Modeling CO_2 pipeline systems: An analytical lens for CCS regulation

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What is CCS?

CCS: Carbon Capture and Storage

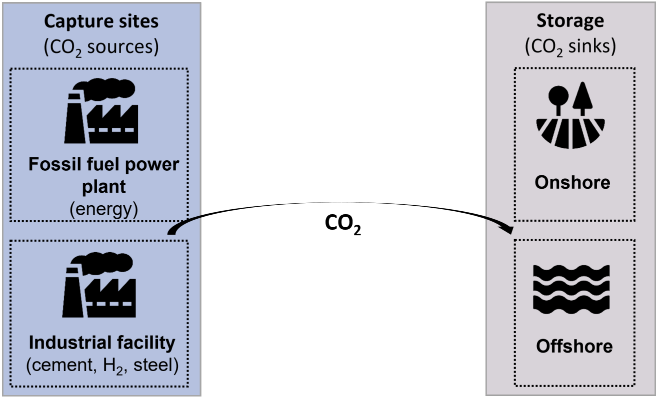

Figure 1: A first representation of CCS

What is CCS?

CCS: Carbon Capture, **Transportation** and Storage

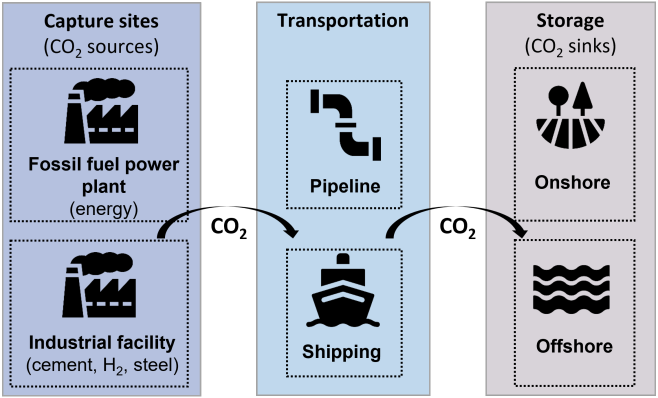

Figure 2: A better representation of CCS

High hopes... and disillusionment

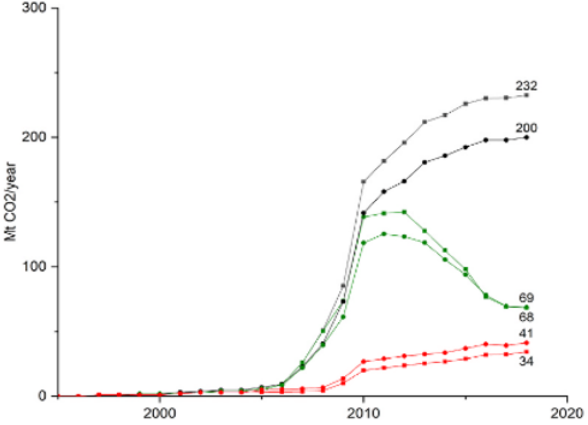

Figure 3: CCS capture and storage projects' capacity (Wang et al., 2021)
In black: planned capacity. In green: projects under construction & in operation. In red: projects in operation

Overcoming CCS' barriers

A main barrier: Lack of a clear CCS regulatory framework

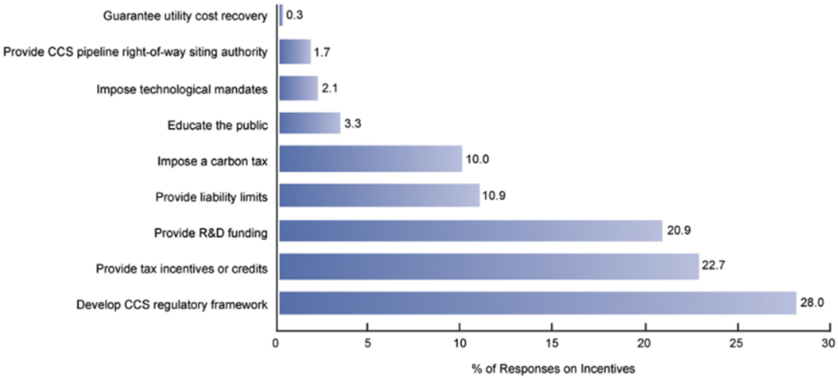

Figure 4: Percent of combined open-ended responses identifying preferred CCS incentive (Davies et al., 2013)

Research question

Research question:
⇒ How does regulation affect social welfare of CCS pipeline transportation?

Scope of this presentation:

1. Current regulation and gaps
2. Cost function of a CO2 pipeline system
3. Discussion

Current regulation: fuzziness prevails

Current regulation of CCS pipeline transportation:

	UK	U.S.	EU	Norway
Regulator	Ofgem	Unclear in most cases	Silent	State: project leader + stakeholder
Regulated pricing scheme	Rate-of-return	Project-dependent	Silent	Two-tariff
Main observation	Inspired by natural gas	Fuzzy	Early -stage	State implication

Policymakers and regulators have dedicated scarce attention to CCS transportation

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Policymakers and regulators have dedicated scarce attention to CCS transportation

In particular, the monopolistic nature of the pipeline operator seems widely overlooked

Literature review

Natural monopoly aspects:

→ Barely mentioned in the economic literature (Krahé et al., 2013; Roggenkamp & Haan-Kamminga, 2010)

→ barely mentioned in the grey literature (Whitmore, 2021)

→ ignored in network optimization models (IEAGHG, 2016; Jagu Schippers & Massol, 2022; Middleton & Bielicki, 2009; Morbee et al., 2012; Oei et al., 2014)

⇒ **Natural monopoly aspects have not been addressed (either) by the literature**

Natural monopoly & CCS deployment

Why is the monopolistic nature an issue?

For the capture sites:

→ subject to monopoly pricing

→ needs to be ensured that its consumer surplus will be protected

⇒ **This calls for a regulatory framework** ***(and a regulator)***

Natural monopoly & CCS deployment

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For the pipeline operator:

→ As a **natural monopoly**, it is prone to regulatory oversight

→ needs to be ensured that it can recoup its costs

The regulator and the regulated firm

Which regulatory approach ?

→ Regulators must find a pricing scheme that maximizes social surplus under incomplete information (Laffont & Tirole, 1994)

→ Critical gap: the regulated firm's cost function (Joskow, 1999)

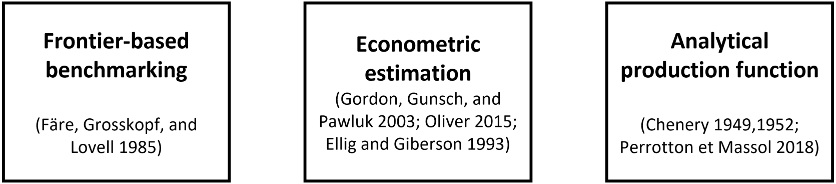

Figure 5: Common regulatory approaches for approximating a cost function

The regulator and the regulated firm

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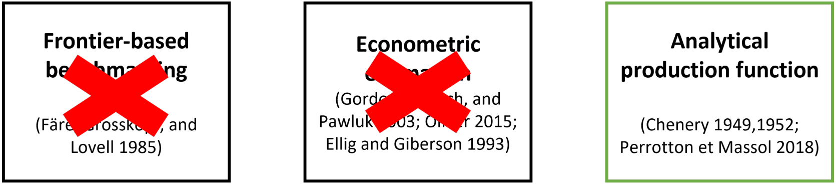

Figure 6: Retained approach for the CCS cost function

⇒ **Due to the lack of empirical data we retain the analytical cost function methodology**

System Definition

System under consideration:

Trunk pipeline + Pumping station

→ Point-to-point pipeline of length L and output Q

→ Constant elevation, no bends

→ CO_2 transported in a dense phase state

→ Onshore or offshore

Engineering-based production function

Flow equation (Vandeginste & Piessens, 2008):

$$D = \left(\frac{4^{10/3} n^2 Q^2 L \rho g}{\pi^2 \rho^2 \Delta P}\right)^{3/16} \quad (1)$$

with n the Manning factor, g the gravity constant, ΔP the pressure drop.

Pumping power (Mohitpour et al., 2003):

$$W_p = \frac{Q \Delta P}{\rho \eta_p} \quad (2)$$

with η_p the efficiency of the pump and ρ density of CO_2.

Combining:

$$\boxed{Q = cst_{tech}^{1/3} \cdot W_p^{1/3} D^{16/9}} \quad (3)$$

with $cst_{tech} = \pi^2 \rho^2 \eta_p / 4^{10/3} g L n^2$.

Analytical production function

Capital investment (Callen, 1978; Ruan et al., 2009):

$$K = p_s w_s L \pi D^2 (a + a^2) \tag{4}$$

with p_s the unitary price of steel, w_s the weight of steel per unit of volume, D the inside diameter and a the thickness of the pipeline.

Energy requirement: energy of the pumps

$$E = W_p \tag{5}$$

Simplifying and normalizing the output:

$$\boxed{Q^\beta = K^\alpha E^{1-\alpha}} \tag{6}$$

with K the capital, E the energy, $\beta = 9/11$ and $\alpha = 8/11$

Key findings

Key findings:

1. First analytical proof of **economies of scale** in CO2 pipelining
2. verifies technical condition for a **natural monopoly** (Sharkey, 1982).

⇒ **There is an urge to include the natural monopoly characteristics in future regulation (and studies)**

Classic regulatory scenarios

We now introduce a demand function $P(Q) = AQ^{-\epsilon}$

Cases	Optimization problems
Marginal cost-pricing (*)	$\max_Q W(Q) = \int_0^Q P(q)dq - C(Q)$
Unregulated private monopoly (^{M})	$\max_Q \Pi(Q) = P(Q)Q - C(Q)$
Average cost-pricing solution (^{avg})	$\max_Q W(Q) = \int_0^Q P(q)dq - C(Q)$ $s.t\ \Pi \geq 0$

with Π the profit of the pipeline operator

Discussion

$1/\epsilon$	1.25
Output ratio	
Q^M/Q^*	0.074
Q^{avg}/Q^*	0.723
Welfare ratio	
W^M/W^*	0.748
W^{avg}/W^*	0.992

$\Rightarrow$ The average cost-pricing solution performs well in terms of welfare

Efficiency gap

$1/\epsilon$	1.25
Output ratio	
Q^M/Q^*	0.074
Q^{avg}/Q^*	0.723
Welfare ratio	
W^M/W^*	0.748
W^{avg}/W^*	0.992

$\Rightarrow$ Efficiency gap $(Q^* - Q^{avg})$

Conclusion

- → Economic regulation is still in early stage but it is necessary to establish the rules now
- → We have proved analytically that the CO_2 pipeline system exhibits economies of scale and verifies the technical condition for a natural monopoly
- → the Cobb Douglas-Douglas production function is a first analytical tool for policymakers
- → We find an efficiency gap between economic and environmental objectives

Thank you for your attention!

Questions/comments?

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