ADVANCES IN CLIMATE ECONOMICS

Climate Economics Chair Fall School

The benefits of building CO_2 pipelines ahead of demand: Evidence from a Minimax Regret approach

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Oct. 13th 2022

WHAT'S CCS?

CCS: Carbon Capture (Transport) and Storage

- **What's CCS ?**

CAPTURE
Emitters:
(coal power plants, industry…)

→

TRANSPORT
Pipeline network, (ship)

→

STORAGE
(onshore, offshore)

- **A CO_2 abatement technology:**
  - IPCC, Mitigation of climate change, SPM (2022)

    "C.4.6. **Currently, global rates of CCS deployment are far below those in modelled pathways limiting global warming to 1.5°C or 2°C**.

    Enabling conditions such as **policy instruments**, greater public support and technological innovation could reduce these barriers. (high confidence)"

→ focus on the transportation

BACKGROUND

CURRENT EUROPEAN CO_2 TRANSPORTATION PROJECTS

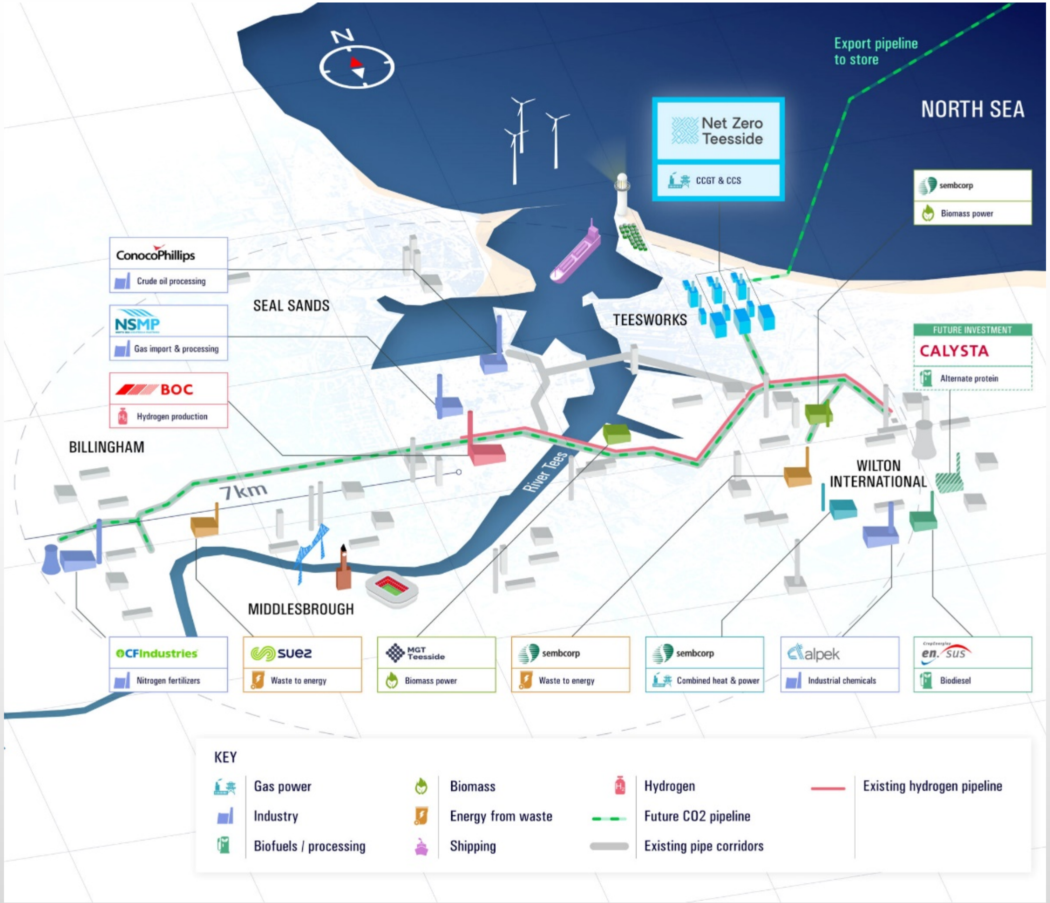
Background: United Kingdom

East Coast Cluster:

- **Capture**: two industrial clusters (Teesside and Humber regions)
- **Transportation**:
  1. **Feeder pipelines** in each cluster
  2. **Trunk pipelines** (145km and 85km) from each cluster to…
- the **Storage** site in Northern Sea

Two-steps deployment:

- Mid 2020s: ECC starts operation
- Mid 2030s: ECC ambitions to be the first net zero industrial cluster



(Source: Net Zero Teesside's website)

Research Question

Observations

- Shared point-to-point trunkline system
- Issue of oversizing in the first stage
  - **Uncertainty** of future demand
  - **Irreversible** decisions at the construction stage

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Research question

In a context of uncertainty, to which extent should the CO_2 pipeline system owner build ahead of demand?

Purpose of this presentation

Clarify the economics of oversizing the CO_2 trunk pipeline system

Two steps approach

1. **CO_2 pipeline system cost function**

   Cobb-Douglas production function

2. **Infrastructure Planning**

   Two subperiods with a *possible* increase in demand in the second period

   Minimax regret to determine the best decision

TECHNOLOGY OF A CO_2 PIPELINE SYSTEM

CO_2 PIPELINE COST FUNCTION IN THE LITERATURE

(Too) Inspired by natural gas' cost functions (Knoope et al., 2013)

- CO_2 transportation is **more expensive than natural gas**…
  - Increased material costs (King and Kumar 2010; A. Cosham, Eiber, and Clark 2010; Andrew Cosham and Eiber, 2008)
  - Management of flows (Chandel, Pratson, and Williams, 2010)

- … but the CO_2 cost function is **based on the natural gas' data**
  - Built upon FERC's natural gas data (Piessens et al. 2008; Dahowski et al. 2009; Heddle, Herzog, and Klett 2003; McCoy and Rubin, 2008; Chandel, Pratson, and Williams, 2010)

- **Pump station** often not included (Knoope et al., 2013)

THE CO_2 PIPELINE SYSTEM

- 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

The CO_2 Cobb-Douglas production function

- *Flow equation (pipeline)*

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

g: gravity constant

n: Manning factor

ΔP: pressure drop

- *Pumping power (pumping station)*

$$W_p = \frac{Q \cdot \Delta P}{\rho \cdot \eta_p}$$

η_p: efficiency of the pump

ρ: density of CO_2

$$Q = A^{1/3} W_p^{1/3} D^{16/9} \text{ where } A = \pi^2 \rho^2 \eta_p / (4^{\frac{10}{3}} g L n^2)$$

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

Where K is the capital, E the energy, $\beta = \frac{9}{11}$ and $\alpha = \frac{8}{11}$

→ $\beta < 1$: economies of scale, oversizing can be justified

(Chenery, 1952; Manne 1961)

INFRASTRUCTURE PLANNING MODEL

Literature review of CCS Network Deployment

Focus on transnational networks

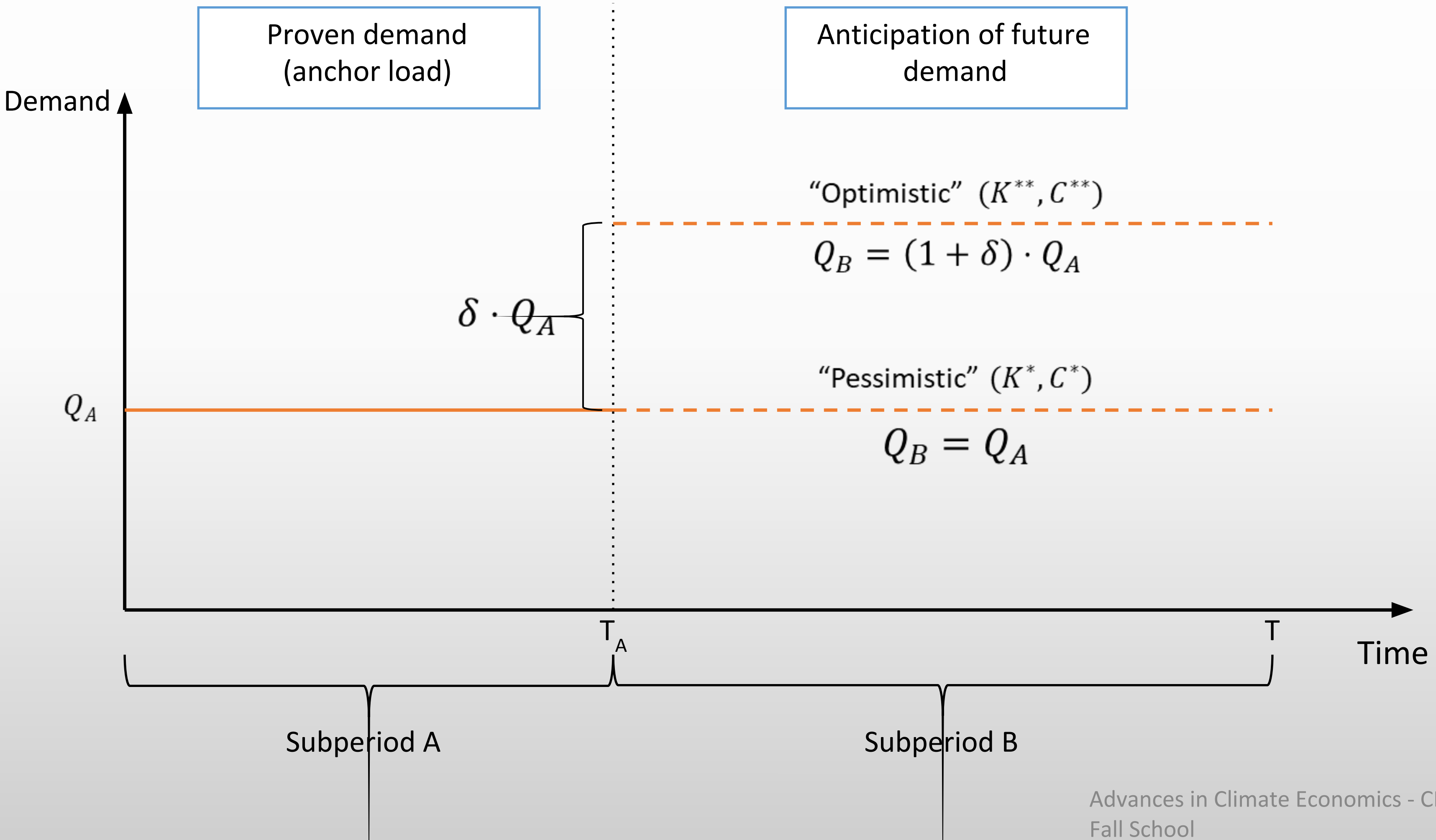
- Static Models
  - the amount of CO_2 transported remains constant over time (Kuby et al., 2011; Massol et al., 2015; Middleton and Bielicki, 2009)
- Omniscient or Myopic pipeline operators
  - Omniscient ⍰ Oversizing (Middleton et al., 2012; Morbee et al., 2012)
  - Myopic ⍰ Duplication (Mendelevitch et al., 2010; Oei et al., 2014)

≠ Project-specific study

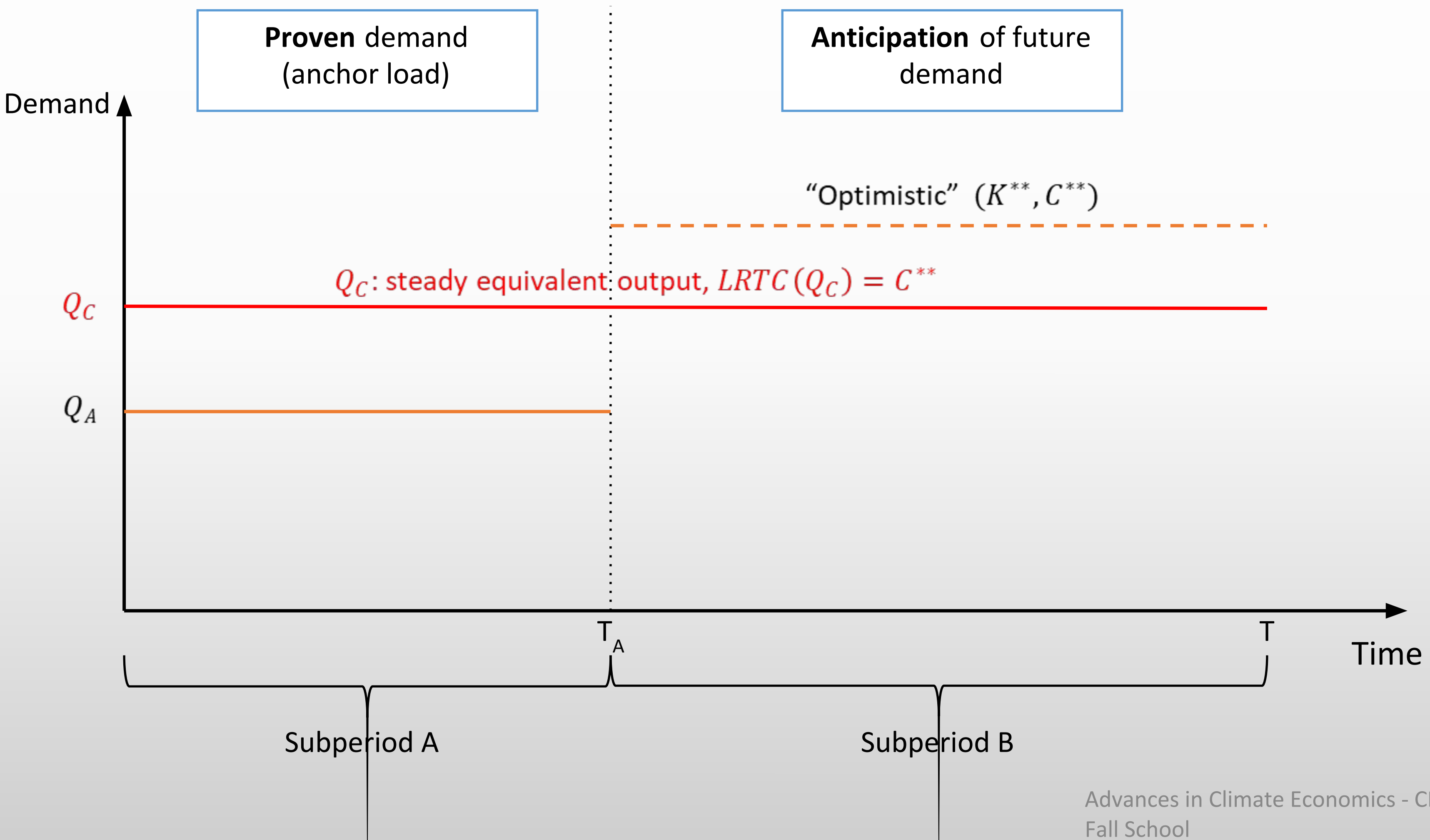
Site-specific study

- Comparison of Duplication VS Oversizing (Wang et al., 2014)
  - Engineering analysis
  - Omniscient pipeline operator

TIME DISCRETE REPRESENTATION



TIME DISCRETE REPRESENTATION



Least-cost infrastructure planning

- **Minimize costs over lifetime of the infrastructure**

With r the cost of capital, s the cost of energy, a_A and a_B discounting factors

Least-cost infrastructure planning

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Proposition 1: *The overcapitalization ratio is:*

$$\text{where } g_0 = (a_A + a_B) \text{ and } g_1 = \left(a_A + a_B(1+\delta)^{\frac{\beta}{1-\alpha}}\right)$$

Minimax regret : Possible outcomes

- **What happens if the pipeline operator's anticipations are wrong?**

	The pipeline operator's decision

With $SRTC_K(Q) := rK + s\ (a_A + a_B)e_K(Q)$ with $e_K(Q) = K^{-\frac{\alpha}{1-\alpha}} \cdot Q_i^{\frac{\beta}{1-\alpha}}$

And $LRTC(Q) := \frac{s^{1-\alpha} r^{\alpha} g_0{}^{1-\alpha}}{(1-\alpha)^{1-\alpha} \alpha^{\alpha}} Q^{\beta}$

Minimax regret : Regret Table

- $$\min_{x \in D} \max_{i \in S} \left(C_i(x) - \inf_{z \in D} C_i(z) \right)$$

	The pipeline operator's decision
Max normalized regret	

Minimax regret : Regret Table

	The pipeline operator's decision	
Max normalized regret		>

Regret-maximizing **Regret-minimizing**

Case Study: Net Zero Teesside

- **Overcapitalization ratio:**

$$\frac{K^{**}}{K^{*}} = 1.83$$

(increase in diameter of 35%)

Regret Table

	Myopic	Optimistic
Low scenario		
High scenario		
Max Regret		

x3 more regret in the myopic situation

CONCLUSION

Establishment of a novel CO_2 cost function:

- Cobb-Douglas production function
- Pumping station included
- Engineering-based, specificity of CO_2
   - exhibits economies of scale **oversizing**

Site-specific infrastructure planning:

 Quantify the overcapitalization ratio

- **Minimax Regret approach**

 Overcapitalization is ***always*** the regret-minimizing decision

 Case study shows **large advantages of oversizing**

THANK YOU FOR YOUR ATTENTION

ANY QUESTIONS?

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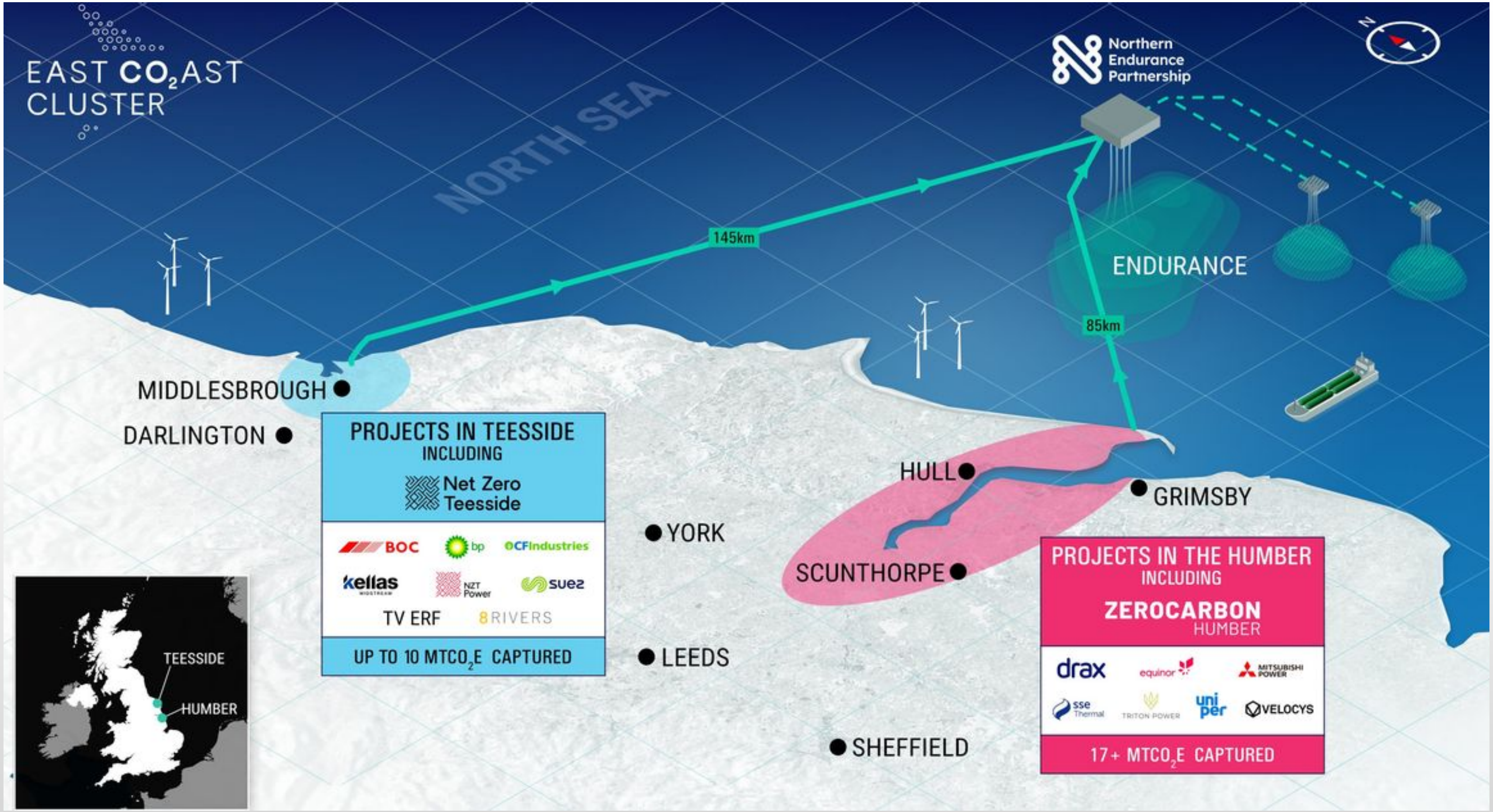
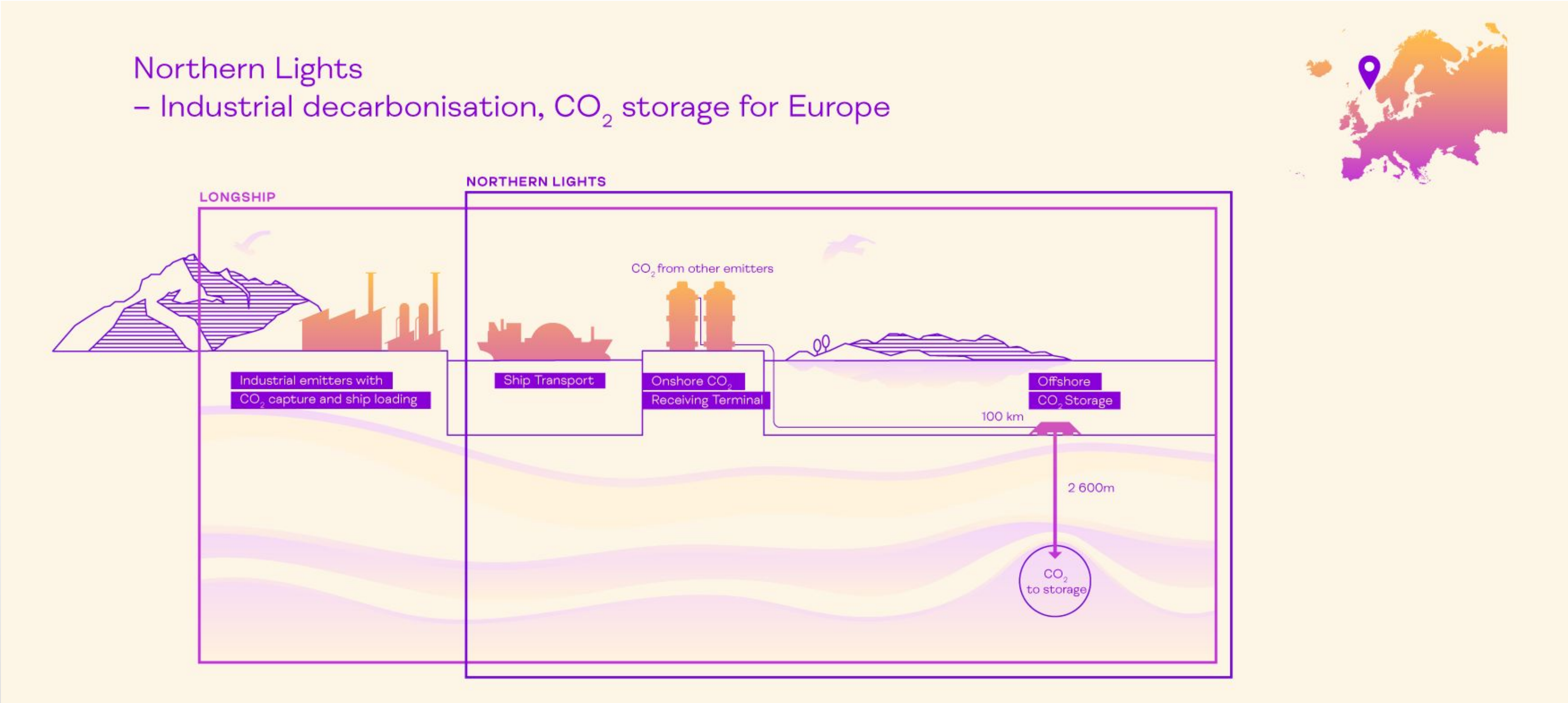
Background: United Kingdom



(Source: East Coast cluster's website)

Background: Norway

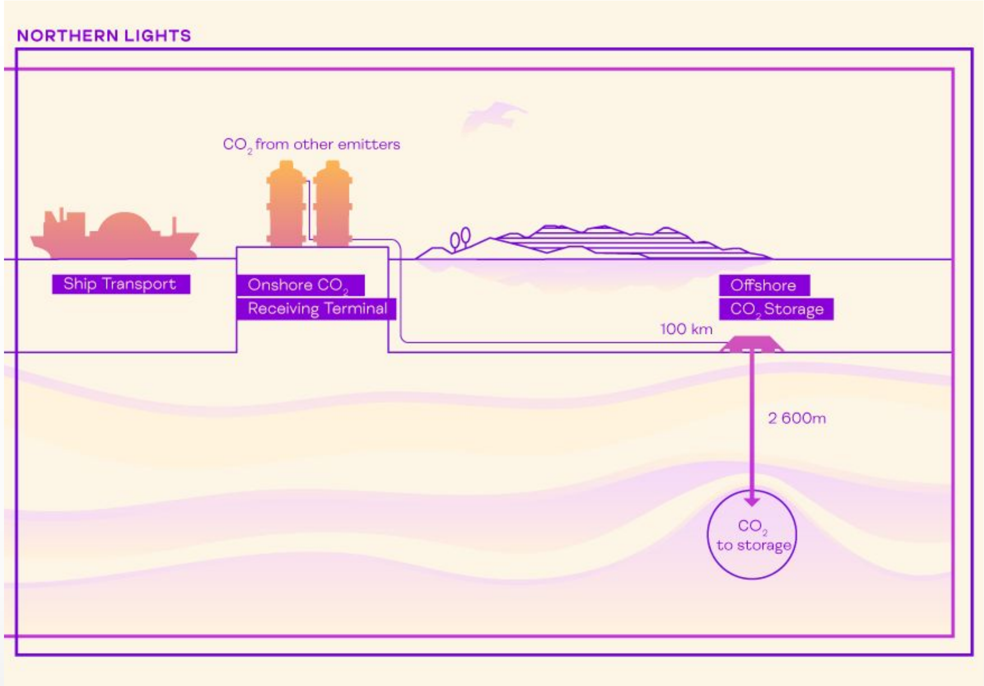


Source: Northern Lights' website

Background: Norway

Two-stage transportation *with ships:*

- **Capture**: CO2 from emitters across Europe
- **Transportation**:
  1. **Ship transport:** Emitters send their emissions to an onshore receiving terminal
  2. **Trunkline** transportation to offshore storage



Two steps deployment:

"Our ambition is to **expand capacity** by an additional 3.5 million tonnes to a total of 5 million tonnes, **dependent on market demand**."

"The offshore pipeline will be built **[in the first phase]** to accommodate the additional volumes **[of the second phase].**"

(Source: Northern Lights' website)

Result of the Minimax regret Table

- **Proposition 2**: *From a Minimax Regret perspective, "building ahead of demand" (overcapitalizing) is **always** a better alternative since*:

$$\boxed{\frac{SRTC_{K^*}(Q_C) - LRTC(Q_C)}{LRTC(Q_A)} > \frac{SRTC_{K^{**}}(Q_A) - LRTC(Q_A)}{LRTC(Q_A)} \quad \textit{for all value of } \delta > 0, d > 0, \beta < 1 \textit{ and } 1 - \alpha < \beta}$$