Building Future-Proof CO_2 Transport Infrastructure in Europe

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CLEAN AIR TASK FORCE

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SECTION 1

The need for a Europe-wide network for CO_2

The capture and storage of CO_2 at large scales is a necessity for the European Union (EU) to achieve its legally binding target of net zero by 2050, enabling the decarbonisation of emissions-intensive industries and the permanent removal of CO_2 from the atmosphere. In February 2024, the European Commission published the Communication on an Industrial Strategy for Carbon Management, setting out a policy agenda to support climate-targeted deployment of CO_2 capture, conversion, and storage in the region.[1] The Strategy foresees the need to capture and store 250 million tonnes of CO_2 annually by 2050, building on the target set under the Net-Zero Industry Act (NZIA) to store 50 million tonnes annually by 2030.[2]

Moving these volumes of CO_2 from emissions sources to locations suitable for permanent geological storage will require an extensive transport network, including pipelines, shipping, rail, and road. The Joint Research Centre (JRC) has estimated that the EU network may need to span from 15,000 to 19,000 km by 2050 (Figure 1).[3]

While this scale of infrastructure build-out is a formidable task, greater rates of pipeline deployment have been achieved in Europe in the past: There are currently over 200,000 km of natural gas transmission pipelines in the EU network, with over 8,000 km of new oil and gas pipelines planning to come online by 2026.[4]

In the United States, there are already over 8,000 km of CO_2 pipeline used for enhanced oil recovery, of which 3,200 km was built in less than a decade.[5] Society has proved itself more than capable of mobilising the necessary financial resources and skills in the service of fossil fuel production and consumption. Transferring that effort towards the creation of new, decarbonising infrastructure is now the challenge facing EU policymakers.

Promoting a wider distribution of geological storage sites across Europe will be critical for improving low-cost access to hard-to-abate industries.[6] However, long-distance transport networks will be needed, particularly if storage remains concentrated in the North Sea and a few other – mostly offshore – locations.

1 European Commission (2024) *Towards an ambitious industrial carbon management for the EU*

2 *Regulation 2024/1735 of the European Parliament and of the Council on establishing a framework of measures for strengthening Europe's net-zero technology manufacturing ecosystem.*

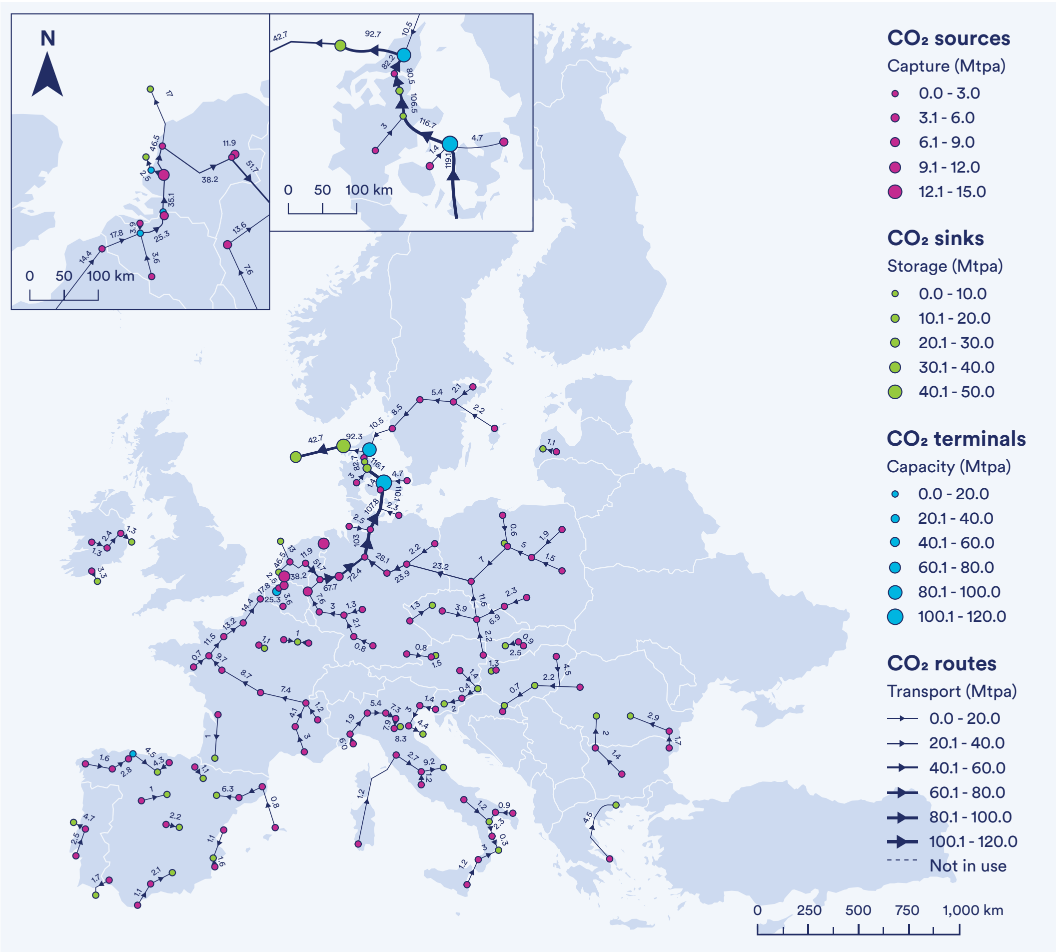
3 Tumara et al. (2024) *Shaping the future CO2 transport network for Europe*

4 ACER (2024) *Gas fact sheet; Global Energy Monitor (2024) Europe gas tracker 2024*

5 PHMSA (2024) *Annual report milage for hazardous liquid or carbon dioxide systems*.

6 CATF (2023) *Unlocking Europe's CO2 storage capacity*

Figure 1. Potential CO_2 transport routes in the EU by 2050 under a modeled net-zero scenario



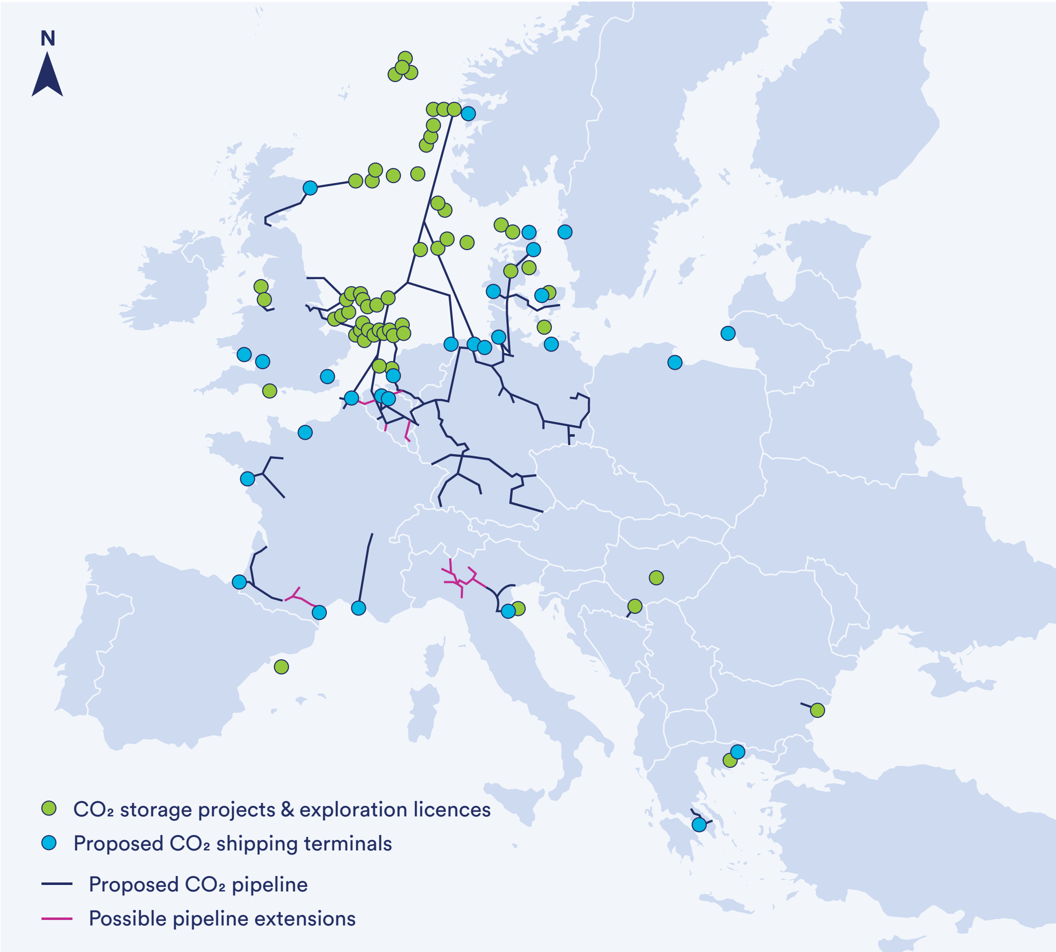
Tumara et al. (2024) *Shaping the future CO_2 transport network for Europe*

Europe's CO_2 transport network is already starting to take shape, with several major offshore pipeline projects proposed by oil and gas producers, and gas network operators in Belgium, the Netherlands, France, Germany, and Italy all planning regional or country-wide onshore CO_2 pipeline networks (Figure 2).

Given the long lead times and high upfront investment costs associated with pipeline deployment, many carbon capture projects are currently planning to ship CO_2 to storage sites in the North Sea or Mediterranean, and rail, barge, or truck transport are considered as viable alternatives for some inland routes. Even as pipelines are progressively deployed, Europe's CO_2 network will likely continue to make extensive use of these other transport modes and the terminal facilities needed to transition between them, due to their flexibility and suitability for smaller or more isolated emitters.[7]

[7] Hagspiel et al. (2024) *Investing in carbon transportation under volume uncertainty and scaling flexibility: A comparative analysis of flexible ships and cost-effective trunklines for CO2 transport to the Norwegian Continental Shelf;* SSRN.

Figure 2. An overview of proposed CO_2 infrastructure in Europe



Pipeline routes are illustrative and may not reflect final plans

CATF analysis based on public sources

Well-designed policy and regulation are needed to ensure Europe builds CO_2 infrastructure that is safe, cost-optimised, resilient, and accessible to all regions and industries which need it. Without such support, the potential for large variation in the decarbonisation costs facing industrial emitters in different regions presents a risk to EU cohesion.[8] This policy brief will examine the emerging regulatory and incentive frameworks for CO_2 transport in Europe, compare them with relevant analogues such as planned hydrogen infrastructure, and set out a series of recommendations for policies at the EU and Member State level.

8 CATF (2022) *The cost of carbon capture and storage in Europe*.

SECTION 2

Goals of a regulatory framework for CO_2 transport

A key commitment in the Industrial Carbon Management Strategy is for the Commission to "initiate preparatory work in view of a proposal for a possible future CO_2 transport regulatory package."[9] This initiative follows the example of the provisions for the planned network for hydrogen, laid out by the Decarbonised Gas Directive and Regulation.

Economic regulation of infrastructure is needed to ensure fair and non-discriminatory access to facilities which are deemed essential for providing an economic service, and where multiple competing facilities would be undesirable for economic or other reasons (such as environmental impact). Such facilities constitute 'natural monopolies', with notable examples including the regulated electricity and gas networks in the EU. Europe's emerging CO_2 transport and storage pipeline network is also expected to be a natural monopoly, for which it will be most cost-effective to develop large-scale, common infrastructure, subjecting network users to monopoly pricing.[10]

Regulations for emerging CO_2 networks are already being introduced at a national level in some Member States (Table 1). To avoid excessive regulatory fragmentation, provide clarity to developers, and eliminate regulatory or technical barriers to cross-border transport, a robust regulatory framework at the EU level is urgently needed.

An appropriately designed EU regulatory framework will:

- Ensure that all emitters that need access to CO_2 transport and storage infrastructure have access on equal terms (third-party access).
- Prevent excessive user tariffs that might deter project investment and the pace of EU decarbonisation.
- Mitigate coordination or 'cross-chain' risks that could also raise project costs and deter investment.
- Ensure a safe, cost-efficient network is developed, which is appropriately sized to meet future demand.
- Include necessary provisions for cross-border connections and non-pipeline modalities.
- Establish network codes, including standardised CO_2 specifications for the region.

Particularly in the near term, a few major storage hubs and trunklines led by oil and gas producers and gas network operators are likely to dominate the route to storage for most emitters in Europe. This creates a risk of monopoly rents for operators and excessive user tariffs, which will – in most cases – be passed through to public subsidies requested by capture projects. Given public budget constraints, this will lead to more limited and slower deployment, focused only on the lowest-cost opportunities.

9 European Commission (2024) *Towards an ambitious industrial carbon management for the EU*

10 Nicolle et al. (2023) *Modeling CO_2 pipeline systems : An analytical lens for CCS regulation*.

Some stakeholders have argued that CO_2 transport can be a relatively competitive sector where, for instance, ship transport may compete with offshore pipelines, and rail or barge transport could compete with onshore pipelines – particularly in the longer term.[11] Similar assessments have been made of the regulatory framework for hydrogen, which could present an excessive level of regulation in the context of more localised and fragmented hydrogen networks.[12] However, there is a significant likelihood that a cost-efficient CO_2 transport network will be more reliant on long-distance, cross-border pipelines than hydrogen.

Large-scale geological storage sites could remain confined to a few key regions where geological suitability coincides with suitable local factors such as legislation, public acceptability, and competition with other resources like geothermal energy. Onshore storage resources are at various stages of development across Europe, but some may often have smaller capacities that are better suited to local emitters.[13] Exacerbated by the current ban on onshore storage in Germany, there is likely to be a fundamental need for CO_2 trunklines serving major inland industrial clusters, such as those already proposed by OGE, Snam, Terega, and others (Figure 2).[14] While non-pipeline modalities can provide competition in some contexts, they will struggle to compete on routes served by large-scale pipeline transport as it is increasingly deployed. For example, Equinor's proposed CO_2 Highway Europe to link the EU to storage on the Norwegian Continental Shelf could effectively create a natural monopoly for access to storage in North-West Europe.[15]

On the other hand, there is a real risk that excessive or inflexible regulation could deter investment or inhibit cost optimisation, particularly for facilities that could operate in a competitive environment. The anticipation of regulation can also stall project development while investors wait to see how the new requirements could impact infrastructure design – for instance, through requirements to grant access to a wider user base, or compatibility with neighbouring networks.[16]

A regulatory framework at the EU level is needed to address these challenges and to ensure a basic level of harmonisation between the diverse approaches already emerging at the national level. However, driving investment towards the transport network in the necessary timeframe will require further policy measures in addition to the planned regulation.

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11 Mulder M (2024) *Exploration of the organization of the market for CCS*.

12 Hancher L and Suciu S (2023) *Hydrogen regulation in Europe*

13 Reuters (2024) *Denmark awards first licences to explore CO2 storage options on land*; PilotStrategy (2024) https://pilotstrategy.eu/; Danube Energy (2024) https://danubeenergy.com/danube-removals/.

14 OGE (2025) CO2 Grid; Terega (2023) *Call for expressions of interest dedicated to H2 and CO2*; Snam (2024) Market survey

15 Equinor (2024) EU2NSEA

16 Jones C (2023) *The future regulatory framework applicable to carbon capture and storage infrastructure*.

SECTION 3

Ensuring equitable access to CO_2 networks

The 2009 Directive on CO2 storage has already established basic provisions for *'fair and open access'* to both transport and storage:[17]

- Member States must take necessary measures to ensure potential users obtain access, in a transparent and non-discriminatory manner.
- Access can be refused due to lack of capacity, however, Member States must take measures to ensure operators make necessary enhancements as far as it is economic do so, or if a user is willing to pay for them.

These provisions mean that any entity capable of capturing and delivering CO_2 to a storage site or associated transport infrastructure must be granted access, provided capacity is available and the delivered CO_2 meets any technical requirements. However, the framework does not provide sufficient transparency for network users or adequate safeguards against excessive tariffs. A report prepared for the Dutch government notes that insufficiently clear 'ex post' tariff supervision (occurring after tariffs have been negotiated or access refused) can be ineffective, with violations being challenging to prove.[4]

Denmark and Belgium have enacted legislation to regulate CO_2 pipeline developments, both implementing negotiated third-party access regimes, but with a significant degree of regulatory oversight on tariffs and network planning (Table 1).[18]

Denmark's Act on Pipeline Transport of CO2 requires network operators to keep to a set timeline for negotiations, promptly publish the terms of agreements with network users, and be able to explain the calculation methods and principles used to determine the tariff. Tariffs must be determined solely on the basis of services provided, and can include risk-adjusted, market-based return on invested capital associated with any spare capacity that the network provider has invested in for use by third parties.

In the Belgian region of Wallonia, legislation empowers the regulators to establish a methodology for approving tariffs, which must be fair and non-discriminatory and ensure a fair balance between the quality of services provided and the costs borne by users, while allowing transport system operators a 'fair profit margin'.[19]

17 *Directive 2009/31/EC of the European Parliament and of the Council on the geological storage of carbon dioxide.*

18 Denmark Ministry of Climate, Energy and Utilities (2024) *Act on pipeline transport of CO2*

19 Service public de Wallonie (2024) *Décret relatif au transport de dioxide de carbone par canalisation*; Vlaamse Overheid (2024) *Decreet over het Vervoer van koolstofdioxide via pijpleidingen in het Vlaamse Gewest*

Table 1: A summary of key provisions in existing national regulatory frameworks for CO_2 pipeline transport

	Status of network operators	Network access	Tariffs	Network planning
Denmark	The Ministry must grant permits to establish and operate CO_2 pipeline facilities (onshore and offshore), excluding pipelines transiting the Danish Continental Shelf to or from other states.	The network operator must grant access on objective, transparent and non-discriminatory terms. Access can be refused based on incompatible technical specifications or insufficient capacity.	Standard tariff ranges are published, but ultimately negotiated with users. They must be reasonable, transparent, and based on clear principles. Tariffs may not cover repayment of investments already expected to deliver reasonable profit.	The Ministry must assess permit applications based on appropriate dimensioning, access, and transport capacity.
Wallonia/ Flanders	There is a distinct framework for regional network operators and local branches (accounting separation between these functions is required). A single network operator for each region is appointed by government. Local and regional operators must be legally distinct from emitters.	Network and local operators must grant fair and open access. Access can be refused based on incompatible specifications, lack of capacity, or other reasonable needs of the operator and other users.	Tariffs are to be objective, transparent, and non-discriminatory, based on actual costs and a reasonable profit margin. In Wallonia, the regulator adopts a pricing methodology. In Flanders, the need for such a methodology is to be reviewed before 2028 and every 5 years.	Network operators and local cluster operators must complete annual (Wallonia) or biennial (Flanders) 10-year development plans, including estimates of future capacity requirements, the need for national and cross-border connections and a corresponding investment programme. Flanders also requires short-term forecasts based on actual investments.
Netherlands	CO_2 pipeline infrastructure requires permitting by the Ministry under a general energy and climate infrastructure regime. The Ministry has proposed that state-owned Energie Beheer Nederland cooperate in the development of all CO_2 transport (and CO_2 storage projects), under market-based conditions.	Third-party access to transport and storage infrastructure is based on the provisions in the Dutch implementation of the EU Directive on CO_2 Storage (the Mining Act) and general Dutch and EU competition law.	Tariffs are negotiated between capture projects, transport and storage companies. The Ministry intends to explore options for closer market monitoring and potential additional rules.	No explicit requirements on infrastructure developers to plan for future network development.
United Kingdom	An economic licence to act as a transport and storage company (T&SCo) is granted by the Ministry and regulated by energy regulator Ofgem.	Users are selected by a government-led allocation process, and must apply for a connection to an existing delivery point or request a new one. The T&SCo must prepare an offer, including a construction plan.	Tariffs are regulated to provide a set rate of return on the T&SCo asset base, with components for booked and used capacity.	All network users provide regular short-term and long-term forecasts of CO_2 delivery. Cluster expansion and the selection of additional clusters are managed through a government-led process.

The Netherlands is a frontrunner in CO_2 pipeline deployment in the EU, with the 55-km Porthos pipeline (10 Mtpa) in the Port of Rotterdam currently under construction. This project has benefited from ownership by publicly owned entities, which have greater flexibility to accept lower rates of return. The much larger (up to 22 Mtpa) Aramis CO_2 trunkline is expected to operate on a fully commercial basis. However, in 2025, majority shareholders TotalEnergies and Shell announced they would exit the transport project once a final investment decision has been taken, leaving state-owned entities EBN and Gasunie as sole owners.[20]

Given the monopoly position of this project in the region, the involvement of the same companies in both transport and storage, and its relatively high benchmark tariffs (90.6 to 112.8 EUR/tonne for transport and storage),[21] it is prudent to guard against potential market failures. An expert report commissioned for the Dutch government notes that a competitive market (without tariff regulation) should emerge for CO_2 transport and storage in the long term,[22] but recommends greater regulatory supervision of access and tariffs in the short term, in addition to measures to improve the market position of alternative transport routes to storage (i.e., shipping). The report also recommends that the risk of future tariff increases (for instance, should the final project costs exceed expectations) is shared between the infrastructure developer and government.

In response, the Ministry of Climate Policy and Green Growth has set out its intent to more closely monitor the evolution of the market and investigate the risk posed by high and uncertain tariffs.[23]

France's energy regulator, Commission de Régulation de l'Energie (CRE), has studied options for regulation of future CO_2 infrastructure, identifying the likelihood of long-term natural monopolies in many parts of the value chain, including pipeline transport, liquefaction terminals, and offshore export pipelines.[24] CRE distinguishes between 'open' CCUS chains, which serve relatively large markets, and 'isolated' chains with few emitters and at a greater distance from collection hubs.

For the former, the regulator recommends a negotiated third-party access regime, with ex post oversight to ensure fair access and reasonable tariffs. However, it notes that such networks may require more regulated tariff structures as they become more extensive and interconnected. For isolated networks, CRE proposes a greater level of public involvement and regulation, with ex ante third-party access conditions (pre-determined tariff structures), but advises against funding any 'oversizing' of these value chains, given their more limited local user base.

Germany's draft carbon management strategy also indicated that ex post evaluation of tariffs will be initially sufficient to prevent abuse of dominant market positions for CO_2 transport, but set out an intent to continuously monitor the risks of monopolies.[25]

Outside the EU, the UK has adopted a greater degree of regulation for its planned CO_2 pipeline infrastructure, in which government-selected 'transport and storage companies' in each region own and operate a regulated asset base (RAB).[26] Similar to existing gas networks, the operator must charge a user tariff based on a regulated rate of return, with tariffs set according to both utilisation rates and booked capacity.

The UK government is currently assessing whether to extend a similar degree of economic regulation to 'non-pipeline transport' such as shipping and associated terminals. However, the approach is demanding for government resources, and the UK has stated an intent to transition to a more competitive market in the longer term.[27]

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20 Kacher (2025) Netherlands backs carbon storage project as Total, Shell step back. *Reuters.*

21 Xodus (2024) 2024 SDE++ *Aramis carbon capture and storage fee review*. The lower end of the range is for gas-phase CO2 and the upper end for liquid CO2 imports.

22 Mulder M (2024) *Exploration of the organization of the market for CCS.*

23 Tweede Kamer der Staten-Generaal (2024) *Bref van de Ministers van Economisches Zaken en Klimaat en Voor Klimaat en Energie en de Staatssecretaris van Economische Zaken en Klimaat.*

24 CRE (2024) *Rapport de la CRE sur le cadre de régulation des infrastructures d'hydrogène et de dioxyde de carbone*; CRE (2024) *Rapport de la prospective de la CRE sur le CCUS*

25 This draft strategy has uncertain status, owing to the change in German government.

26 CATF (2024) *Risk allocation and regulation for CO2 infrastructure*

27 DESNZ (2023) *Carbon capture, usage and storage: a vision to establish a competitive market.*

Negotiated third-party access is evidently emerging as a preferred model for frontrunner carbon capture and storage (CCS) projects in the EU, with varying degrees of regulatory oversight imposed or envisaged. Provided sufficient transparency and clear rules for tariff setting are in place, as established under Denmark's legislation, this could act as an adequate safeguard on monopoly power in the near term, while allowing networks to develop rapidly and flexibly outwards from localised clusters.

However, as CO_2 pipeline networks grow and reach across borders, there will likely be a need to shift towards a regulated third-party access regime in many contexts. In particular, onshore pipeline networks will mostly constitute natural monopolies that should be sized to accommodate all users in a region and not duplicated by competing pipelines. This would be a similar approach to the EU's regulatory framework for hydrogen, which enables negotiated third-party access in the near term but requires a regulated access regime from 2033 for most elements of the network.[28] The key challenge facing both hydrogen and CO_2 networks is the need to plan and introduce regulation while they are being deployed – unlike the process of regulating already well-established electricity and gas networks.

While there is uncertainty over the future extent and composition of Europe's CO_2 transport network, large CO_2 trunklines – both onshore and offshore – are likely to play a fundamental role, particularly if large-scale storage sites remain confined to a few pivotal geological basins. Parts of the network will also be centred on large liquefaction and shipping facilities at key ports, which would be shared among multiple users.

In this scenario, there will be dominant lowest-cost pathways to storage for the majority of CO_2 sources and limited competition, creating a need for regulated access tariffs to avoid monopoly pricing and ensure network development maximises decarbonisation potential (see below). In some storage basins with no or limited competition, tariff regulation may also be necessary for storage site operators. Furthermore, well-defined and consistent tariff structures across the EU will be more conducive to cross-border transport of CO_2.[29] The Impact Assessment for the Decarbonised Gas Package notes the risk of regulatory fragmentation on cross-border trade in hydrogen,[30] while the Agency for the Cooperation of Energy Regulators (ACER) has noted "inconsistent tariff structures across Member States impacted effective cross-border gas transportation".

To ensure equitable access and prevent excessive tariffs, while remaining flexible to uncertainties in network development, the EU regulatory framework and related legislation should:

- In the near term, establish clear minimum regulatory criteria for localised infrastructure that is likely to become operational before the EU regulation comes into force, to be applied by national regulatory authorities.
- Require Member States to appoint a national regulatory authority for CO_2 transport, with the power to oversee access demands and tariffs.
- Establish a Europe-wide platform for coordination between national CO_2 regulators.
- Require operators of CO_2 pipelines to offer fair and reasonable tariffs and to publish those tariffs in a transparent manner, together with the methodology behind their determination.
- Require the sector regulator to regularly assess the potential for emerging monopolies for CO_2 transport and storage and ensure it has the power to introduce further tariff regulation where appropriate.
- Consider implementing a regulated third-party access regime as the default long-term approach for significant shared infrastructure, including major CO_2 trunklines and cross-border pipelines (onshore and offshore), CO_2 liquefaction terminals, and CO_2 storage sites without regional competition.

28 *Directive 2024/1788 of the European Parliament and of the council on common rules for the internal markets for renewable gas, natural gas and hydrogen*.

29 Frontier Economics (2021) *Assistance to the impact assessment for designing a regulatory framework for hydrogen*

30 *Commission Staff Working Document Impact Assessment Report accompanying the proposal for a Directive on common rules for the internal markets in renewable and natural gases and in hydrogen* (2021)

SECTION 4

Planning and funding future-proofed networks

The JRC estimates that building a CO_2 network for 2050 could require up to 23 billion euro of investment.[31] This can be compared with the 80-143 billion euro estimated for the ~53,000-km proposed hydrogen backbone.[32]

Enabling investment in this kind of infrastructure faces a fundamental challenge: it should be sized to accommodate future demand, but first users alone are unlikely to be able to bear the full cost burden of 'future-proofed', large infrastructure, such as pipeline networks.

An important first step in planning and funding appropriately sized infrastructure is to assess the market demand as accurately as possible. Gas grid operators in Belgium, the Netherlands, Germany, and Italy have conducted market surveys of capture demand from industries in their respective regions, often yielding much higher estimates of demand than political targets or academic analysis of future CCS demand.[33]

There are inherent uncertainties on future volumes of CO_2, associated with uncertainty on the future of heavy industrial sectors in the EU, the progress of alternative decarbonisation technologies, the scale of public funding available to CCS projects, and – critically – the trajectory of the EU Emissions Trading System (ETS) carbon price.

This uncertainty ultimately leads to significant increases in the threshold carbon prices needed to invest, particularly in capital-intensive infrastructure such as CO_2 trunklines.[34] The aggregation platform planned under the Industrial Carbon Management Strategy, which should include planned capture and storage projects with their volumes and development timelines, will help provide greater visibility on the market to infrastructure developers. Government-supported analysis of optimum CO_2 transport routes, such as the recent study carried out in Austria, are useful for informing rational development.[35] Promoting the development of local and regional cluster decarbonisation plans, as demonstrated in the UK, France, and the Netherlands, can also help better define infrastructure requirements.[36]

However, the initial infrastructure projects in an emissions-intensive region are likely to need to coordinate final investment decisions (FIDs) with capture plants contracting at least some of their capacity; this has been the case for successful FIDs for the East Coast Cluster (UK), Porthos, and Northern Lights. National funding programmes should consider aiding CO_2 infrastructure planning by coordinating CCS funding awards towards industries with the potential to share transport routes.

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31 Tumara et al. (2024) *Shaping the future CO2 transport network for Europe*

32 Amber Grid et al. (2022) *European Hydrogen Backbone*

33 Cavanagh A and Lockwood T (2025) Carbon Capture & Storage 2030: As the market takes shape, can Europe's CO2 storage projects meet growing demand? *Proceedings of the 17th Greenhouse Gas Control Technologies Conference, 20-24 Oct 2024.*

34 Hagspiel et al. (2024) Investing in carbon transportation under volume uncertainty and scaling flexibility: A comparative analysis of flexible ships and cost-effective trunklines for CO2 transport to the Norwegian Continental Shelf; *SSRN Electronic Journal*.

35 Schützenhofer et al. (2024) *Machbarkeitsstudie über ein CO2– sammel– und transport-netz in Österreich.*

36 UKRI (2024) *Industrial decarbonisation*; Secrétariat général pour l'investissement (2023) *Favoriser le développement de Zones Industrielles Bas Carbone (ZIBaC)* (2023); CATF (2022) *Industrial decarbonization utilizing CCS and hydrogen in the Netherlands*.

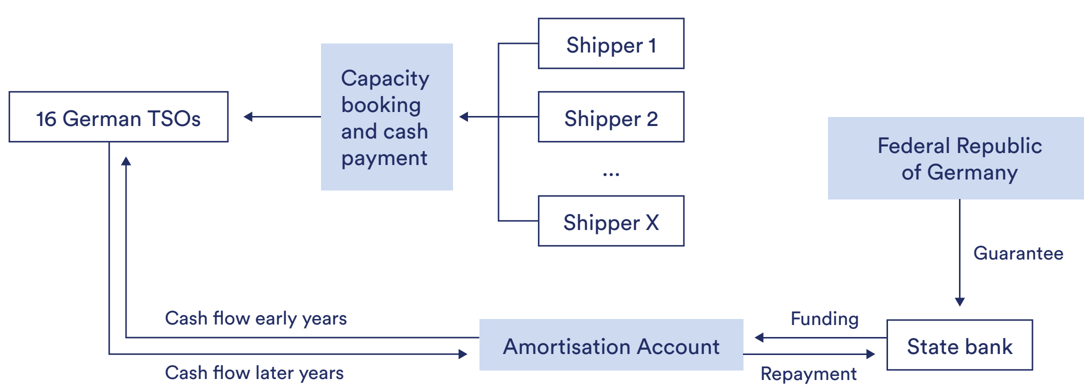
The regulatory framework for CO_2 transport can also help ensure networks are appropriately located and sized, through both tariff regulation and planning mechanisms. Unregulated private monopolies are clearly not incentivised to maximise the volumes of CO_2 they service: an engineering-based economic analysis of a CO_2 network finds that an unregulated monopoly invests in serving only around 10% of the volumes that would be delivered under a regulated, average-cost pricing regime.[37]

The expansion of the gas and electricity grids in Europe currently follows ten-year network development plans, developed by the cooperation initiatives of European system operators (ENTSO-G and ENTSO-E). Under Denmark's CO_2 pipeline act, all plans for CO_2 networks must be approved by the Ministry for Climate, Energy and Utilities, which can help ensure that any plans are compatible with the current or future needs of emitters. The Belgian regional pipeline decrees require the network operator to draw up a ten-year development plan, including estimates of current and future capacity requirements and a suitable investment plan for servicing these volumes – all to be annually or biennially reviewed. In France, the CRE calls for a plan for deployment of CO_2 value chains at the regional level, including regional pooling of resources and infrastructure.

Initial CO_2 infrastructure projects in the EU and Norway have been obliged to load significant costs on to the first users. Notably, the Aramis pipeline is to be sized to accommodate up to 22 Mtpa of CO_2, but the total investment costs must be recouped through tariffs on an initial user base of 5 Mtpa. This has likely contributed to unexpectedly high tariffs, approaching 100 euros per tonne at the last estimate, which are essentially passed through to the public subsidy provided to capture projects. While early users can expect tariffs to decrease as more join, this effect can provide a 'first mover disadvantage' and ultimately deter investment in the whole network.[38] This is particularly challenging where CCS projects are competing for the same funds as other decarbonisation projects (as in the Netherlands). To help address this challenge for Aramis, the Dutch government announced 639 million euros for the pipeline project in April 2025.

Hydrogen infrastructure funding faces the same challenge, leading to the regulation on the internal market for hydrogen and decarbonised gas to explicitly allow for 'inter-temporal cost allocations', which enable network costs to be spread across future customers. In Germany, this is implemented through an 'amortisation account' mechanism, which essentially allows the state to cover unbooked capacity through lending. This is then paid back as network users grow in number (Figure 3).

Figure 3: Financial flows under the amortisation account system used to fund hydrogen network in Germany[28]



[37] Nicolle et al. (2023) *Modeling CO2 pipeline systems : An analytical lens for CCS regulation.*

[38] European Clean Hydrogen Alliance (2023) *Learnbook: Financing of hydrogen infrastructure*

In the Netherlands, direct state grants are being used to de-risk investment in hydrogen backbone infrastructure.[39] In the UK, the depreciation of the regulated asset base can be adjusted to compensate for a period of 'utilisation build-up' with higher revenues in later phases. A government funding package can also be used to cover shortfalls from user tariffs. Network users face a regulated tariff based on the capacity they use and book, but can also be subjected to temporary tariff increases to cover shortfalls (mutualisation).[40]

The planned CO_2 network will clearly also need to benefit from inter-temporal cost allocation mechanisms, such as the amortisation account approach. Other potential risk-mitigation mechanisms could include grants specifically aimed at network 'oversizing' proposals, as implemented under the U.S. 'Carbon Dioxide Transportation Infrastructure Finance and Innovation Program'.[41] Although infrastructure developers and their investors can perceive a risk of oversizing infrastructure which may not be filled, this ultimately represents a lesser risk compared to sub-optimum build-out. A quantitative case study of cluster expansion has shown that a decision to oversize CO_2 pipeline capacity can, in fact, reduce overall economic regret by a factor of three relative to sizing capacity for the 'anchor load' alone, due to the costs incurred by the delayed and sub-optimal build-out.[42]

To ensure CO_2 transport networks are appropriately planned and funded, the forthcoming regulatory framework and related policy at the Member State level should:

- Carry out detailed and regularly updated analysis of CO_2 transport demand, optimum transport routes, and cross-border volumes, particularly as determination of realistic storage capacity and capture demand evolves.
- Require Member State regulatory authorities to assess any proposed CO_2 infrastructure plans against estimates of future demand, including market surveys and decarbonisation pathway analysis.
- Establish a process for long-term, rational planning of a cost-optimised CO_2 network at the European scale.
- Allow inter-temporal cost allocations in the regulatory framework for CO_2 transport and encourage Member States to adopt such measures.
- Coordinate funding towards carbon capture projects so as to fully exploit cost efficiencies associated with regionally shared infrastructure.
- Publish state aid guidelines for CO_2 transport infrastructure funding.
- Establish an Important Project of Common European Interest (IPCEI) for CO_2 infrastructure.

39 Reuters (2022) *Dutch government to invest 750 mln euros to develop hydrogen network*

40 Lockwood T (2024) *Risk allocation and regulation for CO2 infrastructure*

41 U.S. DOE (2024) *CIFIA Future Growth Grants*

42 Nicolle et al. (2023) Build More and Regret Less: Oversizing H2 and CCS Pipeline Systems under Uncertainty; *Energy Policy*; 179. 'Economic regret' expresses the economic penalty of the outcome when compared to planning with perfect foresight.

SECTION 5

Mitigating cross-chain risks

Investment in both CO_2 capture plant and CO_2 transport and storage infrastructure faces a variety of challenging coordination and project-on-project risks, often known as 'cross-chain' risks. These are financial risks faced by each participant in the value chain – particularly during early stages of development – as a result of their direct dependence on other parts of the chain operating as planned. These risks can be categorised as:

- Costs (or lost revenue) incurred by an emitter as a result of transport or storage infrastructure being temporarily unavailable or constrained;
- Costs incurred by an emitter as a result of delay to transport and storage deployment;
- Costs incurred by transport and storage operators as a result of delays in capture facility deployment;
- Costs incurred by transport and storage operators as a result of underutilisation (either from reduced emitter output, or fewer users connecting than expected); and
- Delays in payment by users to transport and storage (bad debt).

Some of the risks faced by infrastructure developers could be effectively mitigated by inter-temporal cost allocation or grants towards CO_2 infrastructure. As outlined above, these can help cover the costs incurred due to initial underutilisation of the network. However, other risk mitigation measures will likely be necessary to cover cross-chain risks associated with unplanned downtime in any part of the chain.

The UK government's support package for CCS has paid particular attention to mitigating cross-chain risks, which were identified as a key reason for the cancellation of an earlier funding programme in 2015.[43] Distinct funding packages known as the Revenue Support Agreement and the Government Support Package can be used to fill revenue shortfalls faced by transport and storage operators as a result of underutilisation of the network or underpayment by users.

Similarly, capture plants faced with unavailability of transport and storage infrastructure (due to delays or downtime) can continue to receive a government subsidy to cover their capital and fixed operating costs. The emitter's free allocation of ETS allowances, which otherwise need to be forfeited by the capture plant, can be returned in the event of network unavailability.

The Netherlands government has also taken on some of the risks faced by developers of the Porthos project infrastructure. Facing project delays due to legal proceedings, the government provided a 'one-off' guarantee of the project's supply contracts for long-lead items, essentially taking on liability for paying off these contracts in the event the project was cancelled as a result of the ongoing litigation.

There are indications that the commercial insurance market is developing its capacity to cover some portion of the cross-chain risk and other risks associated with CCS infrastructure (such as the small risk of leakage from storage). In the Netherlands, cross-chain risks and liabilities are expected to be distributed between actors in the CCS value chain through commercial negotiation and backed by insurance where possible. The UK regime also encourages transport and storage operators to find commercial insurance where available, with the government support acting as an insurer of last resort.[44] While it may be possible to commercially insure against cross-chain risks, it is likely to be less cost effective than other risk mitigation options, ultimately deterring investment or limiting the decarbonisation potential of available public funds.

43 Lockwood T (2024) *Risk allocation and regulation for CO2 infrastructure*

44 DESNZ (2023) *Carbon capture, usage and storage. An update on the business model for transport and storage – indicative heads of terms: explanatory note.*

In the event of transport or storage unavailability, the network operator will incur costs associated not just with its own repairs and lost fees, but the financial impact on all network users. The network users may encounter a number of negative consequences, depending on the nature of their costs, revenue streams, and any funding received.

Unplanned venting of CO_2 to the atmosphere due to network unavailability exposes users to the ETS. Depending on the duration of network downtime, the unabated plants may also lose access to any 'green product' markets, default on commitments to supply green products, or be in breach of conditions for subsidies such as the Innovation Fund, or financing instruments such as Green Bonds.[45] The UK's business model for low-carbon hydrogen producers – essentially a contract for difference on the price of 'CCS-enabled' hydrogen sold – includes provisions to compensate producers for ETS costs or lost sales due to a network outage.[46] Emitters themselves may also be exposed to the high-cost risk associated with network downtime, in the event that they cause an incident through, for example, supplying CO_2 with the wrong specifications.

These cross-chain risks become particularly complex in the context of the cross-border CO_2 value chains which are widespread in EU plans, with publicly funded capture and storage projects frequently relying on counterparts in other Member States. Combined with the importance of rapid CCS deployment to the EU's climate goals, this inter-dependence points to a role for risk mitigation steps at the EU level, including:

- Creation of a state-backed insurance fund to cover specific, pre-defined risks to CO_2 infrastructure providers and network users for eligible projects, potentially using a portion of ETS revenues at the Member State and EU level. Entities across the project value chain could also pay in to the fund, which will also serve to accelerate maturation of commercial insurance available to CCS projects.
- Regularly assessing the development of the commercial insurance market and its capacity to take on cross-chain risk at reasonable cost, as well as other challenging risks such as long-term storage liability, and establish means of regularly disseminating best practice.

45 Carbstrat (2024) *Cross-chain risk and de-risking mechanisms.* Presentation to the Zero Emissions Platform Advisory Council 4 Dec 2024, Brussels, Belgium.

46 DESNZ (2023) *Low-carbon hydrogen agreement standard terms and conditions.*

SECTION 6

A cost-optimised approach to CO_2 purity

CO_2 captured from anthropogenic sources will inevitably contain impurities, which have the potential to create significant risks for the safe operation of CO_2 transport and storage infrastructure. In particular, species such as oxides of sulphur (SOx), oxides of nitrogen (NOx), water, oxygen, and hydrogen sulphide (H_2S) can give rise to highly corrosive acidic environments, even if present in very low quantities.

Many of the EU's planned CCS projects operate on the principle of shared transport network and storage 'hubs', in which several different CO_2 streams are mixed, creating a complex challenge as impurities arising from different industrial processes and capture technologies can react to produce corrosive species.[47] The completion of ongoing research is needed to clarify the full range of safe operating windows that may be available to operators with mixed CO_2 streams.

In the interim, Europe's first projects have tended to implement very demanding specifications for CO_2 impurities (relative to existing specifications for operational networks in North America), particularly for projects involving the transport of liquid CO_2 in ships (Figure 4). Most notably, the Northern Lights project and the Aramis project standard for shipped CO2 have implemented a NOx limit of 1.5 ppm, which would require additional costly purification steps for several combinations of industrial source and capture process.[48]

In recognition of the need for a CO_2 network that is both safe and interoperable, the European Committee for Standardisation (CEN) is currently working to develop standards for the industry, building on work already carried out by the DVGW in Germany, and expects to deliver in 2027.[49]

This process should establish distinct, safe maximum levels for CO_2 impurities for each mode of transport (pipeline, ship, railcar, and truck). Opportunities to specify less stringent or more flexible purity requirements for parts of the value chain should be thoroughly explored, particularly as research furthers our understanding. For example, it may be possible to allow slightly higher levels of some species if the concentrations of other species are reduced. Furthermore, as specifications for pipeline transport are generally less demanding than for transport of liquid CO_2 in ships, value chains incorporating multiple transport modes can apply the most stringent specifications only where they are required – with purification steps introduced to the chain where necessary.

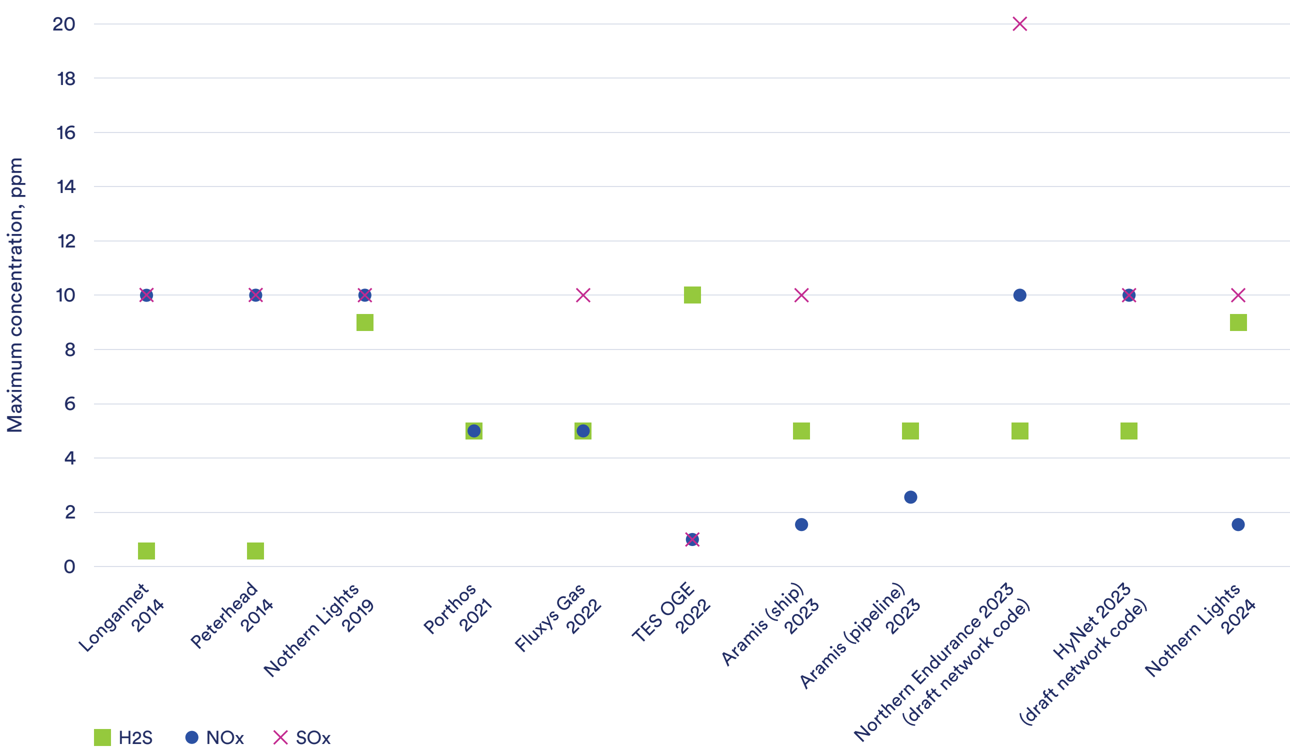
Setting appropriate limits for CO_2 impurities across the value chain is a complex optimisation problem, involving trade-offs in material selection, the number of additional processing steps needed, and the level of operational flexibility desired for the network. Optimising costs for all actors in the network while ensuring the safety of

47 Sonke et al. (2024) Corrosion and chemical reactions in impure CO2, *Int. J. Greenhouse Gas Control*; 133; 104075

48 Northern Lights (2024) *Liquid CO2 (lCO2) quality specifications.*

49 CENELEC (2023) *A new CEN/TC will develop standards for carbon capture, utilization and storage*.

Figure 4: Specifications for H_2S, SOx and NOx content in a selection of proposed CO_2 stream standards in Europe



CATF analysis based on public sources

the network will require a holistic view that considers the benefits of shared purification facilities and options for equitably sharing the cost of additional process steps across the value chain. Placing additional costs entirely on industrial emitters risks hindering the pace of decarbonisation, as the funding gap relative to the carbon price increases and available funding is expended on fewer tonnes abated. Most critically, uncertainty over future standards could lead to delays in investment in capture projects.

In addition to completing the ongoing work to establish standard CO_2 specifications, the Commission and CCS stakeholders should take steps to:

- Ensure that current developers of Europe's CO_2 infrastructure converge as much as possible on a common standard for CO_2 specifications, so as to maximise network interoperability and flexibility.
- Provide a forum for continuous sharing of the latest relevant research and publish interim guidelines on safe specifications, to minimise uncertainty around the future direction of travel for CO_2 standards and the stalling of project progress.
- Actively engage on this issue with developers of CO_2 transport projects outside Europe – particularly in the U.S. and Canada.
- Promote a holistic approach to minimising and sharing the costs of CO_2 purification across the network.

SECTION 7

Final remarks

A common regulatory framework for CO_2 transport is fundamental for ensuring Europe's emissions-intensive industries have fair access to essential infrastructure, which is planned and built in a cost-effective and forward-looking manner. Urgent implementation of this framework will minimise uncertainty and delay for CCS project developers, which would otherwise put the EU's decarbonisation targets beyond reach. In the meantime, there are many projects and CO_2 infrastructure developments that will need greater clarity on the long-term economic and technical implications of regulations under development; ensuring the timely delivery of these projects is a priority.

However, the pace and scale of network deployment currently envisaged by the European Commission and industry stakeholders will not be realised without a significant increase in investment in both CO_2 capture projects and geological storage, which is unlikely to be driven by the ETS price signal and limited public funding pools alone. Recent analysis finds that investment in a large-scale CO_2 pipeline to the Norwegian Continental Shelf could require a carbon price of 400 to 600 EUR per tonne, owing in large part to the challenges in investing based on a volatile carbon price alone.[50] Further regulatory and policy measures to incentivise, de-risk, and finance this build-out should be thoroughly explored.

50 Hagspiel et al. (2024) Investing in carbon transportation under volume uncertainty and scaling flexibility: A comparative analysis of flexible ships and cost-effective trunklines for CO2 transport to the Norwegian Continental Shelf; *SSRN Electronic Journal*.