International transport of captured CO_2: Who can gain and how much?

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Introduction: This paper studies the allocation of benefits from international CO_2 transport infrastructure

- In many model results, **carbon capture and storage (CCS)** plays an important role as a bridging technology between the fossil fuel dependent present and the carbon-free future

- Large-scale deployment of CCS in Europe would require the **development of new pipeline infrastructure to transport the captured CO_2** from its sources (e.g. power plants) to the appropriate CO_2 storage sites (e.g. the North Sea)

- Recent research has produced a number of **models that are capable of determining the optimal** (i.e. cost-minimising) **CO_2 transport network** that can transport CO_2 from sources to sinks, such as Middleton and Bielicki (2009), Broek et al. (2010a,b), Mendelevitch et al. (2010) and Morbee et al. (2010).

If a pan-European CO_2 transport network is to be constructed, how will such international cooperation be structured, i.e. who will pay and who will gain?

We study the optimal CO_2 pipeline network in Europe* in 2050, assuming near-complete decarbonisation

Assumptions

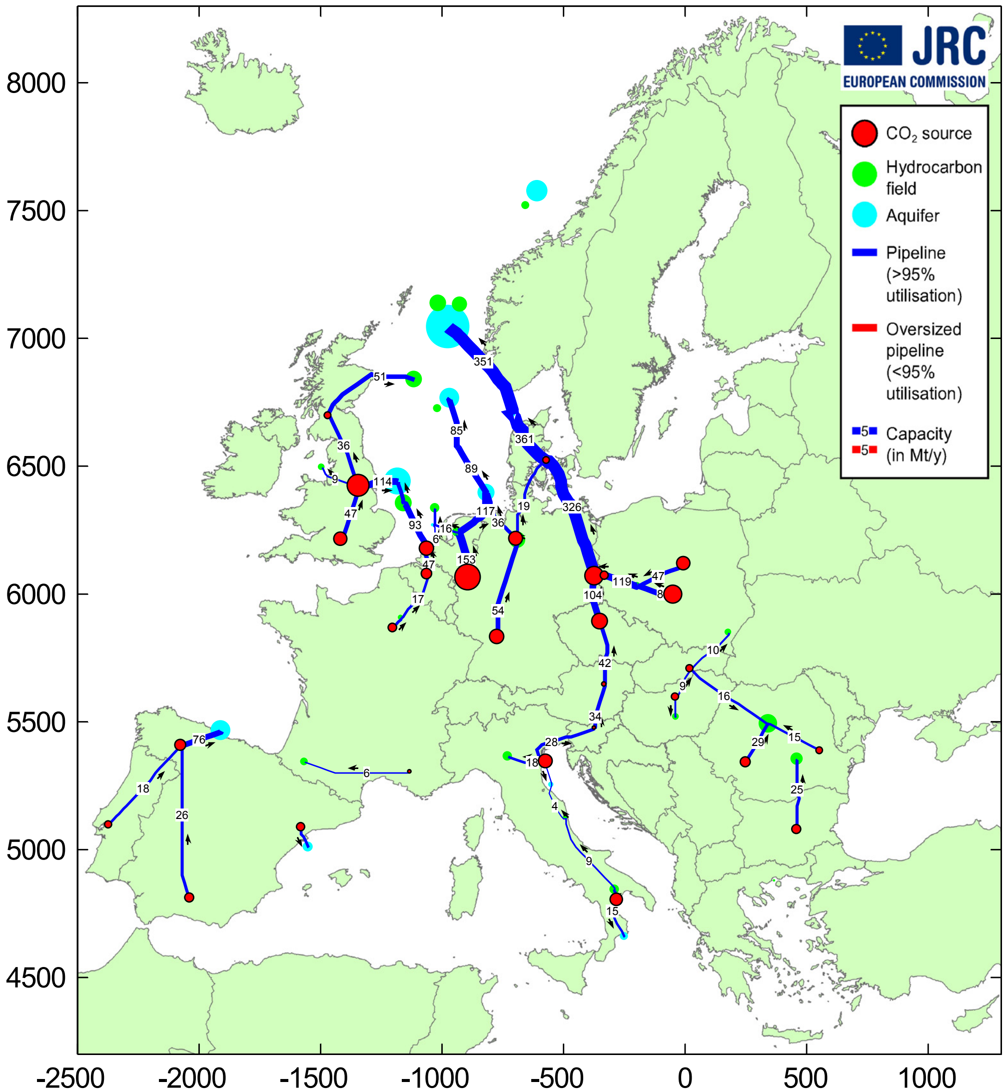
- **CO_2 sources** taken from Eurelectric's *Power Choices* (2010) scenario, based on the PRIMES model, which assumes near-complete decarbonisation of the power sector, thereby projecting **191 GW of CCS capacity by 2050**
- **CO_2 storage sites** (depleted hydrocarbon fields and saline aquifers) obtained from the **EU GeoCapacity project**
- Sources and sinks are clustered and the optimal pipeline network is computed using the JRC's ***InfraCCS*** model, a **cost-minimising mixed-integer linear programming model**, which takes into account the scale effects of pipelines (Morbee et al., 2010).

Country	Annual CO_2 captured Mt/y (2050)	Annual CO_2 storage potential Mt/y (2050)
Austria	8	
Belgium	30	
Bulgaria	25	
Czech Republic	62	
Denmark	15	14
France	27	17
Germany	337	111
Hungary	17	9
Italy	89	61
Netherlands	52	40
Norway		636
Poland	147	17
Portugal	17	
Romania	43	88
Slovakia	16	
Slovenia	6	
Spain	80	108
United Kingdom	173	315
Total	1145	1416

* EU-27 plus Norway

The optimal CO_2 pipeline network transports 1145 Mt/y of CO_2 and requires 28.0 billion EUR investment

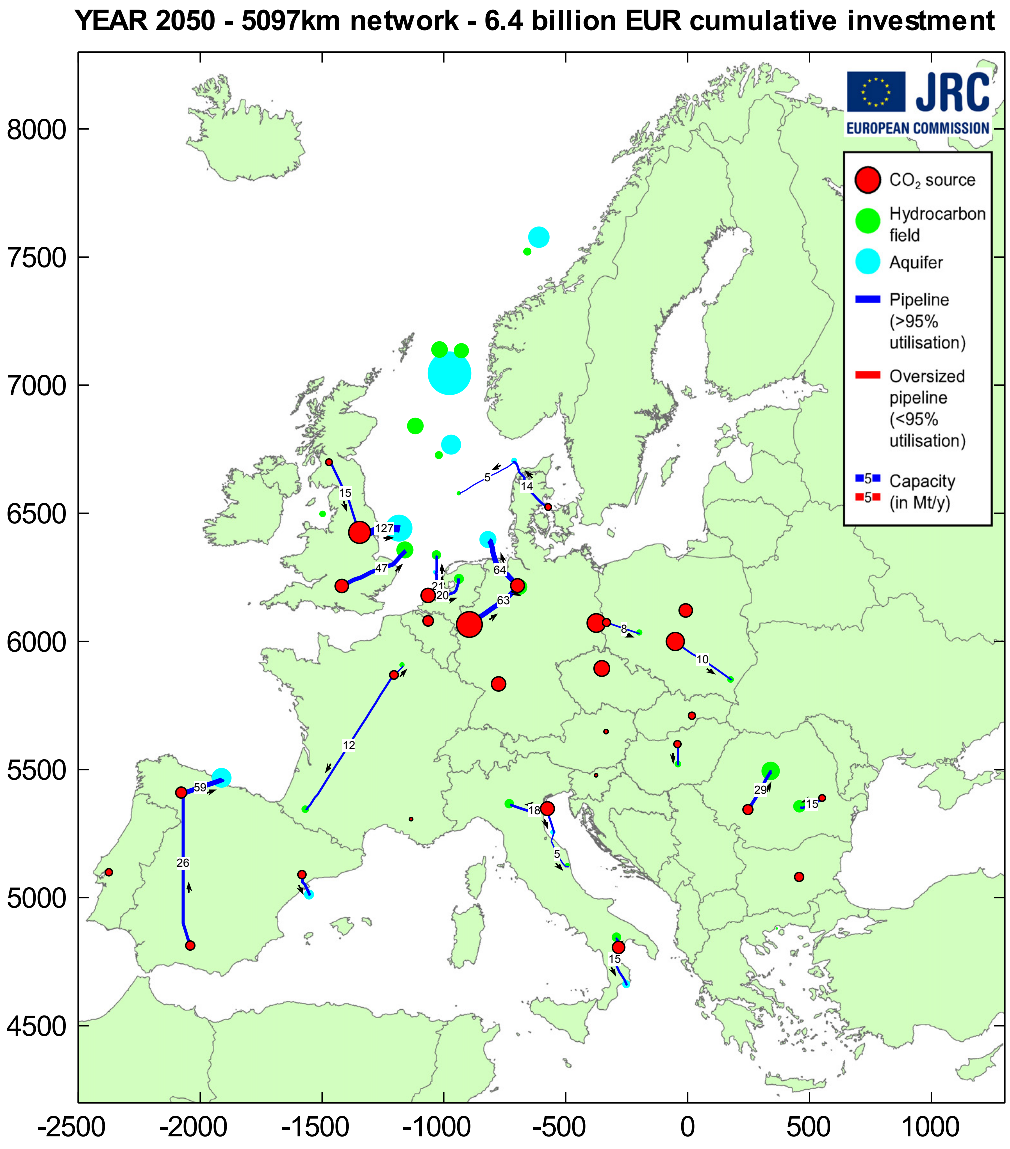
YEAR 2050 - 11001km network - 28.0 billion EUR cumulative investment



Observations

- **Large trans-European backbone network** spanning from Italy and Poland, through Germany and the Benelux, to the North Sea
- Regional network in southeast Europe
- Isolated activities in Spain/Portugal and the south of France
- Total network of **11001 km, requiring 28.0 billion EUR** investment
- **1145 Mt/y of CO_2** transported and stored

If countries do not cooperate, a different CO_2 pipeline network emerges, which transports only 565 Mt/y of CO_2



Observations

- Since not all countries have sufficient storage potential, not all projected CO_2 capture activities can take place.
- The network is **5097 km** in length and costs **6.4 billion EUR.**
- The network transport and stores **565 Mt/y of CO_2**, i.e. 580 Mt/y less than the jointly optimal case.
- We assume the **cost of non-captured CO_2** (i.e. the outside option* to achieve the same total CO_2 emissions reduction) is **19 EUR/t**, based on PRIMES maximum CO_2 transport costs.

* This could be wind, nuclear, emissions reductions in other sectors, etc.

In this setting, the total discounted gains from cooperation amount to 54.1 billion EUR

	Total discounted cost of CO_2 transport activities Billion EUR	
	Cooperation	**Non-cooperation**
• Network investment cost	28.0	6.4
• Cost of outside option (for CCS activities than cannot take place due to non-cooperation)*	-	75.7
• **Total**	**28.0**	**82.1**

The gains from cooperation are 54.1 billion EUR

* At 7.5% discount rate, with a 10-year time horizon.

Gains from cooperation are allocated depending on storage and transit positions of countries

- During the negotiations for the construction of the optimal CO_2 transport network, the **gains from cooperation will be allocated** according to each country's **bargaining power**.

- The bargaining power is mainly associated to **two types of rent**:

  – **Storage rent:** Country A with excess CO_2 storage can offer this capacity to country B, which may reduce country B's cost because it does not have to resort to the outside option. This provides country A with additional bargaining power.

  – **Transit rent:** Countries with a strategic location can help reduce costs of the joint network by allowing for shortcuts between CO_2 sources and storage sites. This translates into bargaining power for transit countries.

We use the Shapley value to analyse a ‘fair’ outcome of the negotiations

- To assess the storage and transit rents in an integrated way, we apply the **Shapley value approach,** introduced by Shapley (1953):
  - A ‘fair' allocation of the benefits of cooperation, taking into account the contributions of each of the players
  - The only allocation that satisfies a set of desirable properties (individual fairness, efficiency, symmetry, additivity and zero-player property)

- The **benefit received by each country *i*** in the negotiation process is:

$$\phi_i = \sum_{S \subseteq N \setminus \{i\}} \frac{|S|!(n - |S| - 1)!}{n!} (v(S \cup \{i\}) - v(S))$$

with: *N* the set of *n* countries
v(S) the pay-off of a cooperation among the countries in *S*

- Intuitively, the Shapley value equals the **contribution of player *i*** to the \`grand coalition' (the coalition of all players), **averaged over all possible sequences** in which this grand coalition can be formed

Simulations are done with and without national pipeline monopolies

Assumptions

1 Case 1: National CO_2 pipeline monopolies

- Every country has a monopoly on CO_2 pipeline construction within its territory.
- As a result, a pipeline through a given country cannot be built by a coalition that does not include this country.

2 Case 2: Liberalised CO_2 pipeline construction

- Any country is free to build pipelines in the entire EU and Norway.
- This does not mean that the land on which these pipelines are constructed is for free: a cost to cover the right-of-way is included in the pipeline costing approach.

Results: Shapley value is allocated mostly to net storage providers, and – in Case 1 – to transit countries

Country	Shapley value				
	Case 1		Case 2		Difference Case 2 - Case 1
	Billion EUR	Percent	Billion EUR	Percent	Billion EUR
Austria	0.4	1	0.4	1	0.0
Belgium	1.8	3	1.7	3	-0.1
Bulgaria	1.0	2	1.1	2	0.1
Czech Republic	1.8	3	3.3	6	1.5
Denmark	4.5	8	0.3	1	-4.2
France	1.4	3	0.6	1	-0.8
Germany	14.1	26	11.9	22	-2.2
Hungary	1.0	2	0.5	1	-0.6
Italy	0.9	2	1.0	2	0.1
Netherlands	1.4	3	0.7	1	-0.7
Norway	11.7	22	16.6	31	4.9
Poland	3.5	7	6.5	12	3.0
Portugal	0.6	1	0.7	1	0.1
Romania	2.2	4	2.4	4	0.2
Slovakia	0.6	1	0.8	2	0.2
Slovenia	0.5	1	0.2	0	-0.2
Spain	1.2	2	1.2	2	0.0
United Kingdom	5.4	10	4.0	7	-1.4
Total	54.1	100	54.1	100	

Observations

- Net storage providers (mostly Norway) capture 38% of the benefits in Case 1, and up to 45% in Case 2.
- Large rent is allocated to transit country Denmark in Case 1, but this disappears in Case 2 due to liberalisation of pipeline construction.
- Conversely, countries located at the end of the network (e.g. Poland) gain from pipeline liberalisation
- Large emitters such as Germany get a large share because they come from a low starting point.

Investment is paid for by large emitters, with large benefits for net storage providers (and transit countries)

Country	Contribution to investment				
	Case 1		Case 2		Difference Case 2 - Case 1
	Billion EUR	Percent	Billion EUR	Percent	Billion EUR
Austria	0.6	2	0.6	2	0.0
Belgium	2.1	8	2.2	8	0.1
Bulgaria	2.2	8	2.1	7	-0.1
Czech Republic	6.3	22	4.8	17	-1.5
Denmark	-3.7	-13	0.5	2	4.2
France	0.5	2	1.3	5	0.8
Germany	16.3	58	18.5	66	2.2
Hungary	0.2	1	0.8	3	0.6
Italy	3.3	12	3.2	12	-0.1
Netherlands	0.5	2	1.2	4	0.7
Norway	-11.7	-42	-16.6	-59	-4.9
Poland	13.8	49	10.8	38	-3.0
Portugal	1.6	6	1.5	6	-0.1
Romania	-1.9	-7	-2.1	-8	-0.2
Slovakia	1.5	5	1.3	5	-0.2
Slovenia	0.3	1	0.5	2	0.2
Spain	-0.1	0	-0.1	0	0.0
United Kingdom	-3.8	-14	-2.4	-9	1.4
Total	28.0	100	28.0	100	

Observations

- Some countries make a net payment, while others are net recipients from the cooperation.
- A large share of the cost is borne by countries with large volumes of excess CO_2, such as Germany and Poland
- Denmark is a net recipient in Case 1 (as a transit country), while it is a net contributor in Case 2.
- Germany (which has some transit rent) contributes more in Case 2 than in Case 1, while Poland (which has no transit rent) contributes less.

The payment allocation can be expressed per tonne of CO_2 exported

Cost per tonne of CO_2 exported

EUR per tonne of CO_2

Case 1		Case 2	
Country	Cost	Country	Cost
Poland	15.0	Italy	13.9
Czech Republic	14.7	Portugal	13.1
Italy	14.3	Slovenia	12.8
Portugal	13.7	Bulgaria	12.3
Slovakia	13.5	Poland	11.7
Bulgaria	13.1	Austria	11.6
Austria	11.3	Hungary	11.6
Belgium	10.2	Slovakia	11.6
Germany	9.9	Germany	11.3
Slovenia	7.4	Czech Republic	11.2
Hungary	2.3	France	11.0
Netherlands	1.1	Belgium	10.7
France	-0.3	Netherlands	9.4

Observations

- The spread of costs is much smaller in Case 2, because in Case 1 there is much more heterogeneity between countries depending on their transit position.
- Note e.g. that Slovenia, although located far away from the North Sea, pays a rather low price in Case 1, due to its role as a transit country for Italy.

The allocation of revenues can be expressed per tonne of CO_2 imported

Cost per tonne of CO_2 imported

EUR per tonne of CO_2

Case 1		Case 2	
Country	Revenue	Country	Revenue
Spain	10.0	Spain	10.1
United Kingdom	8.5	Romania	8.6
Romania	7.9	United Kingdom	6.3
Norway	3.9	Norway	5.6
Weighted average	5.1	Weighted average	6.0

Observations

- Countries with strategically located onshore storage gain revenues when going from Case 1 to Case 2 (e.g. Spain, Romania)

- Storage rent is 5-6 EUR/t, which corresponds to**:**
  - **Oil** field: **~$1 per barrel** of original recoverable oil reserves
  - **Gas** field: **~1 EUR per MWh** of original recoverable gas reserves

- Hence, depleted oil/gas fields provide a rent from CO_2 storage, but this rent is **much smaller than the original rent from oil/gas extraction.**

Conclusions

- Countries with more storage capacity than capture activity obtain 38% to 45% of the benefits of international CO_2 transport, with the higher number corresponding to the case with liberalised pipeline construction.

- Countries with a strategic transit location capture significant rent in the case of national pipeline monopolies, e.g. Denmark obtains a net benefit of over 4 billion euro in case of national pipeline monopolies, but loses almost of all this if pipeline construction is liberalised.

- Liberalisation of pipeline construction reduces by two-thirds the differences between countries in terms of cost per tonne of CO_2 exported.

- As a side result of the analysis, we find that the resource rent of a depleted hydrocarbon field (when used for CO_2 storage) is roughly $1 per barrel of original recoverable oil reserves, or 1 EUR per MWh of original recoverable gas reserves.

Caveats and further research

- The analysis is strongly dependent on the assumptions underlying the Shapley value. The allocation shown in this paper is therefore not necessarily the only possible allocation.

- Furthermore, supranational regulation and enforcement may be required in order to avoid renegotiation once the network is in place.

- An important area for future work is a more thorough understanding of the ‘outside option' through better integration with the economic equilibrium models that generate the scenarios of CO_2 capture rates.

Thank you!

The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.