Some news from the CCS research front

Chair The Economics of Gas

Olivier Massol, Adrien Nicolle, Diego Cebreros, Emma Jagu, Katharina Menke
Stéphane Tchung-Ming, Albert Banal-Estanol, Lucas Bitbol, Thanes Peter

ROADMAP

- **Part I: Some research on the economics of CCS, an overview**
- **Part II: Emerging public policy concerns**

I – Some recent works on the economics of CCS

CCS deployment, a road paved with ~~roses?~~ BRAMBLES!

- CCS in the literature (so far)

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

ENERGY POLICY

What went wrong? Learning from three decades of carbon capture, utilization and sequestration (CCUS) pilot and demonstration projects

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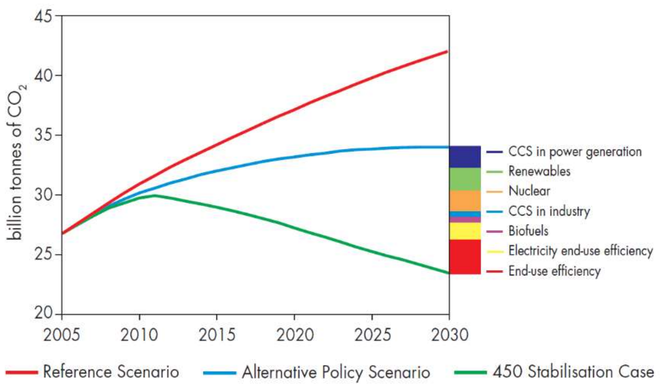
[c] La Follette School of Public Affairs, University of Wisconsin–Madison, USA

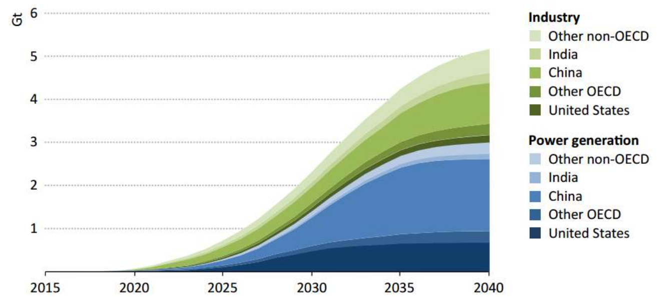
- A uninterrupted series of **missed opportunities**

Figure 5.12: CO_2 Emissions in the 450 Stabilisation Case



Source: IEA (WEO 2007)

Figure 4.4 ▷ CO_2 captured in the 450 Scenario by sector and region



Note: Industry includes the following sectors: steel, cement (energy- and process-related), chemicals and paper production; oil refining; coal-to-liquids, gas-to-liquids and natural gas processing.

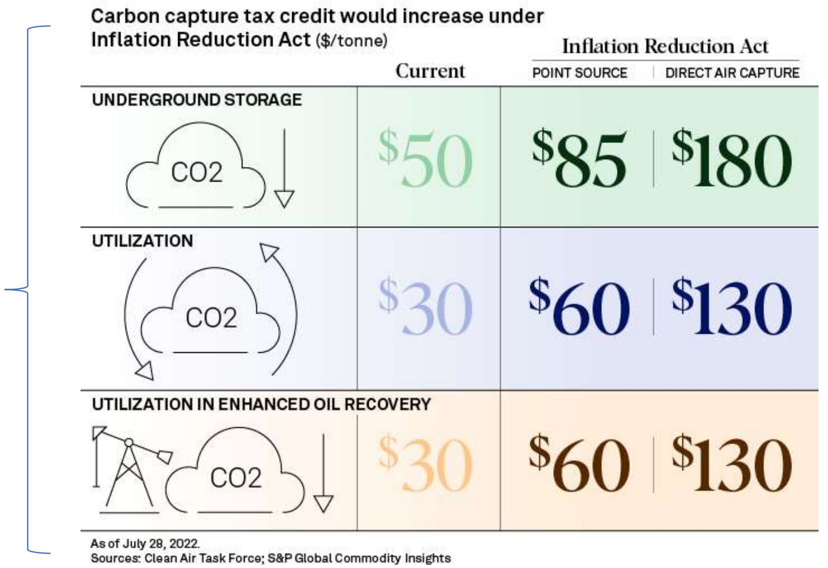
Source: IEA (WEO 2015, Special Report)

CCS deployment: this time is different?

- **Demand-side**

  Changing focus
  - (from powergen to industrial emitters)

  & New policies for a **Technology Pull**
  - The U.S **Inflation Reduction Act** (2022)
  - In Europe
    - Higher CO_2 price levels
    - The EU's **Carbon Border Adjustment Mechanism** (**CBAM**)
    - The EU's **Net Zero Industry Act**



Carbon capture tax credit would increase under Inflation Reduction Act ($/tonne)

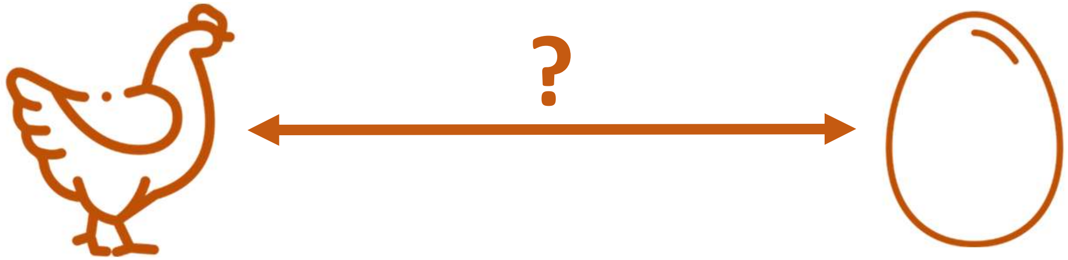
	Current	Inflation Reduction Act: POINT SOURCE	Inflation Reduction Act: DIRECT AIR CAPTURE
UNDERGROUND STORAGE	$50	$85	$180
UTILIZATION	$30	$60	$130
UTILIZATION IN ENHANCED OIL RECOVERY	$30	$60	$130

As of July 28, 2022.
Sources: Clean Air Task Force; S&P Global Commodity Insights

- **Storage**
  - A clarified regulatory framework

- **Infrastructures** ?

Herzog (2011): a chicken and egg problem



Existing regulatory frameworks

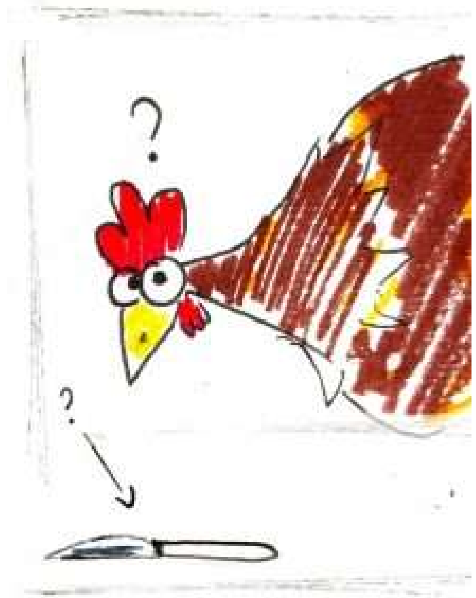
Table 1: Review of regulatory initiatives in early-adopter regions for CCS pipeline transportation infrastructures

	UK	U.S. Interstate	U.S. Intrastate	Norway	EU
Regulatory agency for rates and access	Ofgem likely to be appointed (BEIS 2022a)	Unclear regulatory mandate for pipelines crossing some federal lands and for pipelines not crossing federal lands	No agency, except for common carriers in Texas and Colorado	No agency, but the state intervenes as a project leader and as a stakeholder of the transportation infrastructure (Gassnova SF 2022)	Silent legislation
Non-discriminatory access prices	Yes	Mandatory for common carriers	Generally mandatory for common carriers	Yes (informational discussion)	Yes
Pricing scheme	Rate-of-return regulation combined with performance incentives (BEIS 2022a)	Project-dependent (STB intervenes in case of a dispute, see discussion in Appendix A)	Project-dependent	Two-tariff structure: (i) a user-specific maritime component based on distance, and (ii) a non-discriminatory access charge to the Norwegian onshore receiving terminal, the offshore pipeline, and the storage site	Silent regulation

Adrien Nicolle, Diego Cedreros, Olivier Massol, Emma Jagu Schippers (2023) *Modeling CO_2 pipeline systems: An analytical lens for CCS regulation*. EEEP, 12(2), 157-172.

Three main types:

1. **The explicit approach (e.g., the UK)**
2. **State intervention (e.g., Norway)**
3. **The fuzzy approach (e.g., U.S., E.U.)**



Back to basics: Technology 101

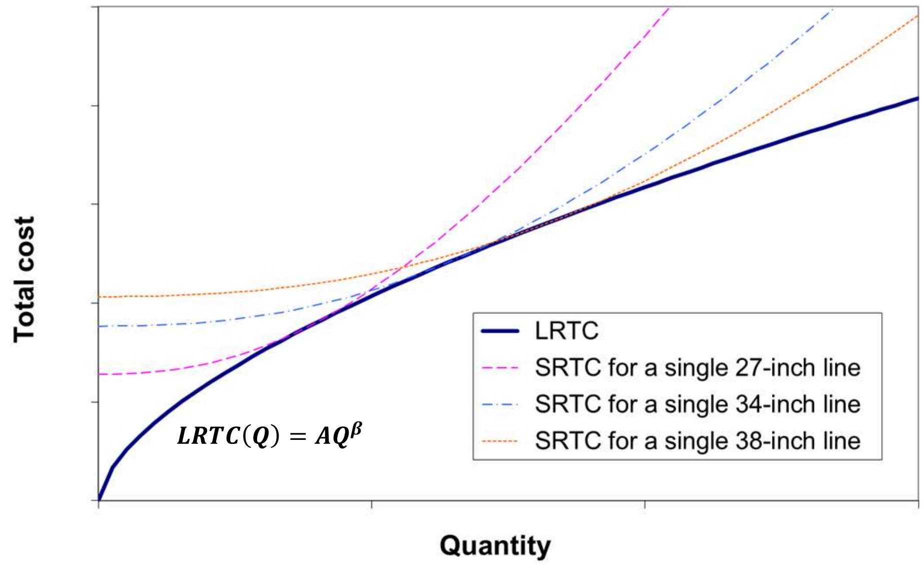
Adrien Nicolle, Diego Cedreros, Olivier Massol, Emma Jagu Schippers (2023) *Modeling CO_2 pipeline systems: An analytical lens for CCS regulation*. EEEP, 12(2), 157-172.

- **Insights from the simplest pipeline system**
  - Point-to-point pipeline (length L) & a pumping station
  - 2 inputs (capital K, energy, E) & 1 output Q
  - CO_2 transported in a "dense phase" state
  - Engineering equations

- Production function

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

with $\beta = \frac{9}{11}$ and $\alpha = \frac{8}{11}$



- **Insight #1: costs are subadditive in the long-run**

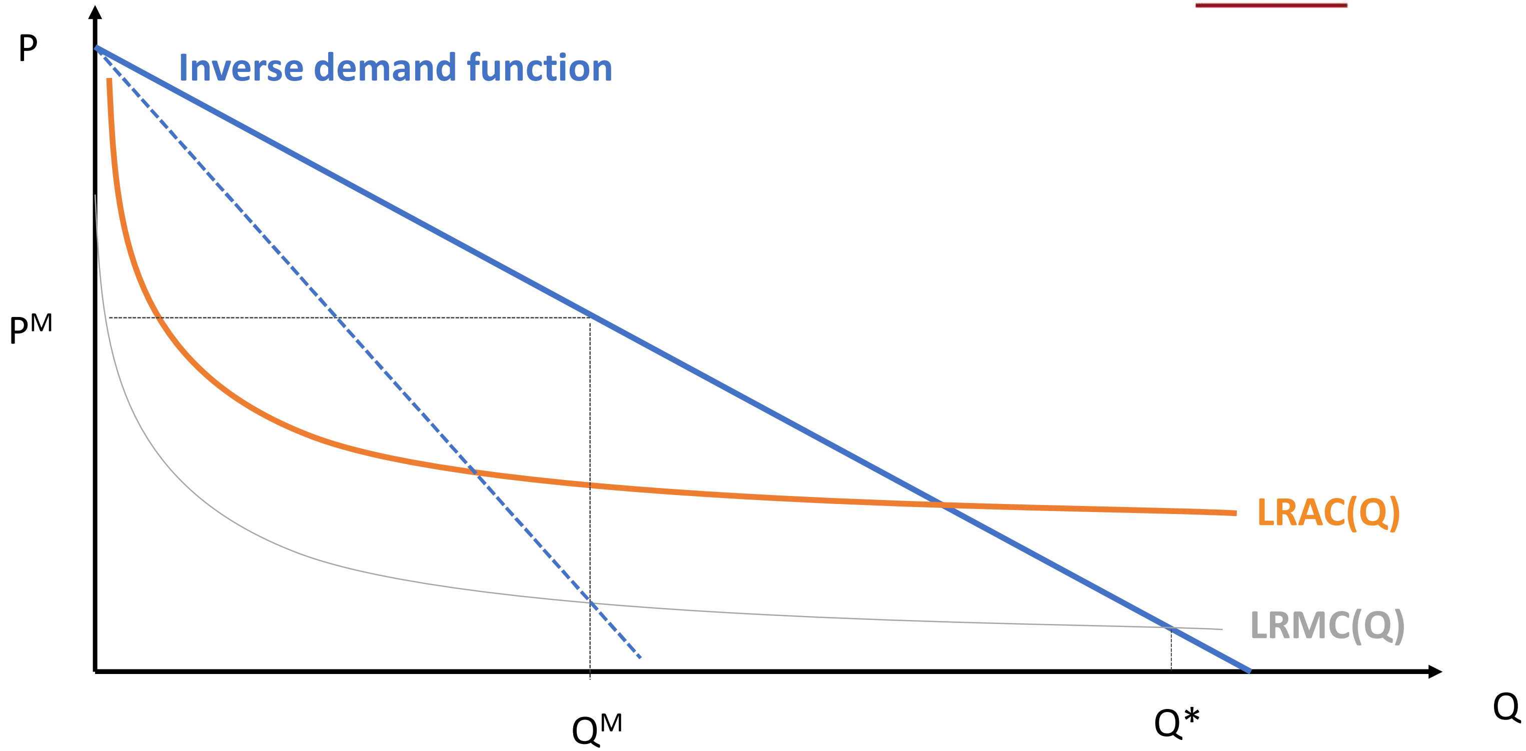
  => a **natural monopoly**

- **Insight #2: K is irreversible + LR economies of scale**

  => **Building ahead of demand** can lower the intertemporal cost (Chenery, 1952; Manne, 1961)

Insight #1:
The case of an unregulated monopolist

Adrien Nicolle, Diego Cedreros, Olivier Massol, Emma Jagu Schippers (2023) *Modeling CO_2 pipeline systems: An analytical lens for CCS regulation*. EEEP, 12(2), 157-172.

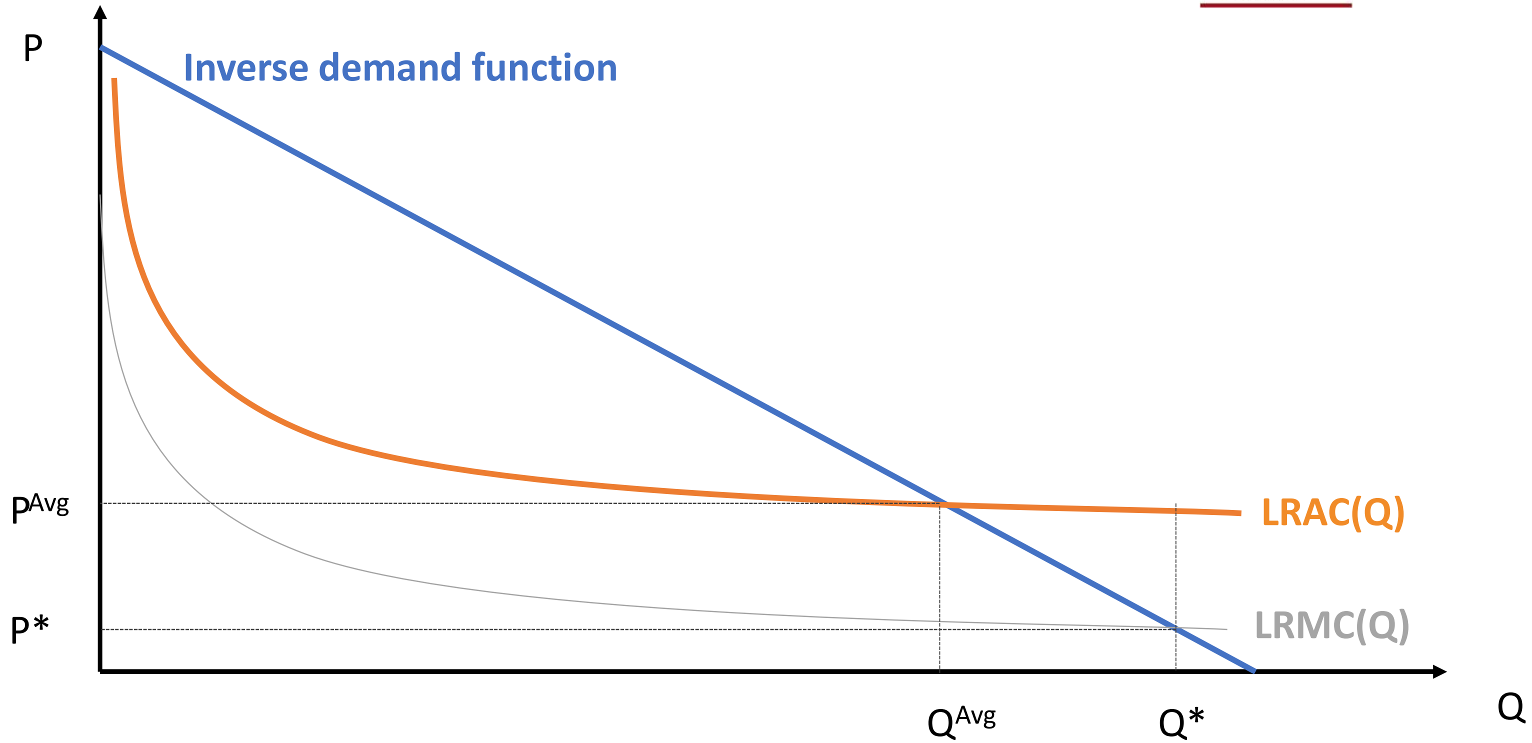


The case of a private monopolist operator

=> Absent any regulation, the amount of CO_2 captured will fall short of Q*

Insight #1:
LRMC pricing cannot recoup the cost

Adrien Nicolle, Diego Cedreros, Olivier Massol, Emma Jagu Schippers (2023) *Modeling CO_2 pipeline systems: An analytical lens for CCS regulation*. EEEP, 12(2), 157-172.

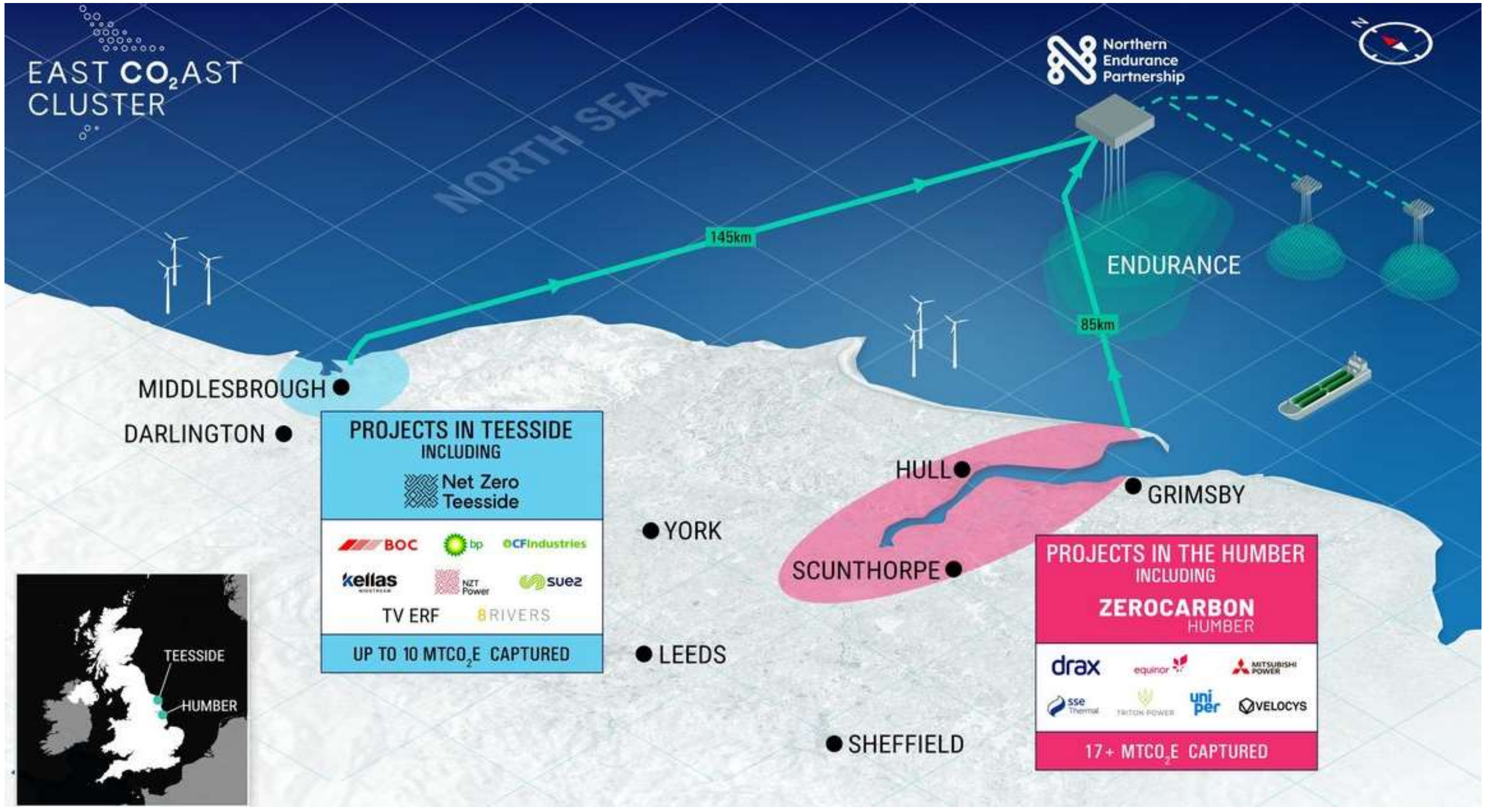


- Uniform (non-dicriminatory) prices => the use of a second-best solution (Q^{Avg}, P^{Avg})

But $Q^{Avg} \approx 0.7\, Q^{*}$ => **2 conflicting objectives**

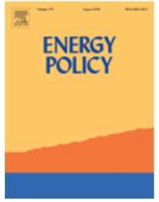
Max Q stored **vs.** **Preserve non-discriminatory prices**

Insight #2: The design problem



(Source: East Coast cluster's website)

Insight #2: The design problem



Nicolle, A., & Massol, O. (2023). Build more and regret less: Oversizing H2 and CCS pipeline systems under uncertainty. *Energy Policy*, *179*

From a regulator's perspective

- How can it distinguish between two types of project planner:

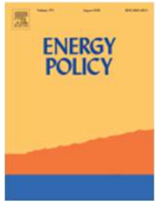
A project planner that **oversizes** its infrastructure to respond to future demand

(and that eventually misjudges its forecasts and ends up with an overcapitalized infrastructure)

A project planner that **voluntarily overcapitalizes** to exploit regulatory flaws

(A-J effect, fuzziness of regulation)

Insight #2: The design problem
Shall we build ahead of demand?



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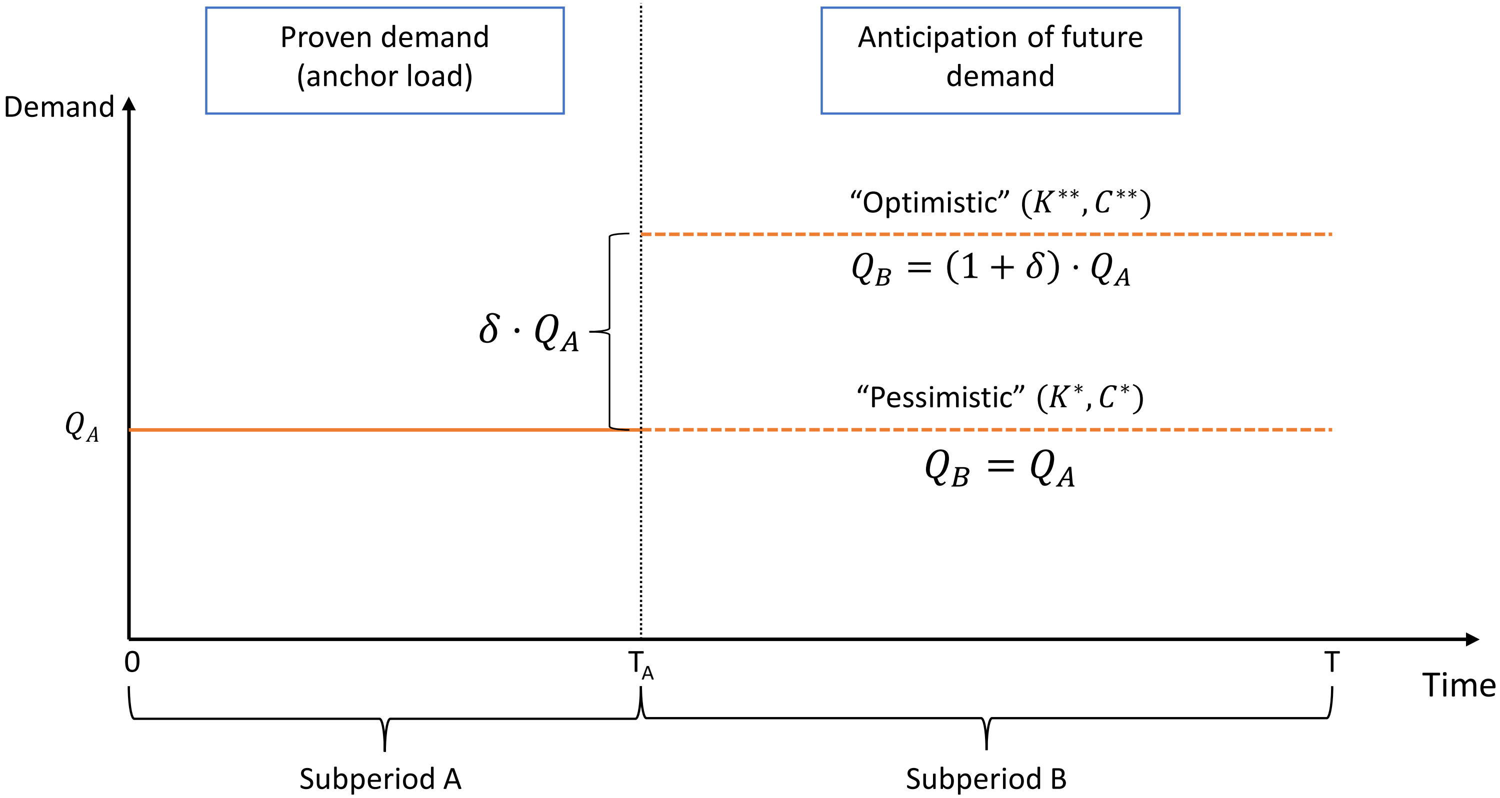
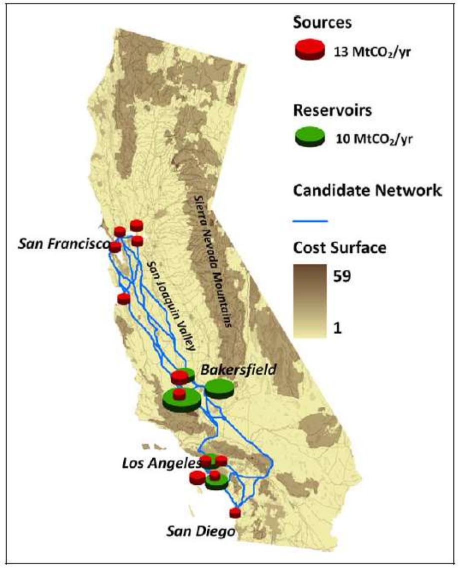


- Insights from **a MiniMax Regret decision rule:**

Building ahead of demand is regret-minimizing

Issue: Network planning

The existing CCS Network optimization literature



Candidate network for California example.

Source: Kuby et al. (2011)

YEAR 2050 - 18728km of pipeline - 28.2 billion EUR cumulative investment

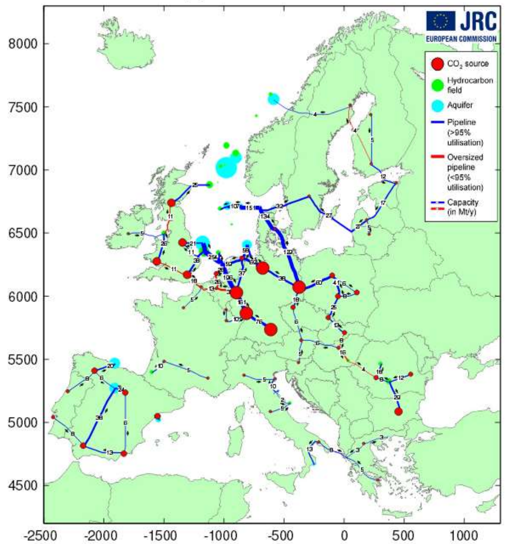
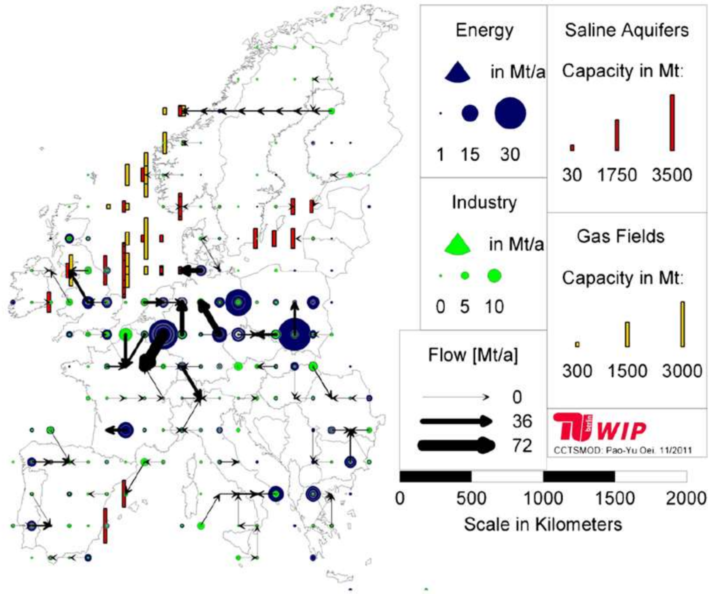


Figure 1 Optimal CO_2 pipeline network in 2050.

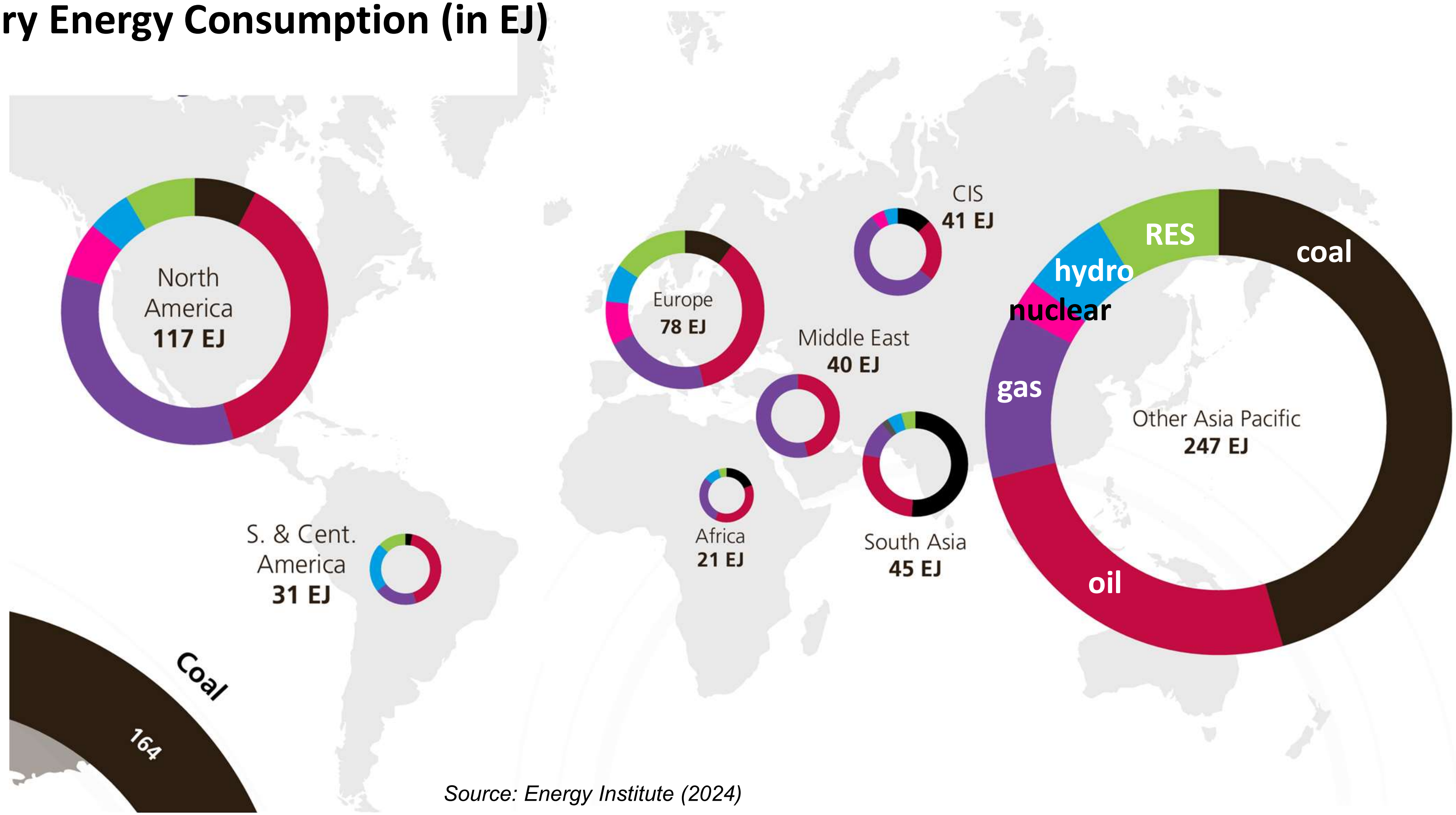
Source: Morbee et al. (2012)



Source: Oei et al. (2014)

The Global Energy Scene

Primary Energy Consumption (in EJ)

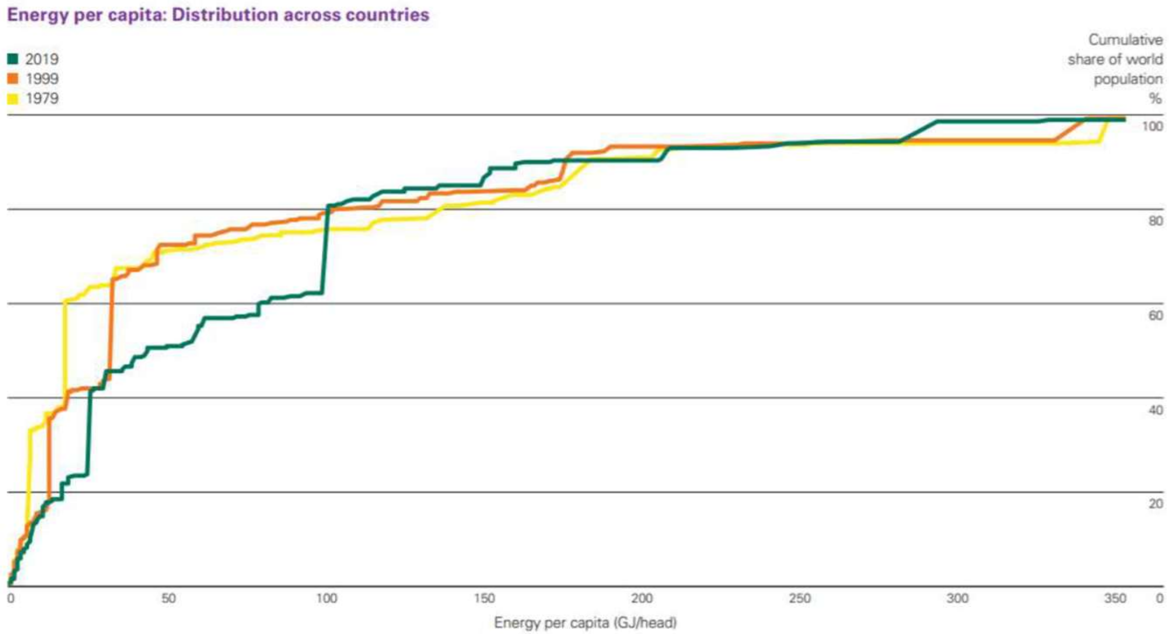


Source: *Energy Institute (2024)*

Issue: mitigation in emerging economies

Nicolle, A., Monjon, S., & Massol, O. (2024). Routing India towards Net Zero: Optimal planning of the CCS infrastructure. *WP (forthcoming)*

An emerging "climate bomb"



In 2019 81% of the global population lived in countries where average energy demand per capita was less than 100 GJ/head, two percentage points more than 20 years ago. However, the share of the global population consuming less than 75 GJ/head declined from 76% in 1999 to 57% last year. Average energy demand per capita in China increased from 17 GJ/head in 1979 to 99 GJ/head in 2019.

Source: BP Statistical Review of World Energy 2020

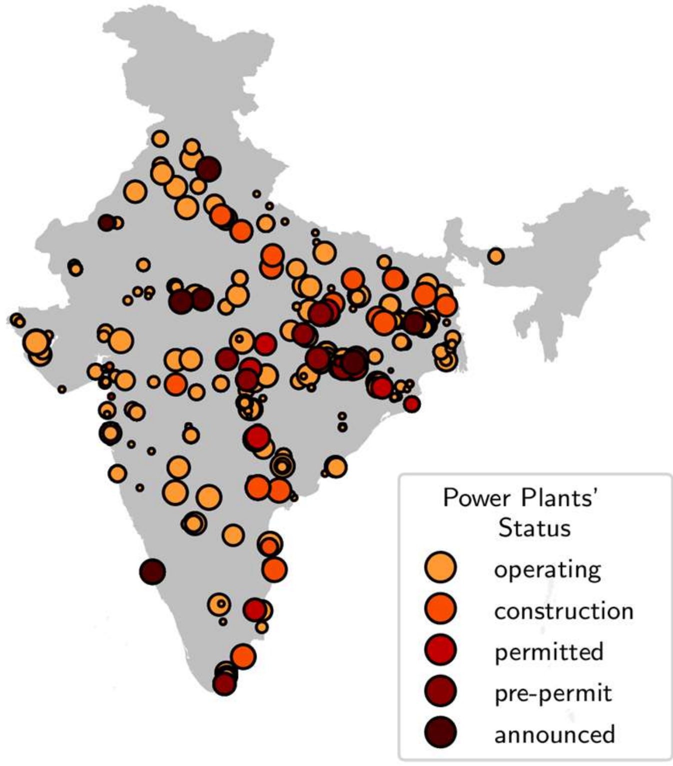
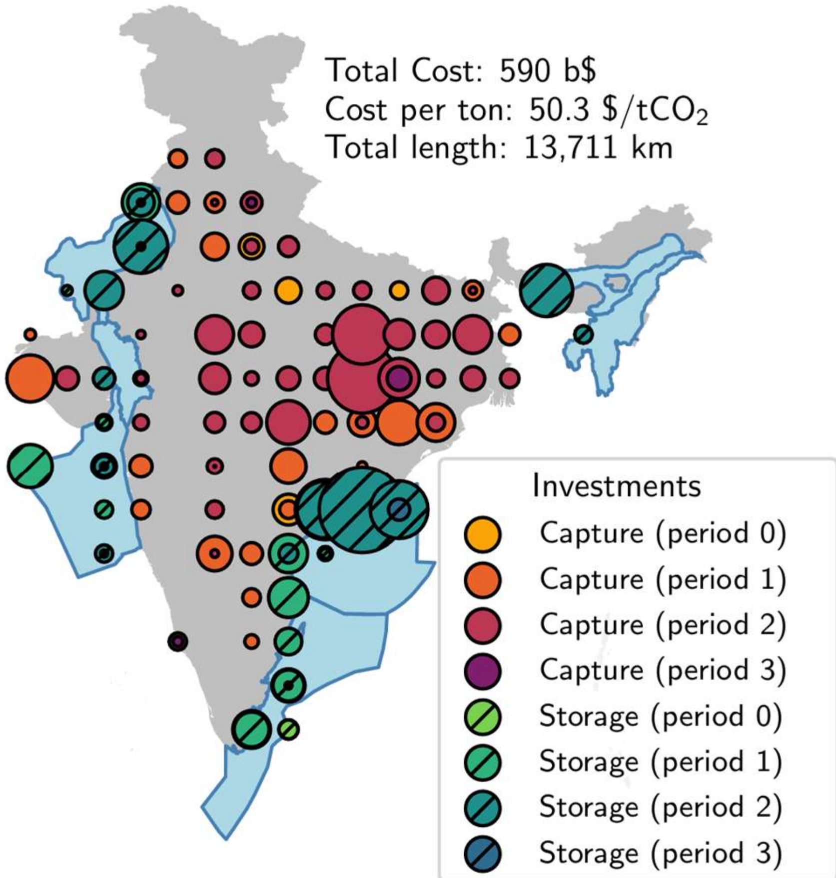


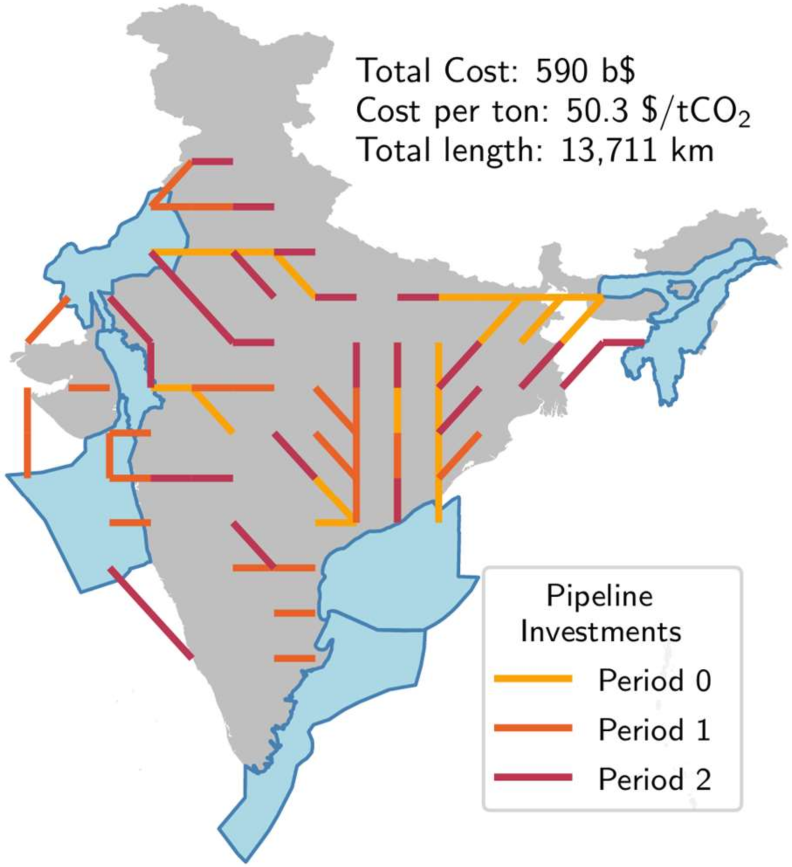
Figure 2: Map of the location and status of coal-fired power plants in India.

Insight #3: Identification of efficient CCS deployment schemes in India

Nicolle, A., Monjon, S., & Massol, O. (2024). Routing India towards Net Zero: Optimal planning of the CCS infrastructure. *WP (forthcoming)*



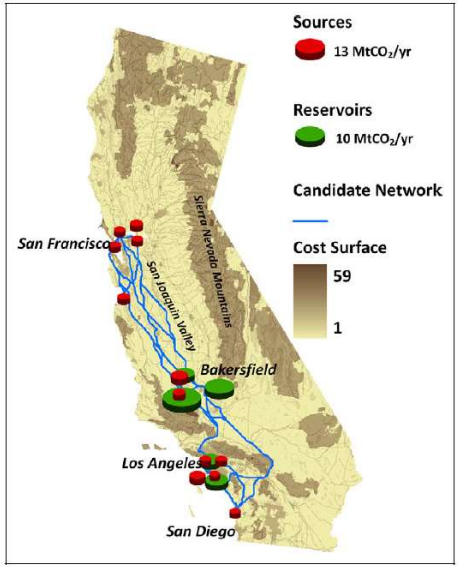
(a) Carbon capture and Storage investments



(b) Pipeline network investments

Issue: CO_2 transportation as a club good

Network optimization models



Candidate network for California example.

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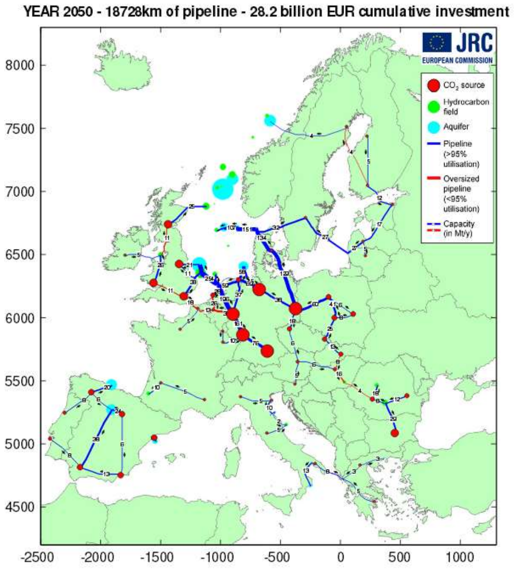

Figure 1 Optimal CO_2 pipeline network in 2050.

Source: Morbee et al. (2012)

The tale of a benevolent planer

Min total cost of pipeline infrastructure

s.t. node balance constraints

pipeline capacity constraints

storage capacity constraints

- However, CO_2 transportation is **a club good**

  => Do emitters obtain a fair share of the benefits?

  => a need for a **cooperative game theoretic approach**

Insight #3: CO_2 transportation as a club good

Contents lists available at ScienceDirect

European Journal of Operational Research (2015)

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

Joining the CCS club! The economics of CO_2 pipeline projects

Olivier Massol[a,b,c,*], Stéphane Tchung-Ming[a,d], Albert Banal-Estañol[c,e,f]

Contents lists available at ScienceDirect

Energy Policy (2018)

journal homepage: www.elsevier.com/locate/enpol

Capturing industrial CO_2 emissions in Spain: Infrastructures, costs and break-even prices[☆]

Olivier Massol[a,b,c,d,*], Stéphane Tchung-Ming[a,b,c,d,e], Albert Banal-Estañol[c,e]

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Energy Policy (2022)

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Unlocking CO_2 infrastructure deployment: The impact of carbon removal accounting

Emma Jagu Schippers[a,b,c,*], Olivier Massol[a,b,c,d,e]

From the conditions for shared infrastructures

Finding #1: The conditions for a vertically integrated club are identical to the one of an independent pipeline operator

Finding #2: **non-discriminatory pricing** can hamper the feasibility of some projects

Finding #3: when multiple storages are identified, the optimal community can have a **regional scale**

Finding #4: the inclusion of **BECCS** critically depend on carbon removal certification

Summary - Key messages from these studies

I – The current regulatory framework governing CO_2 infrastructures is fuzzy

II – Despite the technology's simple nature, economic implications are overlooked

- CO_2 transportation has elements of a natural monopoly
- Regulatory rules and priorities affect environmental performance
- Do we need to impose uniform pricing?

III – Building ahead of demand can be justified

- The knowledge of the technology can help in preventing strategic overcapitalization

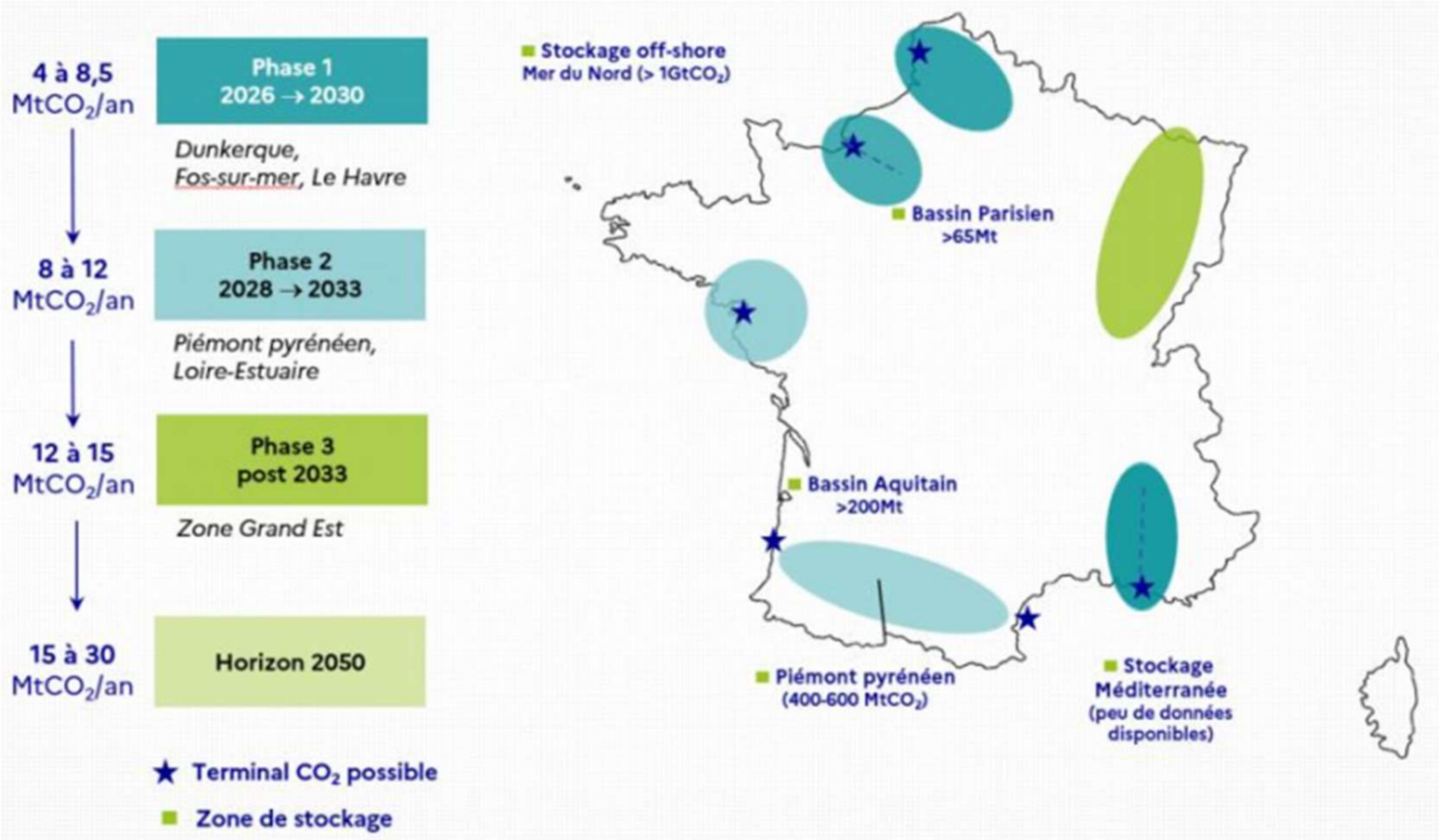
IV – The conditions for CCS deployment should also be examined in growing & carbon-intensive economies

V – A Club perspective yields major insights

- Again non-discriminatory pricing is not justified
- Focusing on simple communities can be preferable
- The feasibility to include BECCS & DACCS critically depend on carbon removal certification

II – Emerging public policy concerns

CCS in France:
A three phase Rollout



Source: DGEC. (2023)

Phase 1: storage in neighboring countries (Norway and Italy)

→ bilateral agreements

Phase 2: national storage or in neighboring countries

→ assessment of the potential of storage by the end of 2023

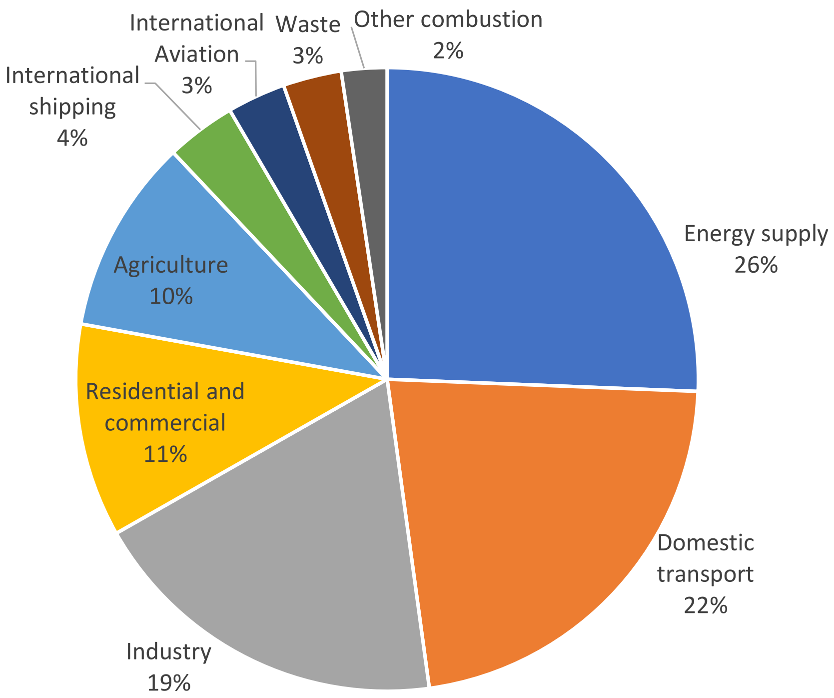
→ initial seismic tests starting in 2024-2025

Phase 3: 15-30 MtCO_2/year

Background

- Challenges of industrial decarbonization

Total GHG emissions in the EU-27 (t CO_{2eq}) in 2022[1)]



Decarbonization challenges in industry

- High investment and operational costs
- Missing market for green industrial products
- Low and unstable CO_2 price
- Late-mover-advantage

The industrial sector is responsible for a substantial part of global and EU GHG emissions,
However industrial decarbonization investments are hindered by challenges including a low and unstable carbon price.

1) Source: European Environment Agency (2024).

The contemporary discussion in France

Strategy CCUS (July 2023)

- **Risk-sharing through "Take or Pay" Contracts**
  → Partial coverage of potential penalties by the State
- **Transportation regulated by CRE**
  → Third-party access
- **Public support through Carbon Contract for Difference (CCfD), awarded by tenders**
  → Launch date : 2024

Consultation Response (Bellona, Oct 2023)

- **Storage objective too low**
  → Nation-wide potential of **90 $MtCO_2$/y** by 2050
- **Supporting CCS and Balancing risk**
  → State should take an active role (similar to Norway, Denmark or the Netherlands)
  → Avoid privately owned **natural monopolies**
- **CCfD**
  → Based on **CO_2 reduced**, **not captured**

Pouring public money into CCS – CCFD in practice

ESG Today

Germany Launches €50 Billion Industrial Decarbonization Subsidy Program

Germany announced the launch of Carbon Contract
subsidy program aimed at helping companies in ene

Jun 6, 2023

The Energy Mix

Canada Commits $7B to Carbon Contracts For Difference

The Canadian government's allocation of C$7 billion to carbon contracts for difference in this fall's fiscal update will promote a stable...

Nov 28, 2023

Fiev

Consultation en préparation d'un futur appel d'offres « Grands projets de décarbonation industrielle

Ce dispositif permettra de financer les grands projets de décarbonation industriel (>20 M€ de soutien public) soumis au système d'échange de...

Jul 2, 2024

CCfDs are increasingly being announced and implemented all over the world to support industrial decarbonization, involving substantial amounts of public resources.

Sources: ESG Today (2023); The Energy Mix (2023); Fiev (2024).

Emerging questions

I – Design of CCFDs

- How should these contracts be defined?

II – Allocation of CCFDs

- How can and should CCfDs be allocated?
  - Competitive tendering mechanism?
  - Beauty contest?
- Should we consider industry-specific approaches?

III – Technology & Infrastructures

- Capture: learning effect? Shared units for industrial clusters?
- Transportation: What regulatory/institutional rules?
- Negative Emission Technologies: DACCS, BECCS
- Utilization

THANK YOU

Key messages to take away

I – The regulatory framework governing CO_2 infrastructures is fuzzy

II – Despite the technology's simple nature, economic implications are overlooked

- CO_2 transportation has elements of a natural monopoly
- Regulatory rules and priorities affect environmental performance
- Do we need to impose uniform pricing?

III – Building ahead of demand can be justified

- The knowledge of the technology can help in preventing strategic overcapitalization

IV – A Club perspective yields major insights

- Again non-discriminatory pricing is not justified
- Focusing on simple communities can be preferable
- The feasibility to include BECCS & DACCS critically depends on carbon removal certification

Remaining questions

I – What policy instruments?

- **Subsidies** for…
  - … pipeline/infrastructure ?
  - … or for capture adopters?
- CCFD: increasingly popular but its economics have to be clarified for some sectors
- State-participation?
- **Binding emission** mandates?
  - By acknowledging possible differences in the sectors' obligations

II – What regulatory regime for CO2 infrastructures?

- **Third-Party access**: OK
- **Discriminatory pricing**?
- **Regulated profitability**?

III – Clarifying the feasibility of CCS in polluting countries

- Europe: Germany, Poland
- ROW: India, Gulf, China, Indonesia, Vietnam?

IV – Clarifying the unknown economics of emerging technologies

- BECCS
- CCUS

FUTURE RESEARCH

- What policy instrument?
  - Subsidies for pipeline/infrastructure ? State-participation?
  - For capture adopters?
  - Binding emission mandate? Possible differences in the sectors’ obligations

- What regulatory regime?
  - Third-Party access: OK. Discriminatory pricing?
  - Regulated profitability?

THANK YOU FOR YOUR ATTENTION

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