, industry, and NGOs. **These principles are an addition by the authors based on stakeholder feedback and core principles of UK environmental law[74] and are not directly referenced in the DESNZ's CCUS Vision. Further analysis on other potential success criteria and sub-criteria for the UK would be valuable for future research (see Section 8).

4. The 'Base Case' Scenario: Current Policies

4.1. What is the 'Base Case' Scenario?

The 'Base Case' scenario in this study envisions the UK CCS sector transitioning from a government-led subsidy-driven model to an ETS-dominated market approach. This transition involves three distinct phases: 'market creation' (2020-2030), 'market transition' (2030-2035), and a 'self-sustaining market' (2035-onwards). This trajectory is summarised in **Figure 4.1** and **Table 4.1**.

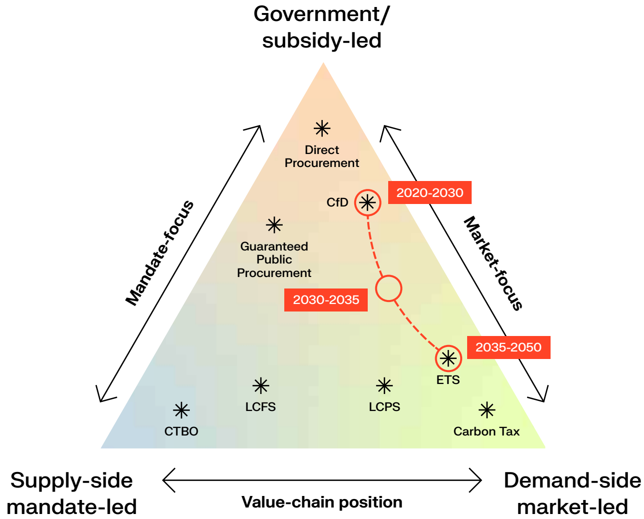


Figure 4.1. Schematic visualising CCS policy space, with examples of individual policies, as represented as stars, and the UK's current CCS vision, as presented in DESNZ's CCUS Vision document, is shown in red.

Table 4.1. DESNZ CCUS Vision outline

Phase 1: Market creation (2020-2030)	Develops industrial clusters using private investment backed with government subsidy, through CfD auctions and other funding, delivering 20-30 $MtCO_2$/year offshore storage. The government has committed subsidies for capture, transport, and storage deployment supporting Track 1 and 2 industrial clusters in four regions by 2030.
Phase 2: Market transition (2030-2035)	Supports the emergence of a commercial market for CCS, scaling to 50 $MtCO_2$/year storage by 2035. Transitionary policy reduces CfD support for new facilities, aiming for subsidy-free project development post-2035. This phase relies on cost-reducing CCS technology innovations, increased investor confidence from Phase 1 demonstrations, the maturity of infrastructure networks for transport and storage, and market mechanisms such as the UK Emissions Trading Scheme (UK ETS) driving deployment.
Phase 3: A Self-sustaining CCS market (2035-onwards)	Establishes a mature CCS system, including domestic CCS for the UK's net zero target and international CO_2 storage services, projected to reach 90-170 $MtCO_2$/year by 2050. The domestic CCS industry is expected to be financed through an expanded UK ETS, with a CBAM to protect domestic manufacturers of high-carbon products, incorporating GGR into the UK ETS, minimal public CCS financing.
Author Proposal: Beyond the DESNZ CCUS Vision	
After net zero (Post-2050)	The future of the UK's CCS market post-net zero involves estimating the scale of engineered CO_2 removal needed to ensure adequate storage capacity and transport infrastructure. The expansion of the UK ETS incorporating GGR could support infrastructure development for this additional capacity. The scale and financing of net CO_2 removal remain unclear, with potential subsidies needed.

Notes: Phases 1-3 are inspired by the DESNZ Vision document (2023)[1]. An additional phase, 'Post-2050', was added by the authors of this report to illustrate linkages between the UK's enduring CCS vision and future GGR policy.

4.2. Benefits and Risks of the ‘Base Case’ Scenario

	1	2	3
Benefits	Initiating a thriving CCS market in the UK	Transitioning to a self-sustaining market	Economic opportunities and global leadership
Risks	ETS insufficient for timely storage development	Over-reliance on ETS could drive carbon price spikes	Uncertainty in future ETS expansions

Figure 4.2. Overview of Benefits and Risks: ‘Base-Case’ Scenario, as identified through research and stakeholder analysis

4.2.1 ‘Base Case’ scenario: Benefits

Benefit 1: Initiating a thriving CCS market in the UK

Timeline: Short term (0-10 years)

The ‘Base Case’ scenario aims to establish a thriving domestic CCS market by 2030. Initially, a government-led subsidy model, employing CfDs, is designed to attract early investment and mitigate risks for the private sector. CfDs are well-recognised as having successfully stimulated net zero energy technology deployment in the UK, such as wind and solar farms, biomass and waste with combined heat and power, and geothermal energy[75]. Internationally, similar models like the Dutch SDE++ scheme have proven effective[76] and have been replicated in other countries, notably in Germany[77]. With this approach, the UK is on track to achieve its 2030 storage ambitions, with four government-supported clusters projected to deliver 20-30 $MtCO_2$/year storage by 2030[78].

Stakeholder Insights

Stakeholders widely acknowledged the positive impact of CfDs in kickstarting the UK’s CCS market by enabling risk sharing, pooling of funding, and de-risking private investments. However, concerns were raised about the vulnerability of subsidy schemes to external factors, such as changes in government and price shocks, and the lack of long-term stability to sustain investor confidence over the medium- to long-term.

Benefit 2: Transitioning to a self-sustaining market

Timeline: Medium term (10-15 years)

In the medium-term, the ‘Base Case’, which includes carbon capture sites receiving revenue support under CfD mechanisms, aims to transition to a market-led system under the ETS, whereby CfD revenue support from the government reduces automatically over time as the carbon price increases. This has the potential to reduce the scope of government support, alleviating the public tax burden and driving cost reductions throughout the value chain. Transitions away from subsidy-led towards market-led policies have been successful in driving the adoption of other technologies like ground-mounted solar park projects[79,80] and electric vehicles[81]. Electric vehicles, in particular, are now supported by a combination of market and mandate policies, including tax incentives for drivers, regulations of tailpipe emissions, and a phase-out of the sale of new petrol or diesel vehicles by 2035[82]. Although cost reductions in the CCS value chain are expected to be less significant than for other technologies[83], this phasing out of public expenditure on CCS is expected to encourage innovation and cost efficiency.

Stakeholder Insights

A majority of stakeholders voiced that transitioning from a government-led to a market-led system is ‘sensible and fair’, both to stimulate cost efficiency and to place the cost burden on fossil fuel users rather than taxpayers. Some stakeholders stated that continued subsidies to fossil fuels companies would be ‘unpalatable’ to the public. While there was low confidence in the ETS (see below), some stakeholders anticipated that if the ETS price stabilises in the 2030s, is applied economy-wide, and includes negative emission allowances, it could deliver investor certainty and cost reductions. This prediction requires further analysis (see **Section 8**).

Benefit 3. Economic opportunities and global leadership

Timeline: Medium to long term (10-30 years)

In the medium- to long-term, the ‘Base Case’ scenario could generate economic opportunities and global leadership through international CO_2 storage services. A system which allows easy integration with international carbon markets, especially the EU ETS, could enable the UK to commercialise its significant storage capacity by offering ‘storage as a service’ to other countries. This has the potential to attract foreign direct investment, drive economic growth (Criteria 3), and position the UK as a global leader in CO_2 storage (Criteria 4).

Stakeholder Insights

Stakeholders recognised the potential for the UK to demonstrate global leadership and attract economic investment through international CO_2 storage services. However, it was emphasised that there would be a need for a wide range of enabling policies first, including policy tackling issues of cross-border CO_2 transport, long-term responsibility over storage, and UK-EU cooperation. It was also highlighted that the UK’s capability to provide ‘CO_2 storage as a service’ depends on a policy suite that supports both domestic decarbonisation goals and offers cost-competitive storage to international partners.

4.2.2. 'Base Case' scenario: Risks

Risk 1: ETS is insufficient for timely storage development

Timeline: Short to medium term (5-15 years)

Under the 'Base Case' scenario, when subsidies are phased out, the CCS sector would rely on the ETS to create a self-sustaining sector. This is likely to be insufficient to stimulate the large-scale investments in CCS that will be necessary to reach net zero. This arises from three main factors:

1. **The functioning of the ETS mechanism[iv].** The ETS is designed to identify the most economically efficient decarbonisation options, with a shrinking emission cap and rising carbon price incentivising emission reduction measures in order of cost-effectiveness. This means investment in carbon storage will likely occur only when ETS prices are sufficiently high, predictable, and stable enough to cover full value chain CCS deployment costs. This 'marginal abatement principle' does not adequately address the long-term, capital-intensive nature of geological storage, which requires substantial and consistent investment, and investment certainty, over multiple decades. Without additional mechanisms, the 'Base Case' scenario therefore risks a 'first-to-nth-of-a-kind' deployment gap where initial projects are deployed with subsidies, but the ETS fails to stimulate timely and additional capacity creation thereafter. This could lead to storage capacity creation lagging behind storage demand[v], risking a failure to achieve net zero targets and potentially forcing a return to government-led deployment.
2. **Current ETS price levels:** ETS prices have consistently remained below the full-chain cost of CCS deployment, failing to incentivise large-scale investment. For example, the EU ETS reached a record high of €100/tCO_2 (£85/tCO_2) in February 2023, but recent estimates suggest a price of at least €150/tCO_2 (£129/tCO_2) is needed to drive wide-scale adoption of CCS[15]. As the ETS cap shrinks in the 2030s, rising prices are expected to incentivise CCS, but this may come too late to incentivise storage on time at the capacity required to meet 2030 and 2050 targets. This is especially pertinent considering the low confidence in long-term ETS forecasts as a basis for investment decisions[6]. Anticipated price rises in the ETS are also vulnerable to factors such as the political will to continuously tighten the emissions cap and phase out free allowances.
3. **External factors and investment confidence.** Even if prices do rise to cover full-chain CCS costs, the ETS may still not generate the long-term investment confidence required. As government support is reduced, relying on a market-led system alone exposes CCS deployment to external uncertainties, such as fossil fuel profitability, fossil fuel supply shocks, and subsidies in other jurisdictions, as well as internal uncertainties, such as the political will to continuously tighten the emission cap and expand the ETS to full market coverage. A recent CCSA survey reflects this investment uncertainty, highlighting that confidence in the ETS is currently low, with 77% of CO_2 capture project developers unwilling to invest based solely on the ETS[6]. This lack of confidence is exacerbated by UK ETS-specific issues that may take several years to resolve, such as recent ETS price halving and market illiquidity due to UK-EU ETS decoupling[84].

These three factors combined mean the 'Base Case' scenario risks failing to meet net zero targets (Criteria 1) and create a self-sufficient sector (Criteria 2), putting pressure on the government to provide ongoing subsidies for CCS with no clear exit strategy.

[iv] This risk is further supported by academic analyses[111], which have found no statistically significant effect of carbon pricing such as ETS mechanisms in driving the technological changes necessary for full decarbonisation.

[v] Time lags are also a result of uncertainty among market actors in the ETS system. This uncertainty risks insufficient storage deployment in the medium- to long-term.

Moreover, the UK's 'global leadership' in CO_2 storage (Criteria 4) hinges on presenting a compelling investment narrative. In the long term, uncertainty could limit the amount of CO_2 storage that is created for CCS and GGR projects in the UK, leading to competition for storage between domestic actors and third parties from overseas. Opening the UK's storage market for third parties in this scenario risks exacerbating the storage supply challenges for the domestic market, especially if interactions between domestic and cross-border transport and storage policy are not clearly defined.

Stakeholder Insights

Workshop participants expressed a distinct lack of confidence in the ability of the ETS to create a self-sufficient market. Many stakeholders in the workshop held the view that current prices were insufficient to build a robust supply chain, drive innovation, and incentivise early investment.

Even if prices were to rise, confidence in the ETS depends on prices being sufficiently high and stable, with some stakeholders suggesting a need for a carbon price above £120/tCO_2. Several stakeholders in the interviews expressed that the ETS might eventually create enough storage demand, but this would arrive too late to meet net zero goals.

Risk 2: Over-reliance on ETS could drive carbon price spikes

Timeline: Medium to long term (10-30 years)

If CO_2 storage supply lags behind the storage demand created by a declining ETS emission cap, it could lead to a 'bottleneck' in storage availability for hard-to-abate sectors, causing carbon prices to spike. This risk assumes that as the UK approaches net zero, the economy has already implemented readily available demand substitution and efficiency improvements for hard-to-abate sectors. Consequently, carbon prices would become highly sensitive to CCS/GGR availability, and, if deployment is slower than required, this could lead to carbon price spikes. This is observed in the IPCC's high-ambition mitigation scenarios relying solely on carbon pricing, which show carbon prices having to rise significantly (often exceeding $1000/$tCO_2$[64]) to meet net zero targets.

The effects of such price spikes need further evaluation, but could result in higher overall societal abatement costs[64], substantial societal pressure to scale back net zero pledges, industry pressure to reintroduce subsidies, or carbon leakage due to the potential offshoring of hard-to-abate sectors.

Stakeholder Insights

Although the long-term scenario of spiking carbon prices was not specifically discussed, stakeholders expressed general concerns about rising ETS prices and their impact on consumer prices. Some stakeholders were sceptical about the political feasibility of increasing carbon prices, expressing that the public may be unwilling to shoulder the costs of investments needed to achieve net zero. We note that this is a common concern for climate policy, as it aims to internalise the external costs of consumer goods, thus increasing prices to reflect the 'true' cost of consumption and disposal[85,86].

Risk 3: Uncertainty in future ETS expansions

Timeline: Medium to long term (10-30 years)

For the ETS to align with net zero goals, it requires expansion across all sectors of the economy, the integration of GGR allowances, and a comprehensive border protection policy such as a CBAM[1]. While these policy tools are in development, their scope and timeline remain uncertain. The Climate Change Committee, for example, has warned that ETS expansion plans need further consideration due to potential adverse impacts on consumers[87]. A CBAM will need careful design to avoid capital flight, damage to UK exports, and offshoring of hard-to-abate sectors. The administrative burden of CBAM could also result in opposition or delays to its implementation[88,89].

Stakeholder Insights

Many workshop participants expressed confidence in the feasibility of expanding the ETS to include GGR. However, some stakeholders raised concerns about balancing CCS and GGR in future net zero policy, emphasising the need to keep emission reductions and removals separate to ensure clear outcomes for UK net zero policy and avoid mitigation deterrence.

Expanding the ETS across the entire economy was seen as more challenging due to concerns about consumer costs, particularly in sectors where consumers would directly see the impact of rising carbon prices, such as in fuel duty and home gas meters. Stakeholders did not reach a consensus on this point, with some viewing it as politically infeasible while others stating it is ‘all planned to happen’. This risk underscores the political vulnerability of ETS when addressing more distributed emitters. Additionally, some noted that higher consumer costs are a common challenge across most climate policies.

Additional stakeholder concerns with the ‘Base Case’ scenario

Stakeholders highlighted several additional concerns not covered in the above risks. Some emphasised the public perception challenge, with CCS subsidies seen as ‘sponsoring’ the fossil fuel industry and failing to adhere to ‘polluter-pays’ principle. Others noted inefficiencies in the cluster scheme, as it slows down deployment rates in non-selected clusters.

Additionally, some stakeholders were concerned about the distribution of storage sites with no clear mechanism in place to effectively ‘match’ emitters to storage providers. Some expressed apprehension that geological storage would be used primarily to decarbonise fossil fuel assets, rather than prioritising industrial emission sources not linked to the fossil fuel industry.

5. The Base Case+ Scenario: A Markets & Mandates Policy Pathway

Given the risks outlined above of relying on a market-led approach, this section explores a policy mix in which the 'Base Case' is supplemented by a mandate policy, specifically a Carbon Takeback Obligation (CTBO), to help establish an enduring CO_2 storage market and drive the net zero transition. This is referred to as the 'Base Case+' scenario.

As elaborated on in **Section 6**, a CTBO is proposed as a CO_2 storage mandate that meets a specific set of criteria:

- → It is a regulatory mandate
- → It operates with independently verified storage certificates
- → It adopts a rising geological net zero aligned stored fraction
- → It requires permanent carbon storage
- → It has compliance conditions with strong and effective penalties

To enable an analysis of this scenario, certain assumptions had to be made around CTBO design. These are clarified in the **Box** to the right. It is important to note that these design choices can be altered, and that the 'Base Case+' scenario requires further research and development within the UK context. As such, this section incorporates stakeholder assessments that require additional scrutiny. This limitation is acknowledged, and areas where further analysis is needed are highlighted.

CTBO design assumptions made in the stakeholder analysis

To effectively collect stakeholder insights on the scenarios, certain CTBO design assumptions were made in preparation of the workshop. Other design choices can be made, and policymakers can tailor these to specific policy objectives. These design choices are detailed in **Section 7**. The CTBO design assumptions for this scenario were as follows:

- → A carbon storage obligation is placed on all producers and importers of oil and gas in the UK market.
- → The obligation starts at a low storage percentage and gradually increases to cover 100% storage of all-scope emissions by 2050 to meet net zero targets.
- → No preference is given for the technology used to capture CO_2, but only permanent (geological) carbon storage is permitted to meet the obligation.
- → CO_2 is required to be domestically captured and stored.
- → Appropriate safeguards for storage are in place, including high MRV standards and measures to prevent leakage, such as well-selected storage sites.
- → Effective penalties for non-compliance are in place, with no preference for type of penalty.
- → Interactions between the CTBO and the UK ETS are acknowledged but not considered in the analysis, as this requires further quantitative assessment.

Additionally, the exogenous factors outlined in **Section 3** are also assumed to affect the outcomes of mixed market and mandate scenarios. **Section 8** discusses future opportunities to quantify these effects, including the importance of accounting for impacts on the UK economy and sector competitiveness.

5.1. What is the 'Base Case+' Scenario?

The 'Base Case+' scenario combines a market-wide ETS and CfD revenue support for CO_2 capture sites with an upstream CTBO on all fossil fuel producers and importers to drive CCS deployment. CfD revenue support is assumed to continue, reducing steadily up to 2035, in line with the DESNZ CCUS Vision. In this scenario, the CTBO mandate is first introduced in parallel with the existing policies in the 'market transition' phase (2030-2035), requiring mandated entities to store a rising fraction of the CO_2 embedded in their products. The stored fraction should start at a small percentage, to allow market participants and the regulators to develop and adapt. In phase 3 (2035-2050), the CTBO evolves into an enduring mandate mechanism, reaching 100% CO_2 storage for all remaining fossil fuel production and imports by 2050, while the ETS cap declines to reach zero by the same year. This is summarised in **Table 5.1** and **Figure 5.1**.

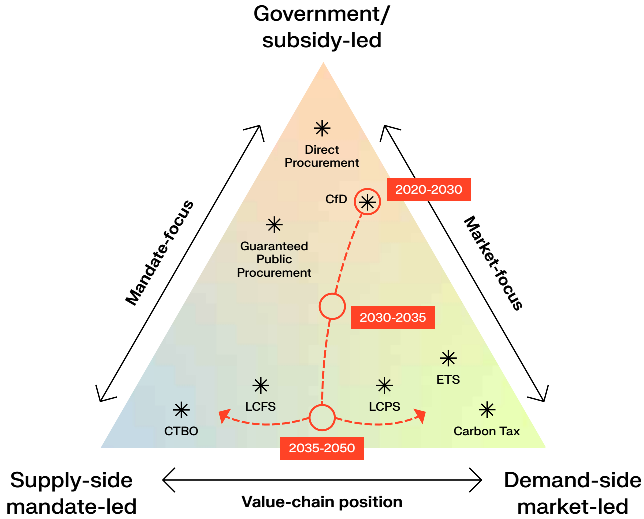


Figure 5.1. Schematic showing the evolution of a CCS policy scenario which transitions from government-led mechanisms to a combination of the UK ETS and a CTBO mandate. The final position in 2050 depends on the relative weight pulled by the market and mandate policies at that time.

Table 5.1. Timeline of 'Base Case+': Economy-wide ETS with upstream CTBO

Phase 1: Subsidy-led market creation (2020-2030)*	Development of decarbonised industrial clusters using private investment backed with government subsidy, in part via CfD-style payments, delivering 20-30 $MtCO_2$/year offshore storage by 2030.
Phase 2: Transition to mixed policy approach (2030-2035)*	Rapid scaling of CCS market to deliver 50 $MtCO_2$/year storage by 2035, with market (ETS), government revenue support (CfD), and mandate (CTBO) mechanisms applied in tandem. The CTBO applies to upstream fossil fuel producers and importers. The three policies provide complementary pressure for supply-side CO_2 storage investment (CTBO), demand-side reductions in fossil fuel use and investment in capture technology (ETS) and capital flow both up and down the value chain to drive full-chain CCS deployment (CfD, ETS and CTBO).
Phase 3: Net zero via market and mandate (2035-2050)**	Long-term policy goals include scaling CCS to capture and store 70-90 $MtCO_2$/year by 2050 and balancing all residual fossil CO_2 production. This is achieved through a mixed policy suite, with an enduring mandate mechanism (CTBO) that reaches a 100% stored fraction of all-scope emissions by 2050, and a market mechanism (ETS) with a declining cap that reaches zero in 2050. Net zero goals are achieved through both policies, influenced by exogenous factors (e.g. CCS technology costs, macro-economic conditions) and endogenous factors (e.g. expansion of ETS market, CTBO design decisions).
Author proposal: Beyond the DESNZ CCUS Vision	
Beyond net zero: (Post-2050)	The Base Case+ policy mix continues to manage the enduring CCS and GGR market to maintain a net zero UK economy. If net-negative CO_2 emissions are required as part of the UK's contribution to overshoot scenarios, they could be included via the CTBO policy (increasing the stored fraction beyond 100%), the ETS policy (requiring greater than 1:1 ETS-GGR permit purchasing for ongoing emissions), or through government-led policy (e.g. direct procurement).

Notes: *Phases 1-2 are inspired by the DESNZ Vision document (2023)[1], but does not reflect the exact Vision. **Phase 3 aligns with the 'self-sustaining market' phase of the DESNZ Vision, but was designed by the authors of this report to reflect the combined approach by introducing an additional regulation such as the CTBO (or other mandates).

5.2. Benefits and Risks of the 'Base Case+' Scenario

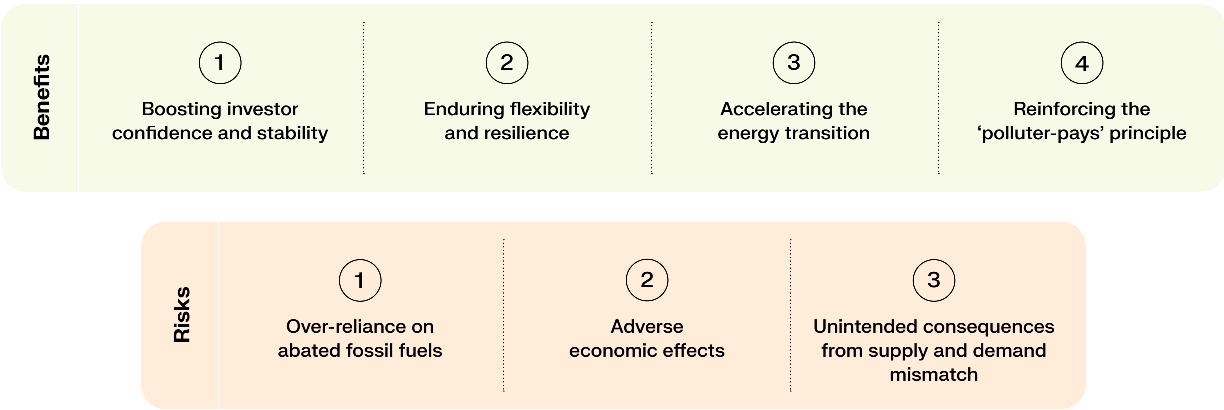


Figure 5.2. Overview of Benefits and Risks: 'Base-Case'+ Scenario, as identified through the analysis in this project.

5.2.1. 'Base Case+' scenario: Benefits

Benefit 1: Boosting investor confidence & stability

Timeline: Short to medium term (0-15 years)

In the short- to medium-term, a combined ETS with CTBO approach can enhance investor confidence and provide the necessary stability for ramping up storage capacity. Supplementing an ETS with a CTBO could offer a more predictable investment pathway than the 'Base Case' scenario. While the ETS would drive cost-efficient decarbonisation, reducing fossil fuel use and capturing emissions when economical, the CTBO would ensure storage development through clear regulatory foresight and a compliance mandate on producers and importers. Depending on its design, the CTBO can scale up geological storage along a clearly defined trajectory, supported by strong regulatory enforcement. The two mechanisms would thus work together to stimulate the CCS market, mitigating 'Base Case' scenario risks of a delay in storage build-out and sudden, disruptive spikes in compliance costs[66].

Additionally, the ETS and CTBO would create incentives for decarbonisation across the entire fossil fuel value chain, not just for emitting entities. If paired with policies that reduce carbon leakage and mitigate competitiveness concerns, this obligation on fossil fuel producers and importers could drive these actors to more rapidly deploy capital than in the 'Base Case' scenario[66].

Stakeholder Insights

Many stakeholders voiced that predictable scale-up of geological storage and investor confidence are crucial for creating a self-sustaining CCS sector (Criteria 2). Many noted that the CTBO could help achieve this. Some highlighted the CTBO's potential to provide a clear business case across the CCS value chain, offering more confidence for storage investment than the ETS alone. For example, despite some industry criticism of the EU Net Zero Industry Act's storage obligation policy[90], a stakeholder noted it has created a 'virtuous circle' of investor confidence in CCS. Stakeholders also highlighted that early action incentivised by the CTBO allows for problem-solving and learning before storage is required at scale.

The CTBO's predictability was also valued by stakeholders for helping with the 'deep' decarbonisation for hard-to-abate sectors (Criteria 1). Stakeholders involved in North Sea storage planning, in particular, valued the potential of the CTBO to enhance long-term geological storage capacity planning up to 2050. One stakeholder highlighted that a CTBO which links storage capacity creation to predicted fossil fuel usage could provide a more accurate estimate of storage needs up to 2050 than current capacity estimation models.

Benefit 2: Ensuring flexibility and resilience

Timeline: Long term (15-30 years)

In the long term, the CTBO and ETS are expected to work together to ensure sufficient CO_2 storage is created to reach net zero. A shrinking emission cap under the ETS reduces fossil fuel demand, while a CTBO with relative storage targets ensures adequate storage to permanently store any remaining emissions by 2050. This mixed policy approach acts as a 'backstop' to ensure that residual fossil fuel emissions are stored in time for net zero, regardless of the specific energy and economic trajectory.

The relative reliance on market and mandate mechanisms to finance CCS will likely depend on endogenous and exogenous factors, such as prevailing economic conditions. Different non-compliance penalties (e.g. financial penalties under the ETS, licence revocation under CTBO) can jointly drive a transition away from fossil fuel energy sources.

Stakeholder Insights

Representatives across several stakeholder groups valued the resilience and contingency planning inherent in a mixed policy approach. The urgency of a robust policy mix for net zero was highlighted in statements emphasising the “value in combining markets and mandates”, the need for a ”belt and braces’’ approach, and the need to avoid the risk of ”putting all our eggs in one basket [with the ETS]”. The CTBO's role as a 'backstop' policy was noted as a distinct advantage, reducing the chance of failure on net zero by having two policy levers working together.

Benefit 3: Accelerating the energy transition

Timeline: Medium to long term (10-30 years)

A core economic effect of the CTBO is to internalise the cost of CO_2 storage into fossil fuel prices. This mechanism can drive behavioural change to reach net zero, making fossil fuels less competitive compared to low-carbon alternatives, especially as the storage obligation rises and renewables become more cost-competitive. Determining the magnitude of this economic effect requires further quantitative analysis that considers the price trajectories of CCS technologies, fossil fuels, and renewable technology.

Stakeholder Insights

There was widespread recognition among many stakeholder groups that a well-designed CTBO could drive an energy transition away from fossil fuels by reducing domestic fossil fuel use and consumption. While some stakeholders saw this as risky, particularly for energy security (see ‘Risks’ below), others saw it as the real 'power' of the CTBO. By making fossil fuels more expensive, the CTBO could create a strong incentive to shift to non-fossil based energy resources and feedstock, accelerating the decline of oil and gas extraction and aligning with national and international climate agreements. One stakeholder drew parallels with the decline of the coal industry in the UK, where stringent regulatory emission standards rendered coal use uneconomic. Similarly, it was highlighted that a CTBO with strict licence-to-operate restrictions built into its design could expedite the decline of oil and gas extraction.

Benefit 4: Reinforcing the ‘polluter-pays’ principle

Timeline: Medium to long term (10-30 years)

A combined ETS and CTBO approach would place responsibilities for decarbonisation on both upstream and downstream entities in the fossil fuel value chain. This approach is designed to build on the ‘polluter-pays’ principle[74] towards a principle of Extended Producer Responsibility (see **Section 6**). This joint approach shifts the risks associated with CCS development to the entities that benefit from the industry’s success.

Stakeholder Insights

Some stakeholders questioned the upstream obligation placement, preferring market-driven instruments like a carbon tax. However, a range of stakeholders saw advantages in the polluter-pays principle, as well as an emphasis on the stronger producer-pays principle. It was noted that oil and gas companies possess the financial resources and expertise necessary to deploy CCS. A strong regulatory instrument could more effectively incentivise a directing of these resources towards storage creation.

Some stakeholders also appreciated the CTBO’s ability to hold large polluters accountable for their climate impact, describing the opportunity to place polluters ”on the hook” as an attractive aspect of the policy if it worked alongside other policies that reduce fossil fuel use. Some stakeholders also saw a CTBO as more politically palatable than additional CCS subsidies, which often benefit fossil fuel companies[91].

5.2.2. 'Base Case+' scenario: Risks

Risk 1: Over-reliance on abated fossil fuels

Timeline: Short to medium term (0-15 years)

In the short- to medium-term, there is a risk of the CTBO slowing the energy transition away from fossil fuels if it is not complemented by appropriate demand-side measures. The design of a CTBO, particularly its technological agnosticism on capture methods, could mean that the cheapest way to fulfil the obligation initially would be through point-source capture or blue hydrogen use. If the ETS or other measures do not effectively reduce fossil fuel demand and encourage a switch to renewables, or if the CTBO scales up too rapidly before renewables are widely available and cost-effective, the lower marginal costs of fossil fuel production with CCS might make continued abated fossil fuel production more attractive than large-scale investments in other clean technologies, even when they do become cost competitive overall.

To prevent locking in unnecessary fossil fuel infrastructure and support the renewable energy transition (aligned with Criteria 1), stakeholders suggested:

- → A strong regulator specifying acceptable CO_2 sources that can be used to fulfil the obligation.
- → A CTBO that progressively phases out point-source options as the economy approaches net zero.
- → Combining the UK ETS and a CTBO with other measures to reduce fossil fuel demand while encouraging renewable uptake before the stored fraction rises, along with a robust and functioning CBAM.
- → Considering a storage fraction exceeding 100%, to achieve net-negative emissions.

Stakeholder Insights

Stakeholders were divided on this issue. Some expressed concern that a CTBO could allow indefinite (abated) fossil fuel use, giving fossil fuel actors an indefinite 'licence-to-operate'. Concerns were also raised about stimulating abatement and the need for measures to avoid double counting.

Conversely, some stakeholders were of the view that using abated fossil fuels is not inherently problematic, and highlighted that mitigation scenarios that achieve net zero include some abated fossil fuels through the transition to net zero. Discussions revealed the possibility of stipulating conditions for acceptable CCS infrastructure application to avoid lock-in and drive fast decarbonisation.

Risk 2: Adverse economic effects

Timeline: Medium to long term (10-30 years)

A combined market and mandate approach is likely to increase fossil fuel prices, particularly if high CCS costs make fulfilling the obligation more difficult. Arising from an upstream obligation, these costs would initially fall on fossil fuel producers and importers, but would likely be passed on to users and consumers, depending on the products' elasticity of demand. This presents several key risks for fossil fuel consumers, producers, exporters and importers. These risks are especially salient if policy is implemented unilaterally by the UK and without supportive measures.

Stakeholder Insights

Stakeholders widely underscored the importance of further research on the economic risks of a mandate policy and how these risks could be addressed. In particular, three key economic risks emerged from the 'Base Case+' scenario in the workshops:

1. **High costs of decarbonisation:** Stakeholders warned of the potentially high costs of decarbonisation enforced by a mandate policy, with some referring to it as "massively expensive" and "very costly". Some stakeholders questioned the willingness of UK producers and consumers to bear this financial burden and highlighted the risks of off-shoring industry. It is important to note that the actual magnitude of these costs – including different entities' ability and willingness to pay – is unknown, and requires further research and quantitative modelling. One stakeholder noted that high costs would apply in any climate policy that achieves net zero, and that this is not a risk unique to the CTBO.

2. **Regressive effects:** A wide range of stakeholders highlighted that without supplementary measures, a CTBO could have regressive effects, disproportionately impacting low-income households who are less able to switch to clean technologies. Stakeholders suggested additional measures, like targeted financial support schemes, to protect low-income households from rising carbon prices. It was noted by some stakeholders that energy and social policies should not be conflated, as regressive effects are expected when internalising the cost of pollution to consumer products, both as a result of the ETS and the CTBO.

3. **Economic impact on production and imports:** Some stakeholders underscored the risk that a CTBO could reduce incentives to produce and import fossil fuels into the UK by reducing profit margins, potentially damaging economic growth and risking capital flight. One stakeholder flagged that excessive regulation in the UK could make it a 'bad place to do business', resulting in carbon leakage. Other stakeholders highlighted that applying the CTBO to fossil fuel production and imports may alleviate this risk as it levels the playing field within the UK. A robust CBAM and coordination with industry were identified as key to avoiding carbon leakage, although some stakeholders did not see either of these measures as sufficient to protect UK energy security and exports. One stakeholder expressed a preference for a prospective obligation (on future emissions) rather than a retrospective one (on past emissions) to give companies' a clearer view on investment prospects. Ultimately, the magnitude of the economic effects should be examined in future work (see **Section 8**).

Risk 3: Unintended consequences from supply and demand mismatch

Timeline: Medium to long term (10-30 years)

If a CTBO is designed to include a storage obligation that rises too rapidly, there is a risk that it could disrupt consumer prices and fossil fuel supply, affecting UK energy security. This underscores the necessity of a mixed policy approach, with demand- and supply-side policy working in tandem to reduce fossil fuel supply and demand simultaneously. This could work, for example, through a simultaneous adjustment of the ETS cap and the CTBO's storage unit price. These policy interaction effects are explored further in **Section 6**.

Stakeholder Insights

Stakeholders expressed concerns about the timing of a rapidly rising storage fraction obligation. Concerns were expressed around a scenario where the storage obligation rises too high, too fast, which could affect consumer prices and cause potential sudden disruptions to the fossil fuel supply, with knock-on effects on energy security and the UK's reliance on imports. One stakeholder noted that policies reducing the profitability of UK production, including a CTBO, could result in early abandonment of fields with 10-15 years of production left, i.e. increase the risk of stranded assets. Another stakeholder suggested that this could be mitigated through other policy changes, such as adjusting the Energy Profit Levy (windfall tax) and implementing a slower scale-up of the obligation. The effects of different policy design choices, including the scale-up rate, are explored further in **Section 7** and should be quantitatively modelled.

Some stakeholders questioned the need for a CTBO, arguing that a global carbon tax or economy-wide ETS including GGR would be sufficient to incentivise the net zero transition. This perspective was previously elaborated upon in the analysis of the 'Base Case' scenario.

5.3. An Alternative Mandate: A Sector-specific CTBO, LCPS or LCFS

This section briefly explored an alternative mandate: implementing a ‘sector-specific CTBO’, or targeted mandate – such as a low-carbon product standard (LCPS) or low-carbon fuel standard (LCFS) – to drive CCS and GGR. Such policy could act to backstop a particular sector, or act as a ‘stepping stone’ to a wider rollout of a full economy CTBO. Low carbon fuel or product standards can be defined as policies that set a minimum standard for the CO_2 emissions intensity of a product sold, such as steel, cement, or vehicle fuels, to drive decarbonisation. A relevant legislative example is the California LCFS, a regulation on transport fuels mandating a declining CO_2 emission intensity over time[25]. Other examples include the UK’s sustainable aviation fuel (SAF) blending regulations[52] and petrol ethanol blending regulations[51].

LCPS/LCFS can be either non-specific by mandating suppliers to decarbonise their product at the point of sale or specific by mandating a particular technology or solution. For example, an LCFS on aviation fuel might require suppliers to use a specific technology (e.g. DACCS) to capture and store CO_2 emitted during its lifecycle, or more broadly require a progressive reduction in emission intensity over time. The latter allow suppliers to decide flexibly how to reach this target, likely resulting in a combination of technology switching, fuel blending, and CCS/GGR. To align with the key principles of a CTBO, a sector-specific mandate should drive CO_2 intensity to zero by the time of net zero, be applied upstream, and ensure any remaining emissions are permanently stored.

Table 5.2 below outlines how a policy mix including a sector-specific mandate could progress in the UK. This example transitions from subsidy-led market creation (2020-2030) to a phase with market-led CCS growth complemented by sector-specific mandates (2030-2035). In this scenario, the ETS delivers a CCS market in most sectors but has a limited impact on others. The LCPS and LCFS are applied to support the creation of a self-sustaining sector.

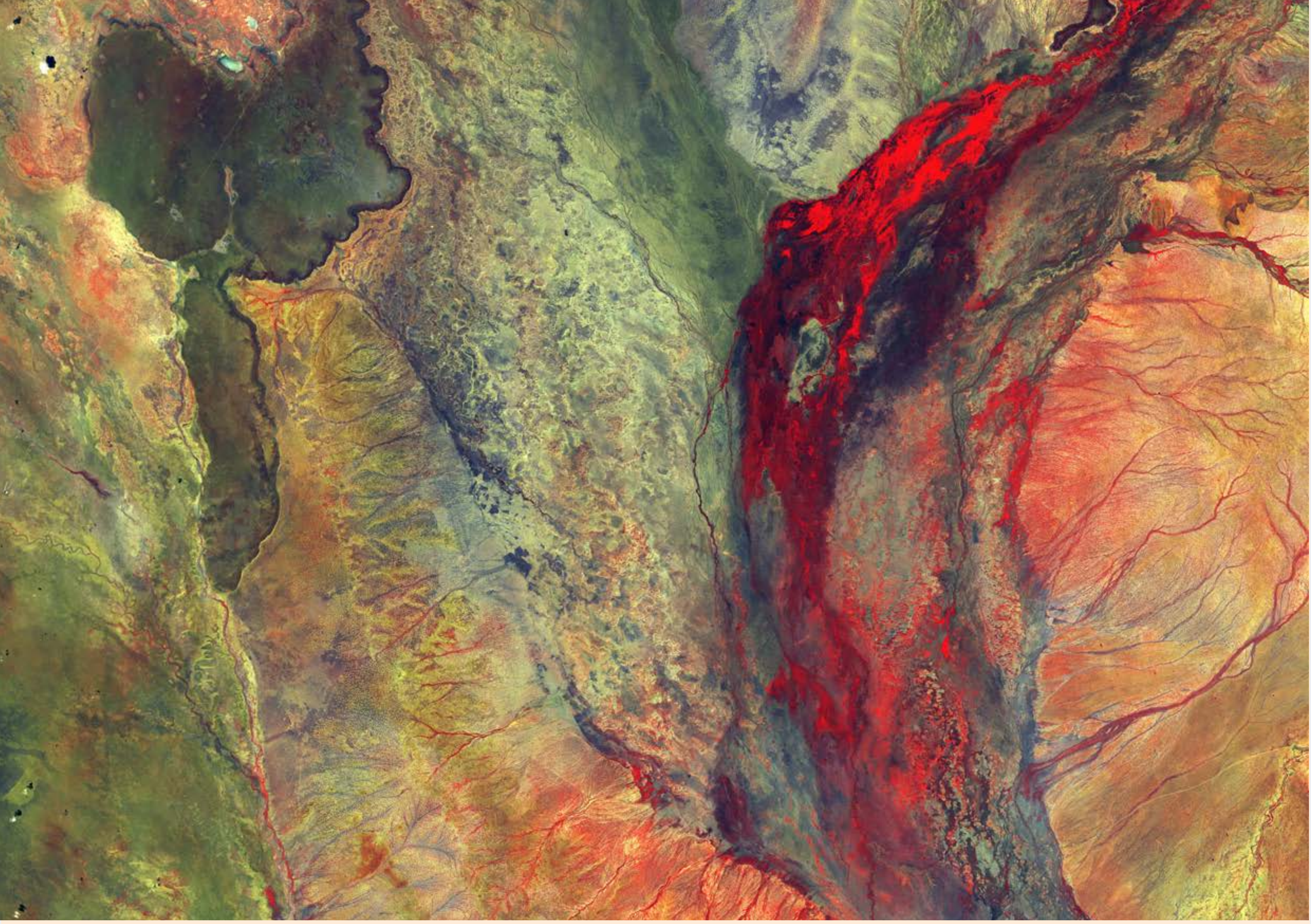
Stakeholder Insights

Stakeholders generally preferred a broader application of the CTBO, and some were strongly opposed to a sector-specific application. The primary concern with a sector specific mandate was the risk of economic inefficiency, as it could potentially pick ‘winners’ and ‘losers’ in the net zero transition that may not align with lowest-cost abatement options for the UK economy. It was noted that the government would need a legally robust rationale for selecting mandated sectors to mitigate perceived unfairness.

Nevertheless, some stakeholders were interested in the concept of a sector-specific mandate. Options discussed in the workshop for target sectors included oil and gas, cement, and transport fuels (see **Section 7** for a further exploration of these options). One suggestion was to apply a CTBO/LCPS to ‘hard-to-abate’ sectors only, which would require a clear definition and feasibility assessments. Additionally, some stakeholders highlighted the possibility of implementing sector- or fuel-specific CTBO as a preliminary step towards a wider rollout across all fossil fuel supply within a jurisdiction.

Table 5.2. Timeline of alternative mandate scenario: Economy-wide ETS with a sector-specific CTBO/LCPS/LCFS

Phase 1: Subsidy-led market creation (2020-2030)	Development of industrial clusters using private investment backed with government subsidy via CfD auctions, delivering 20-30 $MtCO_2$/year offshore storage by 2030.
Phase 2: Transition to market-led CCS growth with sector-specific support through mandate (2030-2035)	ETS market is expanded to cover majority or entirety of the UK economy. ETS policy is used to deliver a CCS market in most sectors, but may have reduced impact in specific sectors (e.g. transport fuels, building heating, or the steel industry). To support the ETS in these areas, a mandate in the form of a LCPS or LCFS is applied.
Phase 3: Market delivers net zero, with mandate development (2035-2050)	Long-term policy goals (scaling CO_2 storage market to 70-90 $MtCO_2$/year by 2050 and balancing residual fossil CO_2 production) are delivered through ETS policy, complemented by an enduring mandate mechanism in the form of LCPS or LCFS, reaching 100% stored fraction in 2050. Opportunity to expand the sector-specific CTBO implementation over time if the ETS approach falters.



Part 2

Mandate Design Choices

Framework for implementing carbon storage mandates and the CTBO: From core principles to practical policy design

6. Carbon Storage Mandate Policies

6.1. Introducing a Novel Carbon Storage Typology

Numerous legislative examples of carbon storage mandates have emerged. These are detailed in **Table 6.1**. As shown in the table below, each policy exhibits slight design variations, contingent upon a policymaker's primary objectives.

As discussed in **Section 2.2**, mandate-led policies, such as carbon storage mandates, are designed to prescribe outcomes that accelerate the net zero transition. These policies vary in design and primary objectives. To categorise the different types of carbon storage mandates, this report introduces a novel typology, illustrated in **Figure 6.2**. This typology highlights two types: mandates based on absolute storage targets and mandates based on stored fraction targets.

The former type requires specific entities to meet pre-defined, often quantity-based, storage goals. An example is the recently enacted Article 23 in the Net Zero Industry Act[23], which mandates oil and gas companies to contribute to a 50 $MtCO_2$ injection capacity target within the European Union. This is also referred to as an injection capacity obligation (ICO)[92].

Table 6.1. Legislative examples for carbon storage mandates

Title, year proposed	Jurisdiction	Bill/Process	Status	Capture Technology	Obligated Entity	Products included	Type
Article 23 (2024)	EU	Net Zero Industry Act	Enacted	Point-source CCS, engineered GGR	Domestic producers	Oil, gas	Legislation
Amendment 40 (2023)	UK	Energy Bill - 2023	Withdrawn	Point-source CCS, engineered GGR	Domestic producers	Oil, gas, coal, peat	Legislation
10% storage fraction target (2023)	UK	Independent Net Zero Review	Recommended	Point-source CCS, engineered GGR	Domestic producers	Fossil fuels	Independent inquiry
Oxburgh Amendment (2015)	UK	Energy Bill - 2015	Not passed	Point-source CCS, engineered GGR	Domestic producers, importers	Oil, gas	Legislation
SB308 (2021)	CA, US	CDR Market Development Act	Paused	DACCS and BECCS	Emitters	N/A	Legislation
Low Carbon Fuel Standard (2009)	CA, US	AB32 Scoping Plan	Enacted	CCS	Fuel producers	Gas, electricity, hydrogen, specific gasoline, biomass-based diesel, propane	Legislation

Notes: Mandatory schemes also exist for offsetting, such as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Yet, this is not highlighted in the main table as offsetting rules differ in permanence compared to the legislative examples for carbon storage mandates.

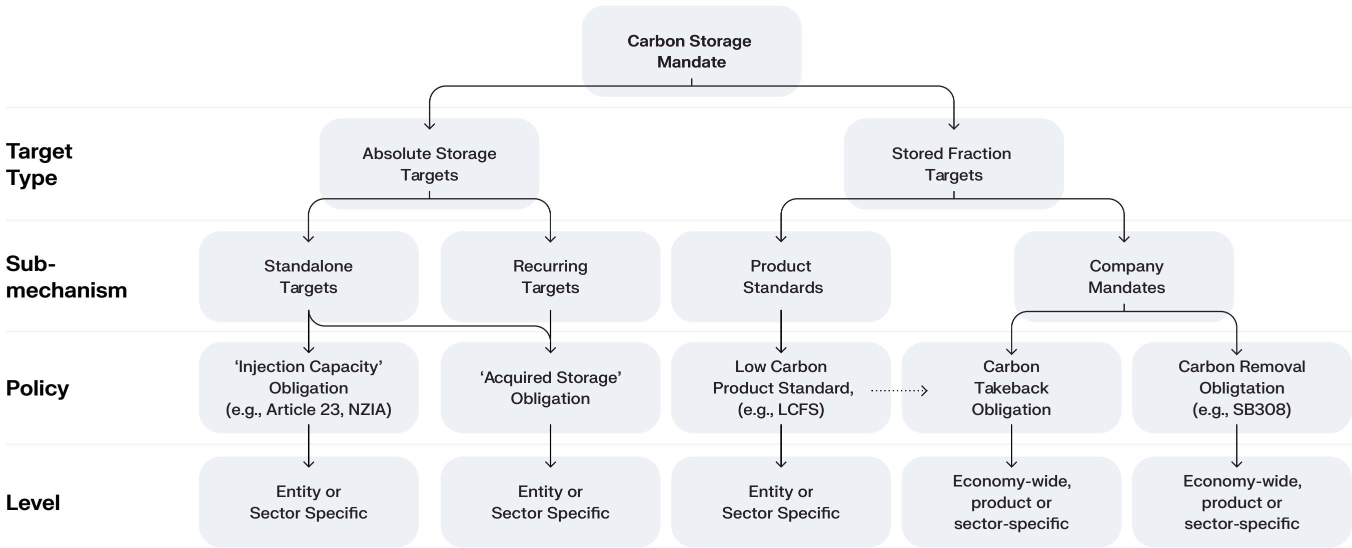


Figure 6.1. Typology of carbon storage mandates.

The second type of storage mandate encompasses stored fraction or intensity-based compliance schemes, which could include low carbon product/fuel standards, a CTBO or a carbon removal obligation (CRO)[67]. The latter focuses on the need for GGR, net-negative emissions and overshoot control through intertemporal mechanisms. Another important nuance, not illustrated in **Figure 6.1**, is that carbon storage mandates can impose immediate and full liability for all current and future CO_2 produced. Scholars argue that this liability provides a clear incentive to minimise emissions from the outset[93]. We define this as a policy design choice in stored fraction accounting, and highlight this nuance in **Section 7** (**Table 7.1**).

While **Figure 6.1** simplifies the categorisation of carbon storage mandates into an illustrative typology, in practice, mandate mechanisms may interconnect and evolve over time. An example is illustrated in **Figure 6.2**.

Next, we detail the characteristics of a CTBO, the mandate policy analysed in this report.

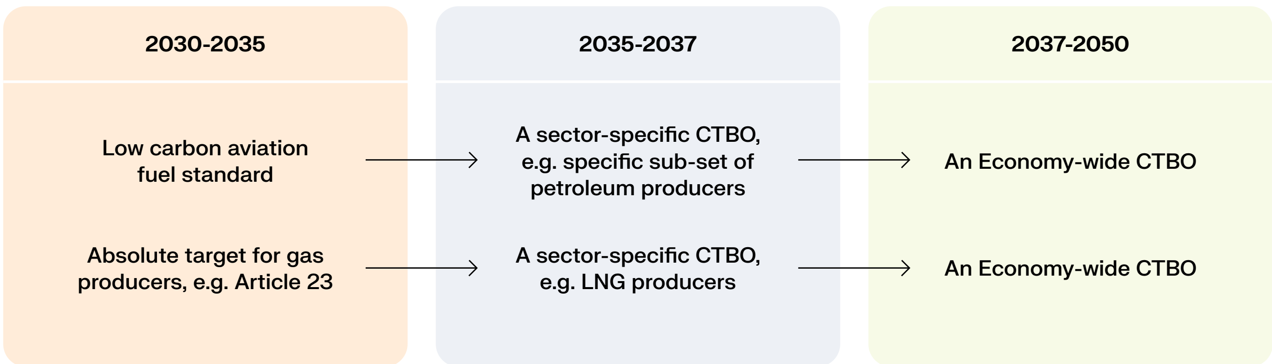


Figure 6.2. An illustrative example of policy implementation routes and interconnection between different mandates

6.2. Building Up the CTBO: Principles, Building Blocks & Objectives

6.2.1. Three core principles of a CTBO

A CTBO is a proposed type of storage mandate built on three core policy principles: (1) the Principle of Like-for-Like Balancing, (2) the Principle of Extended Producer Responsibility and (3) The Principle of 'Backstopping' Climate Policy.

The principle of 'like-for-like' balancing asserts that carbon emissions must be balanced with corresponding carbon sinks to achieve a durable stabilisation of global temperatures[18,19,21]. In essence, this means that any residual fossil fuel use at net zero is balanced by permanent, often geological, CO_2 storage methods ('geological net zero')[19]. This principle prevents obligated companies from relying solely on low-durability carbon sinks (such as nature-based solutions) in the long-term[18,22]. Although the CTBO could allow for the use of credible lower durability storage methods in the short- to medium-term (e.g. through a system of blended credits[22]), by 2050 and beyond, all balancing must adhere to the like-for-like principle.

The principle of Extended Producer Responsibility (EPR) is a widely adopted policy instrument in material products and circular economy frameworks[94]. It assigns upstream producers the responsibility for managing 'end-of-product' waste and subsequent clean-up efforts[94]. In the CTBO framework, this means that, in principle, fossil fuel producers bear the financial and/or operational responsibility of capturing and storing the CO_2 emissions embedded in their products, establishing a direct link between production and storage[64,65]. Although there is inevitably cost passed on to consumers, by assigning responsibility upstream, the CTBO is designed to build on the polluter-pays principle[vi], to a parallel producer-pays principle. How EPR could be applied to domestic versus imported products is discussed in **Section 7.2**.

The principle of 'backstopping' climate policy stipulates that the CTBO aims to achieve alignment with a final net zero goal by complementing other demand-side policies such as the UK ETS by linking production to storage, ensuring net zero is reached without defining a specific energy transition and technology pathway. It would internalise the cost of CO_2 clean-up of fossil fuel use – considered a negative externality – into fossil fuel product prices, potentially reducing their competitiveness compared to alternatives[22]. This mechanism would work alongside other factors that will determine the UK's net zero transition pathway, including storage availability, demand elasticity, and other climate policies to drive down fossil fuel demand.

Additionally, 'backstop' policies are essential for addressing uncertainties around the pace at which the global transition to alternative, cleaner energy sources will occur. Research findings highlight the risk that fossil fuels will be used for longer than predicted in IPCC 1.5°C scenarios[95–98] due to factors such as political willingness, access to technology and materials for the transition, and delays to renewable deployment caused by planning, social, and cost barriers. Consequently, policies that serve as a 'backstop' to the existing policy suite are necessary to minimise the climate impacts of continued fossil fuel use. These measures ensure that, even if the transition progresses more slowly than anticipated, the adverse effects on the climate are mitigated as far as possible. The success of a CTBO as a backstop policy, in turn, will depend on various factors including carbon leakage rates and whether it is implemented in conjunction with other decarbonisation policies.

[vi] Polluter-pays principle is core to environmental law across the EU and the UK (Department for Environment, Food & Rural Affairs, UK Government, 2023)

6.2.2. Key building blocks of a CTBO

Building on these principles, a CTBO policy framework is comprised of five key building blocks (**Figure 6.3**). The prevalence of each component is contingent upon policy design choices, explored further in **Section 7**.

→ Regulatory mandate: Unlike voluntary or subsidy-based schemes, a CTBO operates as a regulatory compliance policy. It is imposed on specific entities or sectors, integrating a CO_2 storage mandate into their 'licence-to-operate' or 'licence-to-sell' procedures. How flexible the mechanism is (e.g. through tradeable storage units) and how it is enforced will vary across jurisdictions and depend on policy design choices.

→ Independently verified storage certificates: A CTBO relies on entities demonstrating storage certificates confirming the permanent geological storage of CO_2. These certificates, verified by either government or independent organisations, may be tradeable, allowing mandated entities to store CO_2 themselves or pay storage companies to do so. These storage certificates can be generated by a verified authority from the purchase of Carbon Storage Units (CSUs), where each unit represents one tonne of CO_2 permanently stored and is retired after use[65,66,99].

→ Geological Net Zero aligned stored fraction: A CTBO mandates a progressively increasing stored fraction, requiring entities to store a rising percentage of the CO_2 embedded in their products. This culminates in a stored fraction of 100%[vii] by the net zero target year, which is 2050 in the UK. It may even exceed 100% to achieve net-negative emissions[22,66]. The feasibility of exceeding 100% depends on the size of residual emissions from fossil fuel sources, the financial ability of entities to comply, and the demand elasticity for fossil fuels.

→ Requirement for permanent carbon storage: The like-for-like principle denotes that carbon storage under a CTBO must be permanent, based on robust and credible definitions of permanence in scientific literature. For instance, suitable CO_2 storage sites might require a 'gold standard' CO_2 leakage rate below 0.5% over 10,000 years, indicative of geological carbon storage[100]. Alternatively, some definitions consider storage over 1,000 years as high permanence, reflecting the atmospheric lifetime of fossil fuel-derived CO_2[101]. Definitions of permanence should follow the like-for-like principle.

→ Compliance benchmarks with strong penalties: A robust CTBO framework incorporates compliance mechanisms. This involves setting a reasonable compliance period (e.g. a 1 year or 3-year compliance window), defining carbon accounting rules and inventory parameters, and enforcing penalties for non-compliance[66].

[vii] Note that 100% stored fraction on the emissions embedded in fossil fuel products will necessitate point-source capture and GGR methods such as BECCS and DACCS.

Three Core Principles	The principle of 'like-for-like' balancing		The principle of Extended Producer Responsibility		The principle of 'backstopping' climate policy
Building Blocks	Regulatory mandate	Independently verified storage objectives	Geological Net Zero aligned stored fraction	Requirement for permanent carbon storage	Compliance benchmarks with strong penalties
Objectives	Long-term market stability	Low-subsidy route to building CCS and GGR	Alignment with Paris Agreement and GNZ	Stimulating a competitive market	Active carbon management and fossil fuel phase-out

Figure 6.3. Carbon Takeback Obligation: principles, building blocks & objectives.

6.2.3. Objectives of the CTBO

Given the nascent stage of CTBO scenario modelling for the UK, this report cannot provide quantitative insights into the likely outcomes of a CTBO. However, based on CTBO-specific literature and stakeholder feedback as highlighted in **Section 5**, key objectives of such a policy include:

1. **Long-term market stability:** A CTBO aims to create a predictable investment pathway for carbon storage, with a rising storage percentage driving steady capacity building. The mandate ensures a level playing field between mandated companies, helping to direct companies' financial resources and geological expertise towards capturing and permanently storing carbon.

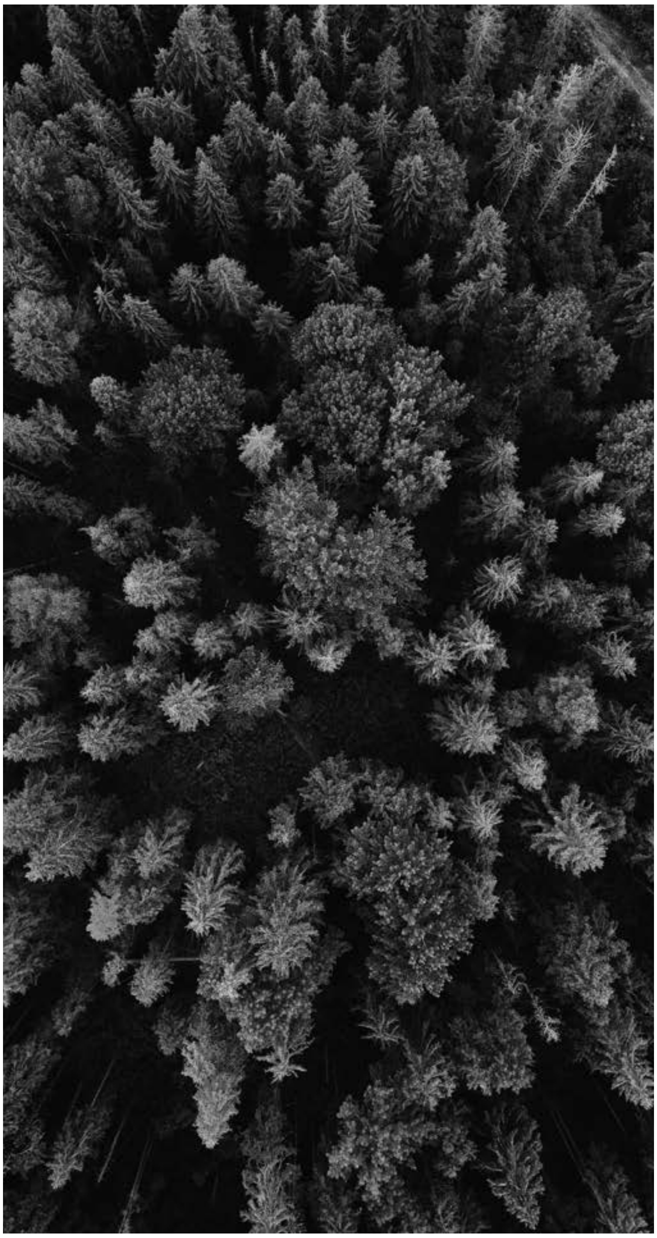
2. **Low-subsidy route to building CCS and GGR:** Implementing a CTBO enables the government to reduce financial support for CCS development, decreasing the dependence on subsidies for reaching net zero. There might be instances where government support and blended finance are necessary, but the CTBO ensures this is the exception rather than the rule. CTBO also promotes the technological development needed to reach net zero and net-negative emissions.

3. **Alignment with the Paris Agreement and Geological Net Zero (GNZ):** A CTBO ensures adherence to the Paris Agreement goals by linking production to storage levels, based on entities' cumulative emissions and a pre-determined carbon budget. This approach also enhances the accuracy of carbon accounting[19,93], making it easier for downstream users to decarbonise while ensuring that, by the time of the net zero target, any remaining CO_2 generated by fossil fuels is geologically stored[19].

4. **Stimulating a competitive market:** The upstream obligation, with costs passed down the value chain, helps drive innovation to reduce costs, promoting a competitive CCS market. Cost distribution is influenced by demand elasticity and the availability of alternative low carbon energy sources. Moreover, starting with a low-level obligation at first stimulates early learning in the storage value chain.

5. **Active carbon management and a transition away from fossil fuels:** The CTBO promotes carbon management plans and could aid the global commitment in the UAE Consensus to transition away from fossil fuels[102]. This is driven by increased costs of high-carbon sources and regulatory penalties[22,64].

In addition to the intended consequences of a CTBO, there are potential unintended consequences of relying on CTBO-specific policy scenarios. This was elaborated upon in the scenario analysis in **Section 5** of the report.



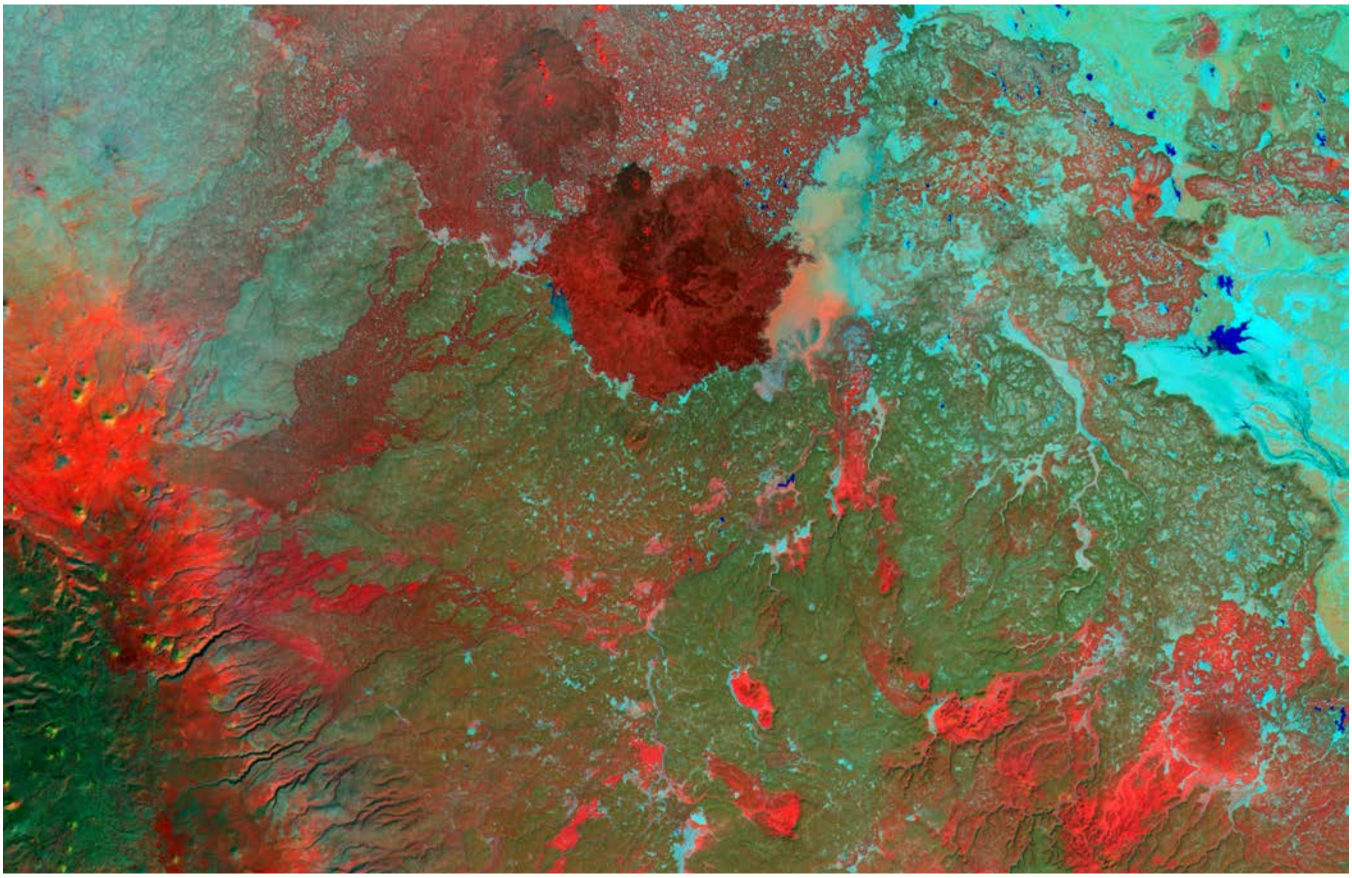
6.2.4. Comparing CTBO to alternative storage mandate policies

A CTBO policy is built on the three core principles and five key building blocks laid out above. Different carbon storage mandates contain different elements of these principles and building blocks. **Figure 6.4** provides a comparison of different carbon storage mandate policies and their adherence to key tenets of a CTBO. Note that this is not an evaluative table of different policies, but is rather an illustrative figure to highlight the design differences in proposed storage mandates policies.

	Principles			Building Blocks				
	Like-for-Like	EPR	Backstop	Mandate	Certificates	Stored Fraction	Permanence	Compliance & Liability
Carbon Takeback Obligation	✓	✓	✓	✓	✓	✓	✓	✓
Article 23, Net Zero Industry Act	✓	✗	✗	✓	–	✗	✓	✓
Amendment 40, Energy Bill	✓	✓	✓	✓	–	✓	✓	✓
SB308 Carbon Dioxide Removal Market Development Act, California	–	✗	✓	✓	✓	✗	✓	✓
Low Carbon Fuel Standard, California	–	✗	✗	✓	✓	✗	–	✓

Figure 6.4. Demonstrates how different carbon storage mandate policies align with the key principles and building blocks central to the CTBO. Green signifies inclusion of the principle/building block, red indicates exclusion, and yellow indicates uncertainty or decisions yet to be made. For instance, in the SB308 legislation, durable sequestration of carbon is referenced, but the specific criteria for removals included in the legislation are yet to be approved by the State legislator[112] and State Board. The SB308 in this figure refers to the first iteration from May 2023.

7. CTBO Design Choices: Exploring Alternatives



When designing a carbon storage mandate such as a CTBO, policymakers need to consider various design options, which can be tailored to specific policy objectives. We identify five key design choice categories within a CTBO, informed by stakeholder input from workshops and interviews. Due to project constraints, it is beyond the scope of this report to explore the benefits and risks of each choice in depth. We have summarised stakeholder insights on each design category in more detail in **Annex B**. The five key design choice categories of a CTBO are:

1. **Shape & Endpoint of Stored Fraction**
2. **Obligation Placement**
3. **Technology & Location Accreditation**
4. **Governance Mechanisms**
5. **Interaction with Other Climate Policies**

7.1. Design Category 1: Shape & Endpoint of Stored Fraction

Table 7.1. outlines decisions regarding the shape and scale of the stored fraction to align with the UK's net zero commitment by 2050. Policymakers may calibrate this according to various factors such as domestic carbon storage targets, policy objectives around fossil fuel phase-out, and distributional effects.

Research on the CTBO suggests starting with a 'low and slowly rising' trajectory for storage targets, acknowledging that the CO_2 storage sector will take a decade or more to mature under existing market-creation policies[64]. To ensure compliance with Paris 1.5 °C scenarios, findings from CTBO modelling recommend starting with an initially small storage fraction target, rising in a quadratic trajectory reaching around 10% in the early 2030s, 50% in the early 2040s, and reaching 100% in the 2050s to achieve net zero[64]. Achieving this trajectory would also rely on significant reductions in fossil fuel use, necessitating a comprehensive policy suite that includes demands control measures and promotion of renewable energy deployment.

Table 7.1. Design choices for the shape & endpoint of the stored fraction

	Description	Options
Starting stored fraction obligation	This choice reflects the initial stored fraction that a mandated entity is obliged to store in the first compliance period.	→ A low initial percentage, e.g. 3%, to facilitate testing and learning within the new regulatory framework. → An initial percentage aligned with the UK storage targets for the implementation year. → A high initial percentage, such as 10%, to establish an ambitious compliance regime. → An immediate 100% liability, utilising futures accounting for storage compliance[93].
Speed of obligation increase	This choice reflects how fast the stored fraction increases from the implementation year to net zero, and potentially beyond. The increase in obligation percentage can occur annually or at specified interval periods.	→ A linear increase per year might delay net zero alignment depending on the initial obligation percentage, and rate at which suppliers increase CO_2 storage or decrease CO_2 production. → A quadratic increase aligned with IAM 1.5 °C scenarios (e.g. 0% in 2025, ~10% by 2030, ~45% by 2040, 100% by 2050) as presented by Jenkins et al. (2021), resulting in a plateau around or post-2050. → A percentage increase in 5 to 10 year intervals, determined in co-operation with CCS stakeholders to determine viability at key intervals.
Endpoint	This choice reflects the 'final' obligated stored fraction. The endpoint depends on the objective of the CTBO and other policy mechanisms' complementary contributions to the UK carbon budgets (e.g. whether overshoot is covered by other instruments).	→ A stored fraction below 100%, which does not align with the objective of achieving geological net zero. → A stored fraction of 100%, which ensures that obligated entities or sectors reach geological net zero. → A stored fraction above 100%, which incentivises net-negative emissions for the UK's remaining fossil fuel use*.

Notes: *Note that the ability to raise the stored fraction above 100% depends on the size of the residual emissions from fossil fuel sources, the supplier's capacity to comply, and the demand elasticity for fossil fuels. This implies that guaranteeing the net-negative storage/removal pathway might be challenging. Policymakers need to balance these considerations and determine the appropriate acceleration rate and final stored fraction.

The trajectory of the obligation percentage would be influenced by exogenous factors such as the cost of fossil fuels, renewable energy, and CCS technology; the time required to issue transport and storage licences; social acceptance; and international policy ambition. Given this complexity, it is crucial to model the CTBO's impact within a socioeconomic framework of the UK economy and energy system, considering factors such as impacts on UK competitiveness and economic opportunities.

In **Annex B – Table B1**, stakeholder insights reveal that while there was no consensus on the shape and endpoint of the stored fraction, it is clear that decisions on this design choice must balance climate ambition with feasibility, including storage availability.

7.2. Design Category 2: Obligation Placement

Table 7.2 outlines decisions regarding the placement of the obligation, also known as the compliance point[66]. Factors to consider when selecting the obligation placement include alignment with net zero targets and impacts on fossil fuel prices, market structures, and industry competitiveness. Policymakers may consider a flexible approach, differentiating obligations based on entity or production size, with the potential to expand from a limited scope to an economy-wide application by 2050 and beyond. Depending on final design choices, the obligation might need to incorporate risk-sharing mechanisms and commercial contracts stipulations to address cross-chain risks for CO_2 storage deployment. While we recommend maintaining simplicity in this aspect, we acknowledge existing compliance and liability regulations could affect the government's decision-making process.

Table 7.2. Design choices for the obligation placement

	Description	Options
Type of entity*	This choice defines the entities obligated under the CTBO scheme. Obligated entities would have to demonstrate sufficient levels of carbon storage certificates** as part of their licence to operate or sell.	→ Upstream extractors/producers within a jurisdiction. How far upstream the obligation applies (e.g. at the wellhead versus at production facilities) is a policy decision. → Inclusion of importers to ensure parity between domestic and international products. → Mandating all fossil fuel suppliers, whether upstream or further down the value chain. → Mandating emitters or fossil fuel users to acquire storage certificates.***
Type of product	This choice dictates the fossil fuel products covered by the CTBO scheme. It may evolve from sector-specific to economy-wide by the time of net zero.	A CTBO can cover all or specific fossil fuel products/fossil-derived CO_2 production****, including: → Coal (hard, brown and coal products) for thermal and metallurgical purposes → Natural gas → Manufactured gases → Peat and peat products → Oil for energy (fuel products) → Oil for chemicals/plastics → Limestone and cement

Notes. *Obligated entities can be differentiated by size, ability to pay or ability to comply. **The obligation placement decision also involves identifying the specific point in the value chain where MRV and export/import regulations would apply, and where carbon storage certificate compliance checks would be integrated. ***Mandating emitters/fossil fuel users to acquire storage certificates would contravene the principle of extended producer responsibility (a core principle of CTBO) and would therefore be categorised as a different type of storage mandate. Additionally, this approach could increase complexity by increasing the number of mandated entities compared to an obligation placed further upstream. ****Due to the limited scope of this study, we have not appraised the impact of each specific product option. We thus recommend caution in assuming a CTBO is viable for each product, as this requires further investigation.

It is important to note that this report focuses on examining a CTBO as a mechanism to regulate domestic fossil fuel production and imports within the UK jurisdiction. We do not explore how this regulation might be applied to the overseas operations and trade of UK entities. This requires further investigation.

Stakeholder insights in **Annex B - Table B2**, as well as the scenario analysis in **Section 5.3**, show a strong preference for an economy-wide application of a CTBO, covering all fossil producers and importers. Some stakeholders indicated a preference for a phased approach, starting with a sector- or product-specific CTBO that ultimately developing into an economy-wide mechanism.

7.2.1. Exploring obligation placements

The stakeholder conversations in this project briefly explored different types of fossil fuel products falling under a CTBO. This is discussed further in **Section 5.3** and **Annex B – Table B2**. A summary of the most prevalent options discussed – a CTBO on gas, a CTBO on cement/limestone, and a CTBO on transport fuels - are highlighted below.

Gas

A 'gas only' CTBO could serve as a starting point for CTBO implementation since gas is likely to remain in the UK's electricity system through to net zero[4]. Some stakeholders highlighted that the gas market's composition and demand also make it suitable for a carbon storage mandate sponsoring CCS deployment, as it is typically utilised in high-heat industrial processes, which are well-equipped for point-source CCS. One stakeholder noted that the gas market is less complex compared to other fuels, with fewer supply-side actors and more limited input flanges into the pipeline network. However, some workshop participants cautioned that focusing on gas could produce a waterbed effect, where adjustments in one system affect the other, inadvertently stimulating demand for other fossil fuels.

Cement/Limestone

Further research is needed on the potential of a sector-specific CTBO on other sectors with fossil-derived CO_2 production, such as limestone/cement producers. Limestone and cement face unique decarbonisation challenges, and a storage mandate scheme covering the cement industry could give the sector the advantage of offering a near-pure CO_2 stream for generating carbon storage units. However, the complexity of the supply chain, along with low market liquidity and narrow profit margins, necessitates further analysis to understand the potential impact of a CTBO on this sector.

Transport fuels

While not a primary design option discussed in this report, some stakeholders in the workshop advocated for the adoption of a low-carbon or net zero fuel standard to encourage investment in technologies such as hydrogen, e-fuel synthesis, biofuel production, and direct air capture. Decarbonising the transport sector, particularly international aviation and maritime transport, presents unique challenges, including complex accounting methods, persistent demand for transport, and limited opportunity for large-scale fuel switching, particularly for long-haul flights and shipping. Stakeholders highlighted the need for further investigation to ensure decarbonisation claims are robust and to address potential issues, such as transport providers refuelling in countries without such mandates. This underscores the necessity of a coordinated cross-border approach to effectively manage emissions from both aviation and shipping.

7.3. Design Category 3: Technology & Location Accreditation

Table 7.3. outlines options for how the obligation could be fulfilled, including CO_2 capture technology (e.g. BECCS[viii], DACCS) and storage locations. These choices determine how storage certificates (CSUs) may be generated.

[viii] BECCS, as referred to in this report, can encompass all forms of carbon removal, capture, and permanent storage through biomass. This can include biochemicals, pyrolysis, torrefaction, biochar, bio-oil storage, biomethane, bio-hydrogen, and bio-ethanol. An overarching term is Biomass with Carbon Removal and Storage (BiCRS).

While geologically stored CO_2 would meet permanence requirements, regulators may deem certain forms of storage inappropriate, such as CO_2 used for enhanced oil recovery, which some scholars describe as “counterproductive” to climate goals[88]. Regulators might prioritise a CTBO for sectors that require CCS and GGR to align with net zero targets, inspired by existing CCS ‘priority ladders’[99].

The latter could involve starting with a CTBO for hard-to-abate sectors and sequencing the implementation based on technical feasibility and environmental guardrails. Although this faces risks of economic inefficiency, proponents contend that CCS sequencing and prioritisation can prevent delays in the renewable energy transition and reserve storage capacity for true residual emissions[103]. Regulators should consider whether methodological frameworks like ‘priority ladders’ are valuable for assessing the opportunity cost of CCS, prioritising licensing, and allocating government support.

Table B3 in **Annex B** presents stakeholder insights on ‘Technology & Location Accreditation’. Stakeholders highlighted the importance of permanent CO_2 storage for achieving credible, durable net zero. However, there are disagreements between stakeholders regarding the physical origin of CO_2, storage access priorities and the strictness of storage standards.

Table 7.3. Design choices for technology & location accreditation

	Description	Options
Physical CO_2 origin & location of storage	This choice defines which capture technologies (i.e. the source of CO_2) and storage locations (i.e. where CO_2 ends up) are permissible for complying with the storage obligation.	The physical origin of CO_2* can be divided into: → Different point-source CCS methods. → Various GGR methods, including direct air capture and biogenic-based capture.** Storage methods must adhere to permanence criteria, following the like-for-like principle. Options include, but are not limited to: → Geological storage, either offshore or onshore. → Other forms of durable GGR***, such as mineral carbonation or enhanced terrestrial weathering.
Geographical CO_2 origin & location of storage	This choice specifies the geographical origin of the captured CO_2, as well as the locations for where CO_2 can be stored to be compliant with the storage obligation.	→ Restrict to domestically captured and stored CO_2. → Restrict to domestically stored CO_2, but allow internationally captured CO_2 to fulfil the UK obligation. → Permit international storage of CO_2 through a system of international storage credits (CSUs or equivalent), either globally or within specific jurisdictions. This can be established through bilateral agreements to ensure standards parity with UK storage locations.
Rules & standards for qualification	This choice specifies the additional rules and standards imposed on carbon storage certificates used to fulfil the CTBO.	Options for additional regulation include, but are not limited to: → Permanence qualifications**** → Monitoring, Reporting and Verification (MRV) frameworks → Accounting rules → Purity of CO_2 stream → Exclusion/inclusion of enhanced oil/gas recovery → Compliance with energy efficiency standards → Assessment of storage location fitness (e.g. seismicity)

Notes.*It is a policy decision whether CO_2 sources should include CO_2 separated from natural gas during extraction or CO_2 injected for enhanced oil recovery. Guardrails must be highlighted if such sources are accepted. **Consideration should be taken on the accreditation of CO_2 source, especially if a CTBO is not applied on all fossil carbon extracted. For instance, if a CTBO only applies to oil and gas suppliers, it could be counterproductive for CO_2 from coal and cement to qualify for compliance credits for the oil and gas suppliers. ***The regulatory body is responsible for defining the criteria for durability. ****Permanence qualifications can be flexible, potentially utilising a two-phase system or blended credits.

7.4. Design Category 4: Governance Mechanisms

Governance questions around the CTBO include the legislative route to implementation, the assigned regulator for moderating compliance, compliance conditions, penalties for non-compliance, and accounting rules.

7.4.1. Legislative routes

Discussions in the stakeholder workshop highlighted potential legislative routes for the CTBO, including anchoring the legislation in the Climate Change Act 2008, or amendments[ix] to the Petroleum Act 1998 and the Energy Act 2023. Another potential implementation route is through legislation that mandates CO_2 injection, storage capacity creation, or procurement plans as part of the extraction approval process. This could be, for example, through current climate checkpoint processes[x] for domestic extraction and production under the NSTA.

7.4.2. Regulator and non-compliance

Potential regulators of the CTBO include Ofgem, NSTA and DESNZ, with the choice depending on which entities are obligated, interactions with other policies (e.g. UK ETS), and how closely storage licences would be linked to fossil fuel extraction. Once decisions have been made on the above design choices, the regulator would need to establish a period in which companies would have to comply, and define explicit compliance and reporting rules. Like other compliance schemes, the regulator would need to consider how to provide sufficient lead times for projects, the level of flexibility in the banking & borrowing of CSUs, and implementation of price collars (minimum and max price) for CSUs. Lessons can be drawn from ETS mechanisms such as the Cost Containment Mechanism and Auction Reserve Price. The regulator could establish a state-controlled authority for these mechanisms and for the verification of CCS storage delivery, as well as draw inspiration from ideas such as that of a carbon central bank[104]. Alternatively, the regulator could grant verified third-party companies the right to issue, verify and monitor carbon storage certificates based on demonstrated storage by obligated entities.

Potential non-compliance with the CTBO that a regulator could monitor include:

→ Failure to meet storage targets: Entities failing to achieve the required stored fraction of CO_2 production within the compliance window.

→ Inaccurate reporting: Submitting false or misleading information regarding the amount of CO_2 captured and stored.

→ Lack of certification: Failing to obtain verified carbon storage certificates from approved entities for the claimed stored CO_2.

→ Delayed reporting: Missing deadlines for submitting required reports and documentation on CO_2 capture and storage activities.

→ Insufficient Verification: Using unapproved or uncertified third-party verifiers for carbon storage certification.

7.4.3. Non-compliance penalties

Table 7.4. outlines potential penalty processes for non-compliance within a CTBO regulatory framework.

Stakeholders emphasised the importance of a robust and strict penalty system for non-compliance (**Table B4 – Annex B**). Additionally, regulators would need to clearly define penalties for CO_2 leakage from storage sites to ensure alignment with broader CCS and GGR liability regulations.

[ix] Potential amendments may encompass changes to storage procurement conditions and energy licensing requirements, or the establishment of a new legislative obligation, modelled after the decommissioning obligations in the Petroleum Act.

[x] The UK has a Climate Compatibility Checkpoint for oil and gas licensing for domestic North Sea extraction. Read more in the policy brief Jenkins et al. (2024) 'Paving the way to Net Zero: A New and Credible Climate Compatibility Check- point for UK Oil and Gas Production'.

Table 7.4. Design choices on non-compliance penalty processes

Penalty Process	Description	Options
Financial penalty	A regulator can impose financial penalties in case of non-compliance, issued by the relevant regulator.	→ Penalty based on a shadow price aligned with the damage caused by GHG emissions, potentially aligned with existing carbon pricing mechanisms. → Penalty equal to the cost of capture and storage, whether at the highest or average price levels. → Artificially high penalty fee (e.g. £1000 t/CO_2) to strongly discourage non-compliance.
Payment to government storage procurement fund	A regulator can denote a government-regulated procurer, either as part of a government department or a separate entity, e.g. green infrastructural bank, to collect payment to a dedicated 'non-compliance' fund.	→ A government-regulated fund that receives payments from obligated companies, with the funds used to directly procure carbon storage.
Future storage obligations	A regulator can impose increased future storage obligations in case of non-compliance[67,93].	→ Increased future storage procurement to ensure the original storage obligation is met. → Increased future storage obligation, imposing additional storage procurement as a penalty 'on top of' regular obligations.
Restrictions on operations	A regulator can impose various restrictions on company operations in case of non-compliance.	This could include, but is not limited to: → Production limits → Operational downtime → Restricted access to markets → Licence modifications (also below) → Investment restrictions → Financial penalties → Resource allocation limits → Suspension of permits (also below)
Loss of licences to produce or sell	A regulator can revoke licences if an obligated entity fails to comply. Similar to the ETS, this measure could be imposed as a consequence of persistent non-compliance.	→ Revoke previously issued import/production licences. → Revoke future import/production licences, either immediately or at a specific acquisition stage.

Notes: This table does not include a discussion on the compliance window. This needs to be defined to benchmark the calculated number of certificates/CSUs issued and retired to the regulator.

7.4.4. Other governance questions

Regarding other governance issues, stakeholders primarily expressed concerns about mitigation deterrence and unclear accounting rules. Some were particularly worried about an overreliance on abated fossil fuels, as explored in **Section 5.2**. Discussions highlighted that these risks could be mitigated through clear regulatory oversight.

One stakeholder noted that similar to other climate policies, a CTBO implementation would need to be dynamic, driven by an 'intelligent regulator' who would adapt and refine the policy as implementation progresses (**Table A4 – Annex A**). However, we note that sufficient certainty on how a CTBO will be implemented is essential to foster trust and investor certainty in CCS and the CSU market.

7.5. Design Category 5: Interaction with Other Climate Policies

This section outlines the options for integrating a CTBO with other climate policies, including the UK ETS and CfDs. We note that this is not an exhaustive overview, and further policy development, as well as quantitative research, should take place in cooperation with regulators and government bodies.

7.5.1. Interactions between CTBO and the UK ETS

How a CTBO and ETS could work together

As highlighted in **Section 2.2** and **Section 5.2**, a CTBO and the UK ETS represent complementary approaches to mitigating climate change, addressing CO_2 emissions at different stages of the fossil fuel value chain. The CTBO ensures permanent disposal of CO_2 by regulating upstream entities, while the ETS reduces fossil fuel use by imposing a declining cap on emissions by regulating fossil CO_2 emitters.

As the ETS emission cap decreases and the CTBO stored fraction increases, the two instruments should be designed to work in tandem. As the economy approaches net zero, the ETS nears its endpoint, characterised by the exhaustion of allowances and a zero emissions cap. At this point, the CTBO could effectively transition into a CO_2 removal obligation for remaining residual emissions, placing pressure on upstream entities to develop GGR technologies to meet the rising storage obligation.

Mandated entities under a CTBO must demonstrate storage certificates. Certificates could be based on a number of obligated 'Carbon Storage Units' (CSUs) purchased, with each unit representing one tonne of permanently stored CO_2[65,66,99]. CSUs and certificates could be verified by either government or independent organisations and can be tradeable. This would allow mandated entities to either store CO_2 themselves or pay storage companies to do so.

Interactions between the CTBO and ETS

Earlier European Commission consultations on a 'CCS certificate scheme' raised concerns about potential interference with the ETS[66]. However, stakeholder consultations in this project revealed a widespread, but not unanimous, agreement among stakeholders on the need to integrate CTBO and ETS mechanisms. The following discussion thus assumes that the ETS and CTBO would interact, although the level of interaction would depend on the design choices of each policy and external factors such as the extent of future fossil fuel production. An alternative approach, involving a complete decoupling of the ETS and CTBO, is discussed in **Annex C**, along with a more extensive discussion on how the ETS and CTBO may interact to finance CCS and GGR deployment.

Figure 7.1 provides two simplified options for how it may be possible to allow for interaction between a CTBO and the ETS:

→ Option 1 is based on a carbon storage unit (CSU) price that covers the full value chain cost of CO_2 capture, transport and storage. In this option, the emitter is paid by the storage provider for the CO_2 the emitter has captured, as the storage provider needs this CO_2 to generate CSUs.

→ Option 2 is based on a CSU price that covers only the transport & storage cost, and does not include the CO_2 capture cost. In this option, the emitter pays the storage provider to store their CO_2 as part of their ETS compliance.

In both options, the fossil fuel producers/importers (the 'obligated entities') are mandated to acquire CSUs. The choice between these options, as well as how the eventual costs for CCS are distributed across the value-chain in the UK, would depend on market efficiency and the regulator's design preferences. It would also be influenced by the value of a CSU compared to the cost of emitting CO_2 in the ETS compliance market, both of which would evolve over time in the transition to net zero. This requires further quantitative modelling (see **Annex C**).

There would also be a CTBO compliance cost embedded as a surcharge within fossil fuel products sold throughout the wider economy (represented by the 'CSU in product price' in **Figure 7.1**). The relative size of this cost for the emitter would depend on the ability of the market to distribute the compliance cost across the entire value chain, from the upstream producer to the downstream user. This distribution would also be influenced by the approach taken to ETS/CTBO integration. Note that the compliance cost would be likely to impact company/shareholder profit margins, for upstream producers, midstream entities, and downstream users of fossil fuel products.

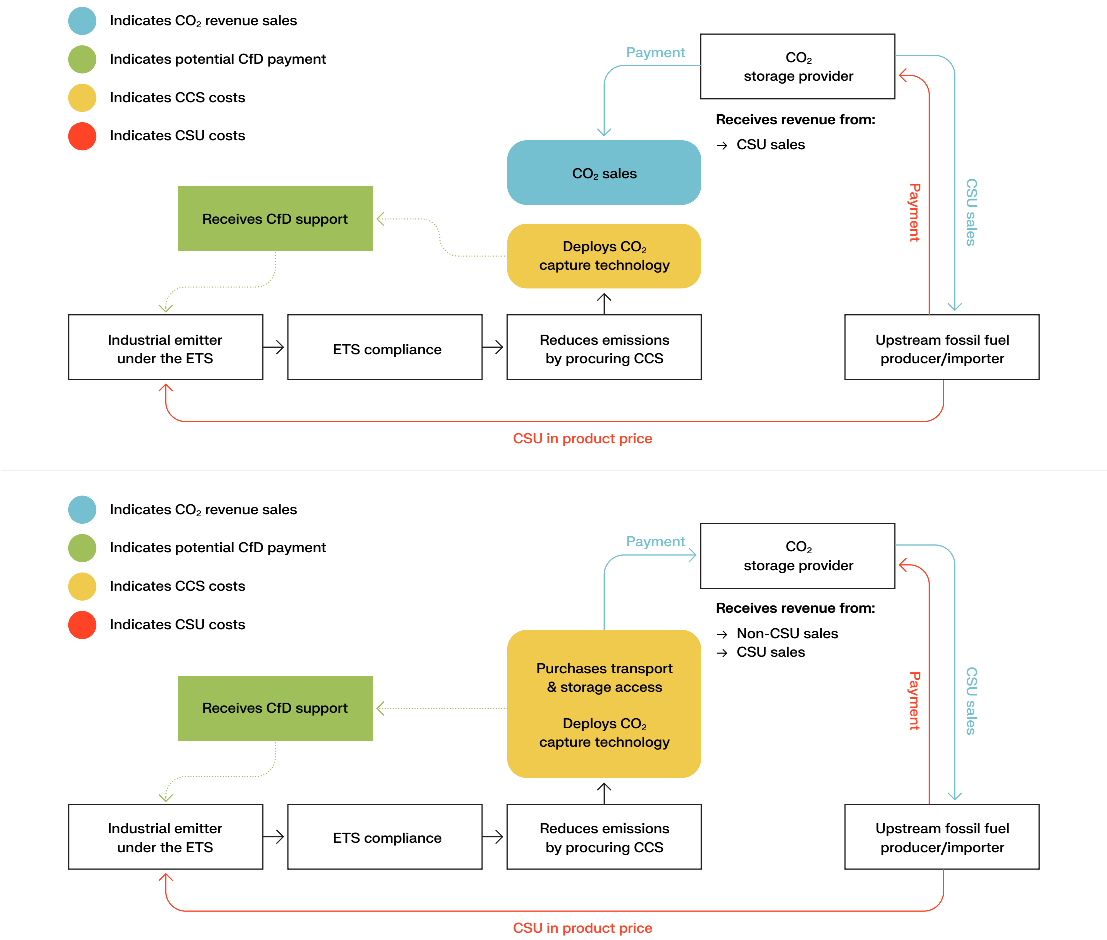


Figure 7.1. An illustrative example of optionality in interactions between ETS and CTBO. In this figure, we assume that CO_2 storage providers and fossil fuel (FF) producers/importers are separate entities. This might not be the case in real life and depends on how the government regulates the market. CfD support depends on ETS and CSU prices and is thus reflected with a dashed line as it is a potential payment. Moreover, the exact cost distributions, including the size of CSU cost in product price, should be modelled ex-ante.

Potential interaction risks

Similarly to other climate policies, the interplay between the ETS and the CTBO would require some form of adjustment to the ETS cap. In particular, it is crucial to account for the 'waterbed effect' in which adjustments to one system affect the other. Failure to adequately cap ETS allowances could lead to continuing high fossil fuel use, increasing demand for CSUs and potentially undermining the efficacy of both mechanisms, thus illustrating the complementary nature of markets and mandates[66].

Additionally, without stringent guardrails and accreditation standards for CO_2 sources and industrial processes, there could be incentives for overproduction of CO_2 to generate CSUs, leading to risks such as potential 'on-shoring' of emitting industries and maintenance of inefficient processes solely to generate CO_2 (e.g. production of high CO_2 gas fields). These perverse incentives, however, should face diminishing returns as the CSUs will embed the cost of storage in any fossil fuel extraction, increasing the price of fossil fuels over time. Moreover, policy restrictions can be made to mitigate these risks, including standards for credit claiming and storage prioritisation. Further investigation should be conducted on these risks, which are contingent on a quantitative assessment of fossil fuel prices and CCS costs.

Furthermore, as noted in **Figure 7.1**, it is assumed that carbon storage providers and fossil fuel producers/importers are separate entities, which might not be the case. For integrated fossil fuel producing and storage companies, a strong monitoring, reporting and verification (MRV) regime is essential to ensure transparency in carbon storage certification generation.

Interaction design and accounting rules should also be explored for the Carbon Border Adjustment Mechanism (CBAM) as it is likely to be implemented alongside the UK ETS. Border adjustments will act as prerequisites for long-term success for the ETS and a CTBO. Although detailed accounting is beyond the scope of this report, it is crucial to recognise that an economy-wide upstream CTBO would apply to all fossil fuel products, including imported fossil fuels. Under a CTBO, the adjustment of imported product prices to reflect CSU prices in UK-manufactured goods could be achieved at the border via the CBAM or equivalent mechanism. This should be considered in future quantitative modelling.

7.5.2. Interaction between CTBO and UK CfD

How a CTBO and CfD's could work together

A progressively increasing obligation percentage under a CTBO would ensure that a larger share of CCS costs are absorbed by upstream fossil fuel producers/importers. Over time, the rising stored fraction under a CTBO should phase out the need for CfD payments from the government.

Potential interaction risks

A previous study on the CTBO in the Netherlands highlighted potential interaction risks of subsidies and the CTBO. In this study, stakeholders highlighting that due to the "large revenues that are still generated in the fossil energy supply chain (for both companies and governments)" and after initial rounds of funding through the Dutch SDE++ Subsidy programme, "it was considered important that the additional costs of a CTBO [to obligated entities] should not continue to be compensated by subsidies"[xi]. A government regulator may therefore opt to deduct CTBO compliance costs from the CfD payments. We note that in the short term, the subsidy overlap under a CTBO is likely to be minimal due to a low storage obligation and compliance cost, making cost integration into company balance sheets more palatable.

We acknowledge that CfDs and subsidies are key to certain first-of-a-kind project support, and therefore some forms of government-led subsidy schemes may be needed in the short and medium term for R&D and infrastructure development of novel CO_2 storage technologies.

7.5.3. Interaction in export-import dynamics

A potential unilateral implementation of a CTBO in the UK raises several important considerations. While a CTBO could position the UK as a global leader in carbon storage and net zero aligned policy mixes, it could also pose risks to national competitiveness and export-import dynamics. Implementing a CTBO unilaterally on domestic entities, without supportive policies in place, could risk placing domestic producers at a disadvantage compared to those in countries without such obligations, especially as the stored fraction rises. This has the potential to lead to carbon leakage, as discussed in **Section 5**. The magnitude of this effect is uncertain and should be explored in follow-up research.

Any unilateral UK CTBO would likely need to operate alongside CBAM-type mechanisms in the medium- to long-term. Importers would be required to either purchase CSUs or pay an equivalent price levy that adds the domestic CSU price on top of the CBAM price. This would ensure that the CTBO standards are applied across both domestic production and overseas production. A CTBO would also need to consider how to address fossil fuel products intended for export, such as North Sea extracted oil, of which an estimated 80% is exported[105]. **Table 7.5** presents an initial exploration of options for how a CTBO could treat exports.

One option would be to exclude these goods from the CTBO obligation (see **Option A**), though this raises questions about the effectiveness of a CTBO for abating overall global CO_2 emissions. Consequently, the UK could consider phasing out export licences over time, or incorporate conditions on future export licence arrangements, such as the importing nation having a robust and credible climate policy package in place.

In the medium- to long-term, the UK could pursue a 'climate club' model[106,107] for export-import considerations under a CTBO scheme (see **Option B**). This approach involves collaboration on storage obligation standards between countries, enabling two or more countries to implement similar CTBO standards as well as trade abated fossil fuels and CSUs freely across borders. For instance, a UK entity importing gas from Norway would see the Norwegian producer purchasing CSUs in either Norway, the UK or any other compliant country, ensuring the gas is CTBO-certified for the UK market. In this system, the UK could choose to trade only with nations that have similar standards, making cross-border collaboration, particularly with the EU and Norway, important to alleviating medium- to long-term economic risks of a CTBO.

Policymakers operationalising the CTBO would need to consider exports and imports dynamics, including the complexity of global oil markets,

[xi]Quotes are taken from p.43 in Kuijper et al. 2021.

Table 7.5. Export-import dynamics of the CTBO

	Option A (short term)		Option B (medium to long term)	
Objective	**CTBO jurisdiction**	**Non-CTBO jurisdiction**	**CTBO jurisdiction**	**Non-CTBO jurisdiction**
Production for domestic use	CSUs required	N/A	CSUs required	N/A
Import for domestic use	CSUs required	CSUs required at the border	CSUs required	CSUs required at the border
Production for export	Excluded*	Excluded	CSUs required	CSUs required**
Import for re-export	Excluded*	Excluded	CSUs required	CSUs required**

Notes: *Specific rules would need to be defined for domestic CO_2 emissions associated with exported products. **The methods for CSUs sales and CSU standards would need to be defined, as discussed in Section 7.5.3.

the placement of obligations on different types of importers, and methods for border compliance (e.g. whether importers should purchase CSUs or face an equivalent price levy). These nuances are reflected in **Table 7.2**, **Table 7.3** and **Table 7.4** above.

7.5.4. Interaction between CTBO and other regulations

A CTBO and supporting regulation would need to fit into the broader environmental and energy policy regime. This includes various regulations under the NSTA and DESNZ, including compliance with storage licensing standards for onshore and offshore CO_2 storage, oil and gas regulations in the Petroleum Act[108], and environmental and decommissioning regulations. In terms of GGR standards, a CTBO would need to align with new frameworks for defining permanence[xii], methodologies for MRV, and robust accounting rules. A recent illustrative regional example is the Carbon Removal Certification Framework (CRCF) in the EU[109].

Future research should explore how a UK CTBO mechanism would interface with and enhance policies and regulations in other jurisdictions, such as the EU ETS, EU CBAM, the EU's Industrial Carbon Management Strategy[110], and cross-border standards for transport and storage. While this analysis is outside the scope of the current report, it is important to acknowledge that international cooperation and cross-border initiatives have the potential to amplify the effectiveness of a UK CTBO. Conversely, unilateral adoption of the CTBO could lead to adverse effects for UK-based entities, as referenced in **Section 7.5.3** above.

[xii] Permanence should be defined according to best-available scientific definitions following fungibility of carbon sources and sinks (i.e. like-for-like principle). See **Section 6.**

8. Recommendation for Future Work

8.1. Next Steps for Policymakers

The 'Markets & Mandates' project is a first-of-a-kind analysis of market and mandate policy mixes to incentivise CCS deployment and help deliver the UK's net zero target. Further policy development is urgently needed. We recommend four next steps to build upon the 'Markets & Mandates' project:

1. Policy development within DESNZ

Further policy development requires several actionable steps. Firstly, the government should define clear and measurable metrics to track progress towards the success criteria outlined in the DESNZ Vision (**Section 3**), aimed to build an objective assessment of future policy mixes. Secondly, DESNZ should conduct an internal analysis, identifying current policy gaps and risks with the 'Base Case' scenario (**Section 4**). This should be used to clearly identify what a supplementary policy instrument, such as a storage mandate, should achieve in the short-, medium-, and long-term. Finally, this assessment should guide any potential carbon storage policy design choices, informed by stakeholder input (**Section 5**).

2. Quantitative assessment of future policy mixes

A quantitative assessment of the effects of implementing a CTBO in the UK, as well as other potential carbon storage mandate policies, is crucial. Conducting the analysis requires selecting various policy mixes to be evaluated, clear and credible assumptions for scenario timelines and interactions, preliminary design choices aligned with policy objectives, as well as defining endogenous variables for evaluation. These scenarios should be stress-tested with various exogenous variables, such as different fossil fuel prices and CCS technology costs, the UK's relative economic performance, and global collaboration or competition. The study should also explore the interaction between a carbon storage mandate, e.g. a CTBO, and other key policies, including the ETS and CBAM (as outlined in **Annex C**). Further details on preparing for a 'Phase 2' study are expanded upon below.

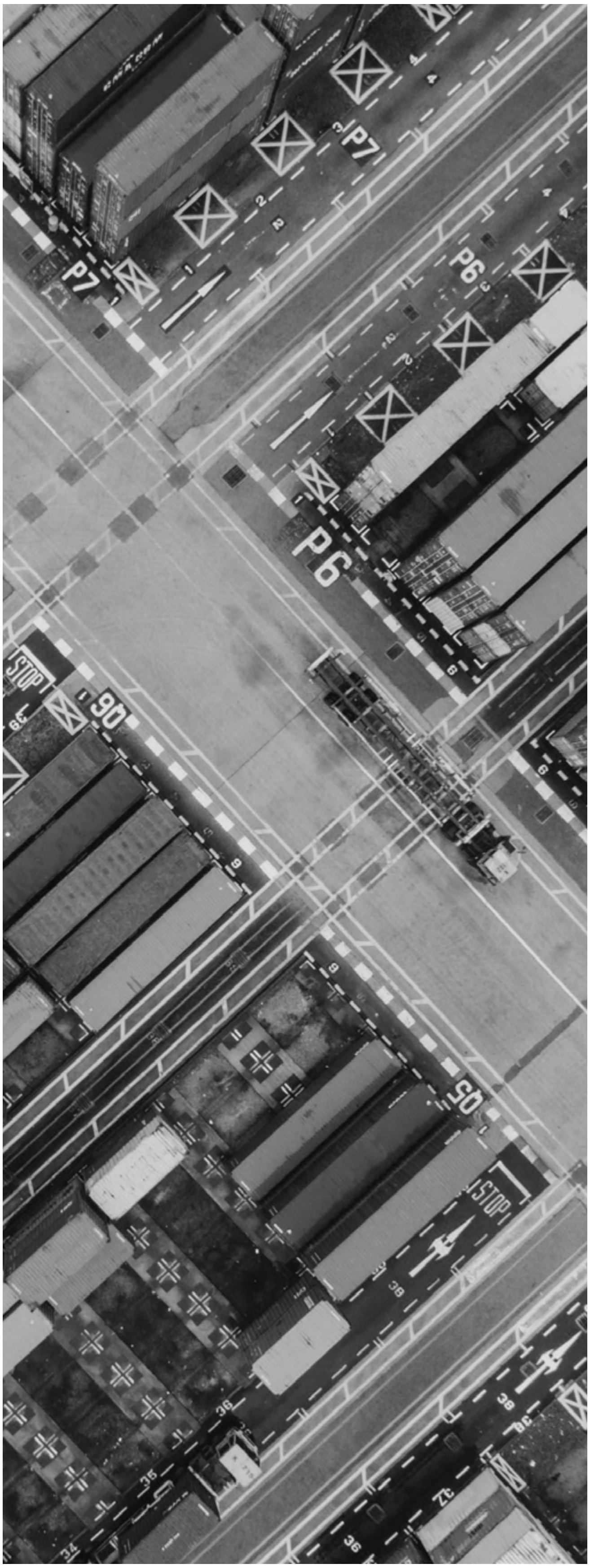
3. Wide-ranging and regular stakeholder engagement

Thirdly, sustained engagement with a wide range of stakeholders is essential. We recommend the inclusion of a diverse group of representatives, including policymakers, regulators, academics, environmental NGOs, civil society, CCS and GGR developers, storage providers, and fossil fuel suppliers. These stakeholders will need to collaborate to achieve the UK's carbon storage targets and co-create the legal, regulatory, and MRV requirements for any potential carbon storage mandate policies.

4. Further policy and research development

Finally, we identify several open questions on carbon storage mandates that require further analysis, forming a strong basis for future research. The full list of questions can be found in **Annex E**, and are drawn from the workshops, interviews, and academic steering committee dialogues. Example topics that require further analysis include public perceptions of carbon mandate policies, sector-specific implementation roadmaps, particularly for cement, and potential interactions between a CTBO and international trade policy.

8.2. Preparation for a Phase 2 Modelling Study



A modelling study is proposed as a key part of the follow-up work from this report. Key decisions for this Phase 2 'Markets and Mandates' modelling study include: i) identifying a subset of future CCS scenarios to be evaluated in the modelling study, ii) making preliminary modelling design choices on a potential storage mandate depending on the policy objectives, informed by current and future stakeholder perspectives (**Section 5** and **Annex B**), iii) making a preliminary decision on how market and mandate mechanisms could interact, as elaborated in **Section 6**, **Section 7** and **Annex C**.

Additionally, a modelling study will require compiling a list of exogenous and endogenous variables for modelling CCS policies and their interactions. **Table 8.1** below summarises key exogenous parameters and variations that could be considered. It is crucial to assess the resilience of policy mixes under diverse future macroeconomic and socio-political circumstances, encompassing factors like emergent fossil fuel price levels and volatility, costs of renewables and CCS/GGR technologies, the rate of deployment, maximum market penetration of CCS/GGR and renewables, and the level of international coordination in CO_2 storage development.

As well as these exogenous variables, **Table 8.1** suggests several endogenous variables for evaluating the scenarios chosen for modelling in a 'Phase 2' study. These parameters focus on key outcomes of the CCS policy mix that the government may wish to compare across scenarios, such as sector-specific employment figures, cost distributions along the value chain, and the emerging market sizes of CCS and GGR technologies.

Throughout this report, stakeholder perspectives on key decisions have been highlighted to assist with further examination in Phase 2. These should be considered when evaluating future CCS scenarios, as well as during discussions on the implementation strategy and design of individual carbon storage mandates.

Table 8.1. Parameters for a 'Phase 2' modelling study

Exogenous Parameter/Variable	Description	Possible Variants To Stress-Test
Fossil fuel price/ availability	Prices, market sizes, and reserves for coal, oil, gas, and limestone in the UK market.	→ High stable fossil fuel price → Low stable fossil fuel price → Volatile market
Cost/market penetration/learning rates of renewables	Levelised unit cost for individual renewable technologies, market penetration rate limits, and assumptions on rate of innovation and cost reductions.	→ High and rapid market penetration, favourable and rapid decline in costs → Low and slow market penetration, costs decreases or plateaus → Various maximum levels of energy market penetration
Cost/market penetration/learning rates of CCS and GGR technologies	Levelised unit cost for individual CCS and GGR installations, market penetration rate limits, and assumptions on availability and rate of cost reductions.	→ CCS and/or GGR technologies costs reduced to sufficiently low levels to be cost-competitive with alternative mitigation options for hard-to-abate sectors → CCS and/or GGR technologies fail to innovate, with costs remaining too high. In long term market/scale of CCS and GGR deployment remains small.
ETS coverage and price	Extent of ETS market coverage, including expansion to include GGR, price and stability of ETS credits, and design and function of associated CBAM policy.	→ ETS price stabilises and grows through to 2050; carbon prices reaching parity with the cost of CCS deployment → ETS price fails to stabilise at necessary levels to deliver market signals for high CAPEX investments such as CCS → ETS is expanded across the whole economy, and/or to a broader range of sectors → Political constraints limit ETS market expansion → The impact of competing subsidy market on ETS price in the short to medium term → Options for incorporating the mandate policy compliance cost in the CBAM vs. exploration of alternative border adjustment approaches
Macroeconomic circumstances	GDP and other indicators of UK economy.	→ Economic under/over-performance compared to comparative nations and resulting policy/political/ economic impacts → Relative energy independence of the UK economy

Notes. This is not an exhaustive list. Further evaluation of relevant parameters should be discussed.

Cont. Table 8.1. Parameters for a 'Phase 2' modelling study

Potential Endogenous Parameter/Variable	Description	Intention
Sectoral revenue, job creation, job retention or retraining	Sector sizes measured in terms of revenue, taxable income, employment quantity/quality, job retention etc.	Successful CCS policies should transition jobs in hard-to-abate sectors into work on the net zero transition in similar geographical areas.
Total policy cost, distribution through value chain and across income brackets	Total policy cost, annual policy expenditure for Treasury, either as raw total cost or discounted over time. Cost distributions, both vertically down fossil fuel value chain and across consumer income brackets.	Competitive policy scenarios should minimise policy cost both for the taxpayer and through driving cost reductions. This should be done through delivering cost-effective spending that maximises innovation in CCS and GGR sectors and optimises technology use compared to fossil fuel demand reductions. Additionally, tracking compliance cost based on sector and geography may provide valuable insights. For example, it may reveal that inland companies face higher compliance costs and thus require additional government support.
Annual CO_2 storage capacity, CO_2 production, and CO_2 emissions. Carbon leakage and export of high-carbon activities.	Annual reporting on CO_2 emissions, production, and storage. Detailed reporting on fossil fuel use by type and sector is necessary for policy optimisation across various sectors, fuel types, and supply chains.	Tracking CO_2 storage market size, and residual fossil fuel market size, to allow policymakers to mitigate over- or under-reliance on CCS and GGR technologies. Reporting can include capacity creation, exploration for capacity, and injection rates. Additionally, tracking carbon exports to jurisdictions without equivalent carbon management policies, and/or alternative carbon management policies competing with UK incentives, could be insightful.
Shadow carbon price, fuel prices, demand-side marginal energy prices, supply-side price and energy supply stability. Impact of unilateral policy action and wider policy impact.	Indicators of energy costs for the demand-side, including marginal prices for energy supply, market fuel prices, and shadow carbon prices indicated by ETS or CTBO policy.	Tracking marginal costs to users of fuels or energy is an important indicator of policy success, with the expectation that fossil fuel prices will increase gradually, albeit with fluctuations. Additionally, it is important to assess the impact of acting unilaterally in regards to climate policy, UK competitiveness, and security of supply.

Notes: This is not an exhaustive list. Further evaluation of relevant parameters should be discussed. The endogenous parameters build on and add to the criteria presented in **Section 3**. This table aims to inspire future work.

Annex A: Methodology

The qualitative analysis for Phase 1 'Markets & Mandates' was conducted through comprehensive desk-based research, including a review of academic literature, policy reports, government white papers and reports, and recent press releases. Key topics explored included ETS and government subsidy regimes, regional CCS deployment trends and policy mechanisms, specific carbon storage mandate policies, and climate policy design papers.

Additionally, insights from stakeholders were gathered through three qualitative data collection methods: (1) A roundtable discussion held at COP28 in 2023, (2) A UK specific cross-sector workshop conducted in February 2024 (see **Table A1** for attendees), and (3) Individual follow-up conversations with stakeholders present in the workshop. The roundtable fostered open dialogue and initial reflections, while subsequent conversations enabled more in-depth exploration.

Attendees: Workshop and 1:1 Conversations

During the workshop, participant reflections were recorded using sticky notes and notetaking by facilitators and project leaders. Additionally, individual conversations were held with 15 stakeholder representatives. With 31 workshop attendees, the participants and facilitators were divided according to stakeholder group:

NGO: 7 **Academia: 4**

Government: 10 **Industry: 10**

These insights, combined with those from the workshop, were systemically analysed to generate the tables in **Annex B**.

Academic Steering Committee

In preparation for Phase 2 'Markets & Mandates', which focuses on quantitatively modelling future CCS policy mixes, an academic steering group has been established. Comprising over 11 leading academics from UK and international institutions, the committee brings together a wide range of diverse expertise in energy modelling, CCS and GGR policies, and CTBO-related policy considerations.

Table A1. UK Stakeholder Workshop Attendees

Type	Institution	Type	Institution
NGO	Carbon Balance Initiative (CB)	Government	Climate Change Committee (CCC)
NGO	Clean Air Taskforce (CATF)	Industry	Carbon Capture and Storage Association (CCSA)
NGO	Carbon Gap	Industry	Aker Carbon Capture
NGO	Green Alliance	Industry	Slaughter & May
NGO	Bellona Europa	Industry	bp
Academic	University of Oxford	Industry	Shell
Academic	University College London (UCL)	Industry	Exxon Mobil
Academic	University of Edinburgh	Industry	Equinor
Government	Department of Energy Security and Net Zero (DESNZ)	Industry	Neptune Energy
Government	North Sea Transition Authority (NSTA)	Industry	Associated British Ports
Government	Crown Estate		

Annex B: Stakeholder Insights on Design Choices

Annex B presents all stakeholder insights on the five CTBO design choices outlined in **Section 7**.

Table B1. Stakeholder Insights: Shape & Endpoint of Stored Fraction

Main Theme: Design Choices	Insights
Starting % obligation	→ One stakeholder highlighted that the starting point needs to be pragmatic to ensure the CTBO is accepted. In the workshop, an example of this was highlighted, namely defining the starting percentage at current availability of storage.
Speed of obligation increase	→ In the workshop, a recurring preference was "not too high, not too fast". → According to one stakeholder, a progressive increase of storage targets is seen as more favourable for investor confidence compared to absolute targets, as it provides the entities a clearer understanding of 'what they are signing up for'. → One stakeholder stressed the importance of benchmarking calculations on prospective planned production. This approach aims to discourage production and encourage behavioural change. → Both in the workshop and in 1-1 conversations, several stakeholders highlighted that the rate of increase should be decided based on cost-effectiveness.
Endpoint	→ In the workshop, there was wider support for minimum 100% with some stakeholders highlighting the opportunity to implement net-negative emissions with a CTBO.
Main Theme: Risks	**Sub-Themes**
Technological risks	→ Some stakeholders highlighted the risk of insufficient storage capacity, both due to technological risk and regulatory risk.
Regulatory risks	→ Several stakeholder highlighted the storage licence lead times as barrier for the speed of obligation fraction increase. → One stakeholder highlighted the time delay in meeting the storage requirement, and suggested that it could be a 5 year window to ensure the obligated entities build sufficient project capacity to meet the CTBO requirements.
Economic risks	→ One stakeholder highlighted the risk of carbon leakage due to effects on competitiveness.

Notes: Stakeholder insights presented were collected in the February workshop and subsequent 1-1 conversations with workshop participants.

Table B2. Stakeholder Insights: Obligation Placement

Main Theme: Design Choices	Insights
Type of entity	→ Stakeholders prefer broad application of CTBO on both domestic extractors and importers, encompassing all fossil fuels in the "domestic consumption" market. In other words, CTBO should cover the entire UK fossil fuel sector ('economy-wide'). → One stakeholder discussed if fossil fuel suppliers are simpler to regulate than extractors. Whilst two other stakeholders highlighted that obligation should be placed on those who are most responsible, based on moral judgement. → One stakeholder emphasised that the most theoretically economic efficient is to obligate at the top of the value chain (i.e. wellhead), though some efficiency may be sacrificed for regulatory simplicity. → One stakeholder highlighted that an obligation should align with existing structures and mandates, such as fiscal points for entities. → According to another stakeholder, mandated sectors should be those who possess the necessary technology, engineering know-how and the access to the geosphere. → It would be easier to obligate by operator or entity rather than by project, enabling NSTA to calculate equivalent storage requirement based on overall production. → Differentiating between company size may create unnecessary complexity and a two-tier market, as noted by two stakeholder. → Sector-specific CTBO is opposed by one stakeholder as it picks 'winners and losers'. → The same stakeholder wished for a CTBO to be applied further down the value chain.
Type of product	→ One stakeholder emphasised that we should consider an oil-specific CTBO to support GGR deployment, e.g. DACCS deployment. → Another stakeholder explored a sector-specific CTBO to regulate hard-to-abate sectors as a good idea, and included sectors such as the construction. → A stakeholder highlighted that a CTBO should be applied on products with high elasticity of demand to incentivise demand change. → There was a strong preference for sequential roll-out of a CTBO, beginning with a specific sector and gradually expanding to an economy-wide CTBO. → One stakeholder emphasised that you could start with a low percentage (e.g. 1%) LCPS on cement and other raw material industries. → Within a stakeholder's preference for sequential implementation, it was discussed that liquid fuels are already heavily regulated, making gas regulation less "crowded". → One stakeholder highlighted that coal is already on its way out, so there is no reason to include this in a CTBO regime.
Main Theme: Risks	**Sub-Themes**
Technological risks	→ One stakeholder pointed out the risk of certain sectors lacking sufficient capacity to secure storage access, particularly when considering cost competitiveness against the international market.
Regulatory risks	→ Double counting was highlighted in both the workshop and several 1-1 conversations. → A representative from industry emphasised that their global presence and the potential for market withdrawal if EU/UK regulations become overly stringent. → Stakeholders expressed uncertainty regarding the connection between the CTBO and the regional European market (based on workshop discussions and several 1-1s). → A stakeholder suggested that applying CTBO to all sectors might post challenges, advocating for a sub-set of sectors as a more feasible option. Same stakeholder highlighted if it should be applied to ETS sectors or the construction sector. This was also highlighted in the workshop.
Economic risks	→ Several stakeholders highlighted cost distribution and impact on consumers when applying CTBO on oil or gas. → Carbon leakage concerns if CTBO is solely applied to certain products or sectors. → The cement industry's low profit margins make it vulnerable to a CTBO, according to one stakeholder. Another stakeholder highlighted that more attention should be given to a limestone specific-CTBO. → A stakeholder suggested that CTBO should not be imposed on oil due to its cost inefficiency, advocating for phase-out instead.

Notes: Stakeholder insights presented were collected in the February workshop and subsequent 1-1 conversations with workshop participants

Table B3. Stakeholder Insights: Technology & Location Accreditation

Main Theme: Design Choices	Insights
Physical CO_2 origin & location	→ In the workshop, there was a discussion if a CTBO regulator should specify how much of the obligation needs to be removals (e.g., % terms). → Several stakeholders preferred prioritising access to storage capacity for GGR and CCS for the most hard-to-abate sectors, suggesting the creation of a 'storage access ladder' or priority ladder. → A few stakeholders preferred to allow for all technologies capable of permanently storing CO_2, including both GGR and CCS. → One stakeholder strongly favours permanent engineered removals as the only eligible removal.
Geographical CO_2 origin & location	→ In the workshop, a stated preference was to prioritise UK storage locations, whilst emphasising that the UK regulator needs to define a collaborative regime with the EU/EEA on sharing the existing and future available stores. → One stakeholder emphasised that including international volumes is necessary due to the risks of inadequate domestic storage capacity as well to ensure the 'economics of it' makes sense.
Rules & standards	→ In the workshop, high quality storage standards, coordinated with the EU legislation such as the CCS directive, was discussed as important and a potential benchmark for what storage could be used to fulfil the obligation. → During the workshop, several stakeholders highlighted that there is a need for guardrails to avoid perverse incentives such as artificially generating CO_2.
Main Theme: Risks	**Sub-Themes**
Regulatory risks	→ In the workshop and several 1-1 conversations, the complexity of cross-border storage regulations was highlighted as a factor that should not be underestimated. → A stakeholder emphasised the importance of defining and planning for access to storage capacity, acknowledging storage as a 'finite resource'. → One stakeholder was strongly opposed to the 'Article 6 trading style' of the CSUs, as this risks double/triple claiming.
Transition risks	→ Several stakeholders were concerned about fossil fuel overreliance.

Notes: Stakeholder insights presented were collected in the February workshop and subsequent 1-1 conversations with workshop participants.

Table B4. Stakeholder Insights: Governance Mechanisms

Main Theme: Design Choices	Insights
Penalty process	→ In the workshop, there was support for a non-compliance penalty fee that is sufficiently high to disincentivise unabated production. → In the workshop, stakeholders discussed what a strong, but workable compliance window entails. Some suggested that it equals above 1 year and below 5 years.
Legislative routes	→ In the workshop, stakeholders agreed that the legislative route is likely to be tied to the Climate Change Act 2008, with the involvement of Ofgem (acting as the regulator) and NSTA (acting as the carbon accountant). Details will depend on who is the regulated entity.
Interaction with other policies	→ Many stakeholders agreed that the CTBO needs to integrate into the ETS, with emphasis that clear accounting rules must apply across the ETS and CBAM. → One stakeholder highlighted that if the CTBO could make border adjustments stronger, this would be a 'massive plus' as CBAM is 'a complete nightmare'.
Main Theme: Risks	**Sub-Themes**
Regulatory risks	→ A risk of double counting and unclear accounting rules was a recurring concern that must be addressed. → One stakeholder noted that implementing a CTBO will be legislatively challenging. → Emphasising the renewable obligation, a stakeholder suggested learnings from their certificate system, citing undersupply of certificates as a key risk. → The same stakeholder pointed out that an emitter could evade ETS liability while generating revenue for CSU generation, potentially creating a perverse incentive for deploying CCS. This outcome hinges on ETS integration accounting rules. → One stakeholder expressed confidence in the adaptability of the regulator to refine a CTBO as implementation progresses, suggesting that not every detail needs to be predetermined. The UK has an "intelligent regulator" who will mitigate the biggest risks along the way.
Transition risks	→ One stakeholder stressed that managing fossil fuel lock-in should be achievable through "regulatory oversight". They cited examples such as excluding certain capture sources or projects from CTBO compliance and coverage.

Notes: Stakeholder insights presented were collected in the February workshop and subsequent 1-1 conversations with workshop participants

Annex C: Interactions between the ETS and an Upstream CTBO

Table C1. Optionality in the ETS and CTBO Integration

	Emitter	Storage operator	Fossil fuel producer/importer
No CTBO	Option 1: Pays for CCS capacity*	Paid by emitter to provide storage	N/A
	Option 2: Pays the cost of ETS allowance(s)	N/A	N/A
CTBO	Option 1: Paid by storage company to provide CO_2 streams	Option 1: Pays the emitter to acquire CO_2 to store, to generate CSUs	Producer/importer is the mandated entity and must acquire CSUs from the storage operator. Pays the storage operator.
	Option 2: Pays for CCS capacity.	Option 2: Paid by emitter to provide storage.	Producer/importer is the mandated entity and must acquire CSUs from the storage operator. Pays the storage operator.
Interaction with the CSU regulator	No interaction.	Storage and CSUs generation mandate is acquired by Government.	CSUs are verified and retired at the end of the compliance period.

Notes: This table assumes ETS integration. The optionality changes if this is not the baseline assumption. There is a risk that the CSU demand rises quicker than the ETS price. This would incentivise purchase of CO_2 from emitter. This interaction is dependent on cap size, allowances and the standards permitted in CSU compliance. GGR companies would also be included in this policy framework, but is not included here due to simplicity. *Emitter is defined as an emitting entity included in the UK ETS. Stakeholder insights presented were collected in the February workshop and subsequent 1-1 conversations with workshop participants

Table C1 outlines potential interactions between the ETS mechanism and an upstream CTBO. In the absence of a CTBO, emitters included in the UK ETS face two primary compliance options:

→ Option 1 - Capture and store CO_2. Emitters can avoid ETS compliance payments by investing in CCS technology to capture and store CO_2 (an emission reduction).

→ Option 2 - Acquire ETS allowances. Emitters can emit CO_2 and acquire sufficient ETS allowances to cover their emissions.

Initially, when the ETS cap is high, the ETS price may be below the costs associated with CO_2 capture and storage for many industrial emitters, leading them to pursue **Option 2**. However, when the ETS price rises and exceeds the costs associated with CO_2 capture, transport and storage, emitters may shift to **Option 2** to avoid higher ETS compliance costs.

Without a CTBO, upstream fossil fuel producers/importers have a weak incentive to invest in CO_2 capture and storage capacity, as they do not bear the cost associated with CCS development. This assumes that the obligated entity is neither an ETS emitter nor a storage provider, though this might not be the case in real life.

Scenario: ETS and CTBO Interacts

When a CTBO is implemented alongside the UK ETS, both emitters and fossil fuel producers/importers are incentivised to invest in CCS deployment, driven by bottom-up and top-down policies, respectively. It is important to note that ETS and CTBO operate under different accounting methods: CTBO uses an 'extraction-based' approach, while the UK ETS adopts an 'emitter-based' method.

Figure 7.1 and **Table C1** assume the integration of a CTBO and the ETS, as supported by stakeholders in this project. With a CTBO in place, captured CO_2 gains value for generating CSUs and for avoiding the ETS compliance costs. The dynamics of who pays for CO_2 storage - whether it is the emitter paying for CO_2 storage to avoid ETS payments (**Option 2**; with CTBO) or the CO_2 storage provider paying for captured CO_2 to generate CSUs (**Option 1**; with CTBO) - depend on the emergent price of CSUs relative to the ETS credit prices.

In situations where CSU demand exceeds CSU supply (e.g. due to limited availability of point-source CCS facilities), fossil fuel suppliers could be incentivised to partially finance CO_2 capture projects to secure CO_2 streams for CSU generation.

Such a scenario creates a double incentive for point-source emitters, potentially skewing the market towards point-source and away from GGR operators – with point-source emitters benefitting by both avoiding the ETS compliance cost and selling captured CO_2 to generate CSUs. These market dynamics can be regulated based on the primary policy objective of the policymaker.

Yet, over time, the prices of CSUs and ETS allowances are expected to adjust in response to the relative rates of the ETS cap reduction versus the increase in the stored fraction under CTBO. For example:

→ With a high-stored-fraction CTBO policy and a volatile or weak ETS price, the pressure to implement CCS and GGR shifts toward the fossil fuel producers/importers, who are incentivised to finance CCS and GGR projects to increase the availability of CSUs.

→ With a low CTBO stored fraction and a high, stable ETS price, emitters are primarily incentivised to deploy CCS and GGR to avoid ETS compliance costs, leading to a scenario where emitters pay storage operators for their services.

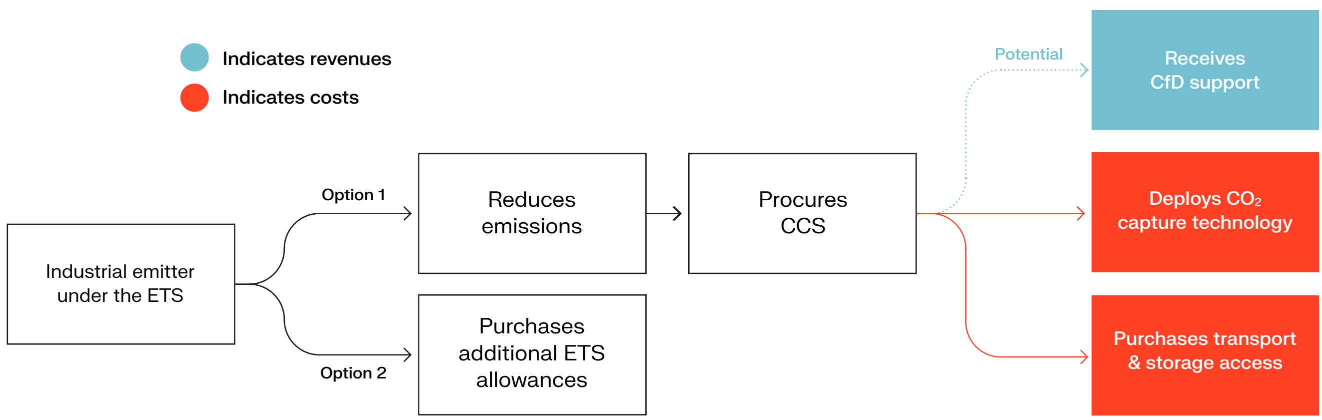


Figure C1. An illustrative example of CCS in an ETS system without CTBO.

Alternative Scenario: Decoupling ETS and CTBO

An alternative scenario involves completely decoupling the ETS and CTBO policies. In this scenario, all emitters comply either by investing in CCS or by purchasing additional ETS allowances (options in **Figure C1**). They would also have the option of selling their CO_2 to storage operators to generate CSUs. Consequently, the CSU price reflects the full-chain cost of capture, transport and storage, which is realised by the fossil fuel producer/importer as far upstream as possible. This may allow for a market-efficient distribution of the total CCS and GGR cost burden across the entire carbon value chain. Emitters offset the cost of deploying CO_2 capture facilities by adjusting the price of CO_2 sold for CSU generation, thereby levelling the playing field with GGR operators, such as DAC developers, who only benefit from the sale of captured CO_2. However, this scenario is disadvantaged by requiring dual-running but separate accounting systems for the CTBO and ETS schemes, adding to the administrative burden for the regulator. This process is not included in the figures or table in this Annex.

Quantitatively analysing the combined dynamics of CSU and ETS prices is beyond the scope of this study, as it requires dynamic modelling of both ETS and CTBO policies in the future UK energy sector and economy. This is proposed as an activity in the 'Phase 2' follow-up study, explored in **Section 8** of the report.

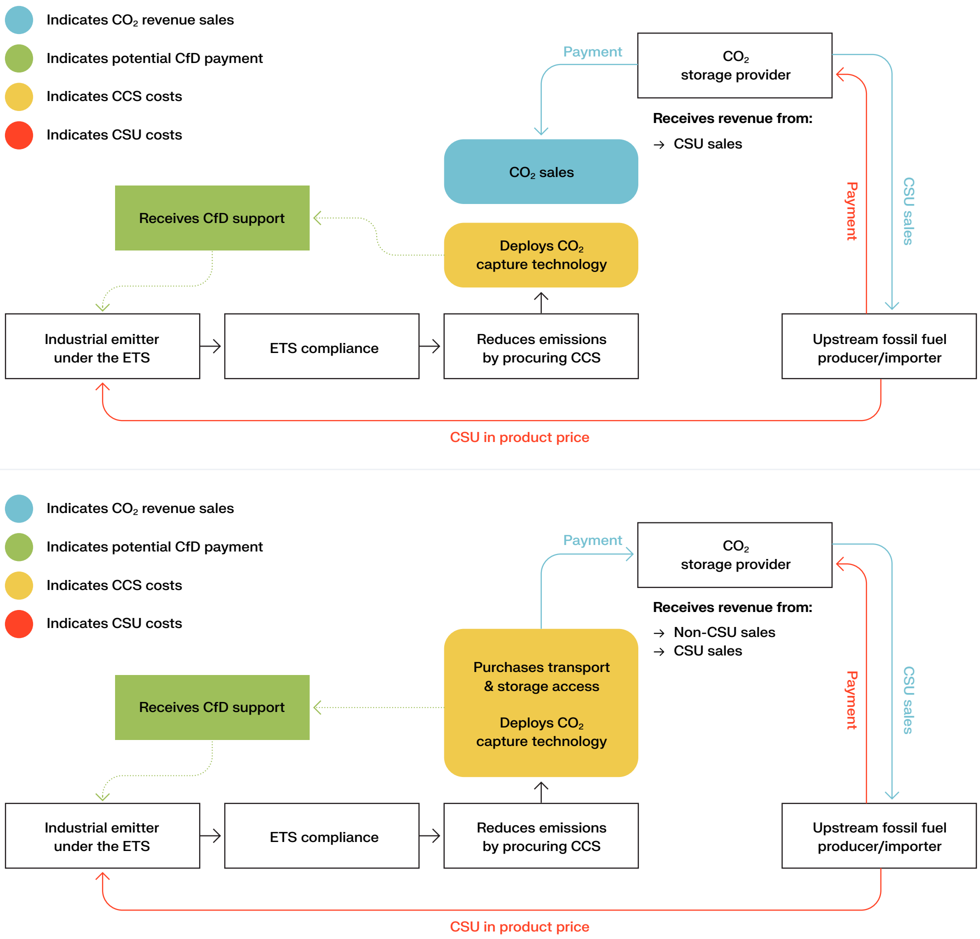


Figure 7.1. An illustrative example of optionality in interactions between ETS and CTBO. Note that in this figure we assume that CO2 storage providers and fossil fuel (FF) producers/importers are separate entities. This might not be the case in reality and depends on how the government regulates the market. CfD support depends on ETS and CSU prices and is thus reflected with a dashed line as it is a potential payment. Moreover, the exact cost distributions, including the size of CSU cost in product price, should be modelled ex-ante.

Annex D: Alternative Policy Scenarios

This study considered several policy scenarios not included in the report due to sub-optimal outcomes. These scenarios are explained in more detail here.

Scenarios with Sole Reliance on Government-led Mechanisms

As outlined in the analysis of the 'Base Case' scenario in **Section 4** of the report, key risks arise from relying on a market-based mechanism for creating a self-sufficient CCS sector, struggling to uphold private investor confidence. **Section 4** discusses potential responses within such circumstances: diminished investor confidence in the 2030s could lead to a carbon storage capacity gap in the 2040s, causing volatile UK ETS prices to rise well above DACCS costs to stimulate demand reduction while CO_2 storage capacity recuperates.

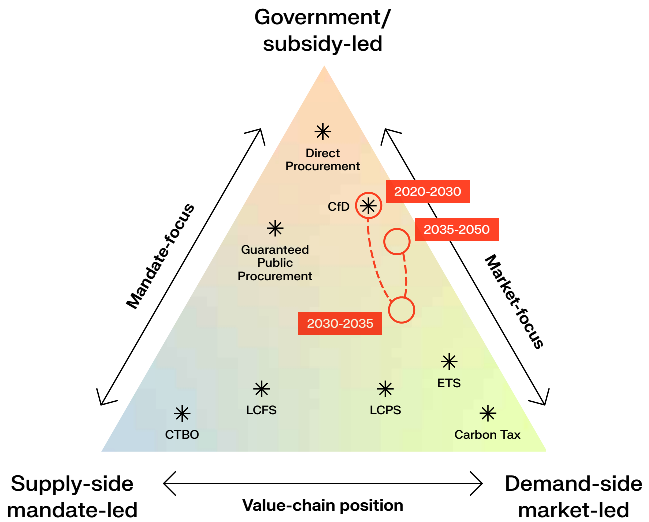


Figure D1. Schematic showing evolution of a CCS policy scenario which attempts a market-led CCS policy future but fails and returns to government-led subsidy mechanisms to deliver CCS sector needed by net zero.

An alternative scenario would be a transition back to government-led subsidies after 2035 to still achieve carbon storage targets in the future with low market confidence. If incomplete or volatile market mechanisms fail to deliver investor confidence in the early 2030s, subsequent reinforcement with government subsidies post-2035 may be necessary. Stakeholder consultations repeatedly highlighted this "return to subsidy" narrative as a route to restore confidence in the CCS market. See **Figure D1** for a schematic illustration.

This route, however, poses several drawbacks:

→ Risk 1: Enduring reliance on subsidies weakens incentives for true cost discovery and technological innovation in the CCS sector, escalating deployment costs at scale for the UK economy.

→ Risk 2: Public expenditure on CCS delivery may become infeasible and politically precarious, particularly in a faltering ETS market upon which the "return to government-led subsidy" scenario is predicated. A subsidy-led approach poorly manages cost burden-sharing, risking public backlash as subsidies are allocated to entities that may also be responsible for fossil fuel emissions and production.

→ Risk 3: The viability of a wider CO_2 storage market under a government-led subsidy package remains uncertain. Questions arise regarding the use of UK public finance for international CO_2 storage capacity development, stakeholder benefits from capacity sales, and the balance between domestic net zero delivery and international market development, potentially burdening UK taxpayers with most CCS development costs or prioritising profits over net zero delivery.

Scenarios with Sole Reliance on a Mandate Mechanism

For research purposes, the project also analysed a scenario that relies solely on a mandate mechanism (e.g. a CTBO applied upstream to coal, oil, and gas suppliers in the UK) without an ETS in place, as depicted in **Figure D2**. Mixed policy scenarios with both market and mandate mechanisms are analysed in **Section 5**.

Research by the University of Oxford[15,28] identifies several risks of relying solely on an economy-wide CO_2 capture and storage mandate to deliver net zero, including the following:

→ Risk 1: Limited impetus for CO_2 production reductions and fossil fuel use while storage capacity is low, potentially resulting in over-reliance on CO_2 storage by mid-century. The CTBO's short-term downstream carbon price may not be adequate to drive CO_2 production reductions, especially as stored fractions grow from current levels.

→ Risk 2: While the CTBO's principle of extended producer responsibility is potent, exclusive reliance overlooks heavy fossil fuel users' responsibility to contribute to net zero delivery and provides fewer incentives for emitters than if combined with the ETS.

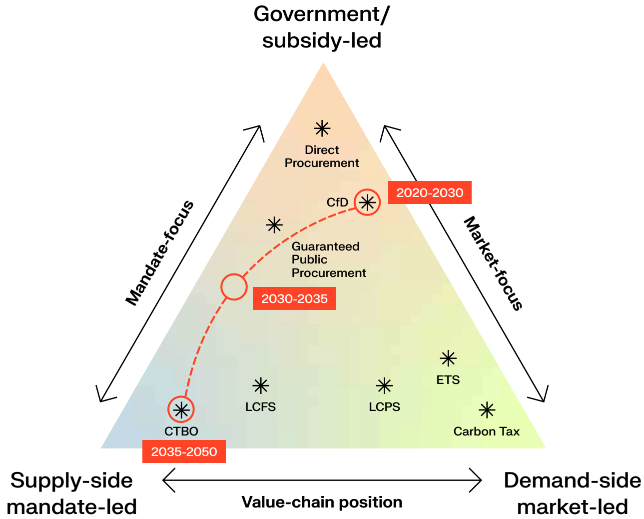


Figure D2. Schematic showing evolution of a CCS policy scenario transitioning into a sole reliance on a mandate.

Annex E: Stakeholder Questions for Follow-up Research

Table E1 presents the most frequently asked questions from stakeholders in the workshops and interviews. A full exploration of these questions, some of which require quantitative analysis, is beyond the scope of this report but provides a basis for follow-up research.

Table E1. Summary of Recurring Questions from Stakeholders

Category	Questions
Cost distribution and impact on consumers	→ How will the costs of the CTBO be distributed along the fossil fuel value chain? → What portion of the costs will be passed on to consumers? → What is the policy 'end cost' on domestic consumers and the public? → Are there measures that can prevent costs from being passed on to consumers?
Applicability to specific sectors and materials	→ How would a CTBO operate with limestone or cement, given the complexity of the supply chain? → Should the CTBO be applied economy-wide, or should sectors like cement or coal be excluded?
Handling of imports and exports	→ How will the CTBO treat fossil fuels that are imported and re-exported? → Should the obligation apply only to domestic consumption market, or also to materials processed in the UK and subsequently exported?
Impact of a unilateral CTBO	→ What would be the effects of implementing a CTBO unilaterally in the UK, considering the global nature of the oil and gas market? → How would a unilateral CTBO integrate with the global market, particularly within the European gas market?
Interaction with the ETS	→ How would the CTBO interact with the existing ETS in terms of prices? → Would the CTBO and ETS work in parallel, merge together, or would one supersede the other?
Investment and carbon leakage	→ What impact will the CTBO have on companies considering investments in UK industries affected by the policy? → How can the design of the CTBO address challenges related to carbon leakage and exports?

Notes. This table is a summary of recurring questions from stakeholders on the CTBO and its implementation.

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