A comparative assessment of national CCS strategies for Northwest Europe and the cost-effectiveness of storing CO_2 at the Utsira formation

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A joint research project

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Background (1)

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Regional CCS studies	Fail to include detailed specific local technical, economic, political or physical constrains	Difficult for local stakeholders and policy makers to interpret the significance of the results
National CCS studies	the development of the energy systems (including CCS) are only optimized for local conditions	Disregard the influence of developments taking place outside the national frontiers: incomplete picture

Background (2) The Utsira formation

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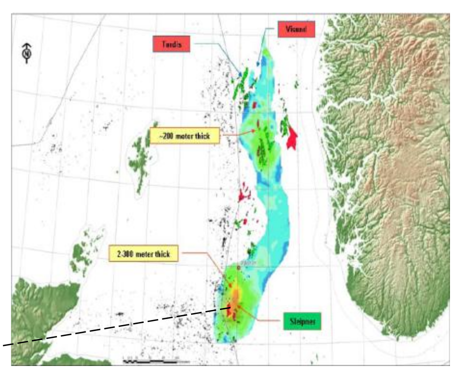
- Aquifer in the North Sea
- Mix of Sand Stones and Claystones
- Extends > 400 km from north to south and between 50 km to 100 km from east to west.
- Depth from 550 m to 1500 m but mostly from 700 m to 1000 m
- Storage of CO_2 happening since 1996 (about 1 Mt/year)



Source map: statoil

- Potential total storage capacity estimated in the order of 20-60Gt ! (how cost-effective?)

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The use of Utsira would depend on....

- Capacity of storage
- Mitigation strategies
- Development of CCS in the region
- Public acceptance
- Legal and policy conditions
- ...

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Objective

To generate insights into the national and regional costs, benefits and bottlenecks of capturing and transporting and storing CO_2 from countries in the North Sea region into the Utsira formation.

The project had 5 key sub-goals:

1. Improve knowledge on uncertainties and limitations to use the Utsira Formation as a CO_2 reservoir
2. Coordinate analysis of CCS for the countries around the North Sea (Norway, Denmark, Germany, the Netherland and the United Kingdom)
3. Analyse techno-economic parameters of future carbon capture technologies and their impact on CCS market penetration.
4. Improve knowledge on CO2 transportation synergies and barriers
5. Develop experience using the TIMES model for infrastructure development leading to an identification of a set of possible stepwise developments

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Set up of the project

- *Establish possible constrains for the use of the Utsira Formation in the Norwegian North Sea* : WP1
- *Identification and standardized of the data and parameters that were to be used in the linear optimization models* (Times/Markal): WP2
- *Assessment of cost-effective pathways for CCS in the countries of the North Sea region : Denmark, Germany, Netherlands, Norway and the United Kingdom: WP 3*
- *Assessment at the Regional level: PanEuropean Times model; WP 4*
- *Evaluation of non-technical issues (e.g. policy, legislation, organization) that need to be in place for the construction of a trans-boundary pipeline network : WP 5*
- *Integration of results: WP 6*

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Key Assumptions (WP 1&2)

Parameter	Harmonized	Country/model Specific
Energy prices	✓	
Final electricity demand		✓
Trade of electricity[1]	✓	
Load curve of electricity		✓
Final heat demand		✓
Vintage structure of the electricity park[2]		✓
Policy scenarios	✓	✓
CO_2 sources considered		✓
CO_2 capture technologies and reference plants		
Type	✓	
Fixed capital cots	✓	
Variable capital costs	✓	
Efficiency	✓	
CO_2 Capture rate	✓	
Other CO_2 mitigation options		✓
Life time	✓	
Discount rate	✓	
Availability factor	✓	
CO_2 transport costs	✓	
CO_2 Storage[2]		✓
Utsira	✓	

Policy scenarios

Scenario		Maximum limit of CO_2 emissions relative to 1990 (%)		
		2010	2020	2050
High CO_2 reduction	C-80	-	-20	-80
Limited CO_2 reduction	C-20	-	-20	-20

Sensitivity scenarios include the following:

- No CCS scenario. Only for the national models.
- High Utsira capacity, with a maximum injection rate at 500 Mt CO_2 per year and a total storage capacity at 100 Gt CO_2
- No storage onshore. For the Danish, German and Dutch models.

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ENERGY PRICES

		2000	2005	2010	2015	2020	2025	2030	2040	2050
WEO 2008 (high fossil fuel price scenario)-BASE CASE										
Oil	€/GJ	4.5	7.5	13.4	13.4	14.7	15.5	16.4	18.1	20.0
Natural gas	€/GJ	2.4	4.1	8.1	8.4	9.3	9.8	10.3	11.7	13.2
Coal	€/GJ	1.3	2.0	3.9	3.9	3.8	3.6	3.5	3.4	3.2
WEO 2007 (low fossil fuel price scenario)										
Oil	€/GJ	4.5	7.6	8.1	7.9	8.1	8.3	8.5	8.7	8.9
Natural gas	€/GJ	2.4	4.8	4.9	4.9	5.1	5.3	5.5	5.8	6.1
Coal	€/GJ	1.3	1.9	1.8	1.9	1.9	2.0	2.0	2.1	2.2

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Energy trade

Country	Scenario	2005	2010	2015	2020	2025	2030	2040	2050
UK	C-20	9	6	26	32	32	32	29	26
UK	C-80	9	6	26	32	32	32	30	22
NL	C-20	18	18	-5	-6	-13	-13	-6	-3
NL	C-80	18	18	-5	-11	-30	-44	-5	-64
NO	C-20	-12	-11	-25	-42	-42	-42	-42	-42
NO	C-80	-12	-11	-25	-42	-42	-42	-42	-42

		2010	2020	2030	2040
NGCC					
Capital	€/kW	676	608	608	608
Fixed O&M	€/kW-yr	19	17	16	16
Variable O&M	€/GJ	0.02	0.02	0.02	0.02
Efficiency	% LHV	58	60	63	64
PC					
Capital	€/kW	1598	1487	1448	1352
Fixed O&M	€/kW-yr	77	72	66	61
Variable O&M	€/GJ	0.36	0.35	0.33	0.33
Efficiency	% LHV	46	50	52	52
IGCC					
Capital	€/kW	2005	1798	1691	1521
Fixed O&M	€/kW-yr	71	66	60	53
Variable O&M	€/GJ	0.29	0.25	0.20	0.19
Efficiency	% LHV	46	50	54	56
NGCC CCS					
Capital	€/kW	1146	1014	938	838
Fixed O&M	€/kW-yr	71	66	60	63
Variable O&M	€/GJ	1.29	1.25	1.08	0.95
Efficiency	% LHV	49	52	56	58
Capture rate	%				
PC CCS					
Capital	€/kW	2546	2328	2110	1892
Fixed O&M	€/kW-yr	95	81	75	68
Variable O&M	€/GJ	1.29	1.25	1.08	0.95
Efficiency	% LHV	36	42.5	45	46
Capture rate	%				
IGCC CCS					
Capital	€/kW	2769	2374	2130	1956
Fixed O&M	€/kW-yr	92	76	70	63
Variable O&M	€/GJ	0.51	0.41	0.27	0.27
Efficiency	% LHV	38	44	48	50
Capture rate	%				
Oxyfuel CCS					
Capital	€/kW	1841	1761	1633	1484
Fixed O&M	€/kW-yr	93	93	93	93
Variable O&M	€/GJ	1.68	1.68	1.68	1.68
Efficiency	% LHV	48.1	50.1	51.6	52.1
Capture rate	%	94	94	94	94

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CO_2 capture technologies

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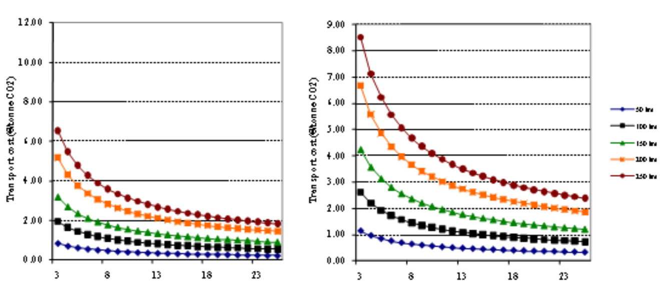
CO_2 transport

$$I = Ft_{Land\ use} * C * D * L \quad \text{Eq. 1}$$

$$D = \left(\frac{8 * \lambda * M^2}{\Pi^2 * \rho * \frac{\Delta P}{L}} \right)^{1/5} \quad \text{Eq. 2}$$

Where, I = investment cost (€), FtLand use = terrain factors for different land use types; C = Constant factor (1600 €/m2) ; D = diameter pipeline (m); L = length pipeline (m); λ = friction factor (0.015); M = mass flow of CO2 (kg/s); ρ = CO2 density (800 kg/M3)
ΔP = pressure drop (3*106 Pa).



Example for
Two different
Terrain factors

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Potential storage at Utsira

- A conservative model assumption for storage costs is 22 M€ per 1 Mt CO_2 injected per year.
- The lifetime of the existing injection well is assumed to be 25 years.
- The maximum storage capacity is assumed to be 42 Gt CO_2 with a maximum annual injection rate of 150 Mt CO_2.

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Key Results (WP 3 to 5)

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MODELING AT THE COUNTRY LEVEL

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WHAT COULD BE THE ROLE OF CCS IN 2050? (C-80 WEO 2008)

- United Kingdom: 2372 PJ. Coal-CCS 12% electricity generated; with WEO 2007: share coal-CCS is 51%. Major trade-off coal-nuclear.
- Netherlands: 1031 PJ. coal/biomass-ccs 70% electricity generated, gas-ccs 10%. With WEO-2007, share 7% larger. Without CCS, CO_2 target could not be achieved
- Germany: 2808 PJ. ccs 40-50% electricity generated, 85% coal based. With WEO 2007, switch from coal to gas. Without ccs, reduction electricity demand, increase renewables and gas.

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WHAT COULD BE THE ROLE OF CCS IN 2050? (C-80 WEO 2008)

- Denmark: coal-CCS minor role. Coal without ccs does not appear. Under WEO 2007, no ccs. Gas with ccs play a moderate role.
- Norway: 104O PJ. CCS minor role. CO2 capture in existing NGCC and 3 Mt from industrial sector

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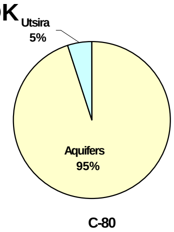
Where is CO_2 stored in 2050?

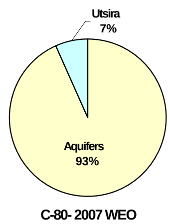
BC: 53 Mt
WEO 2007: 225 Mt

BC: 145 Mt

BC: 268 Mt

DK





BC: 29 Mt
Only 30% local

RECAPITULATING

In the C-8O scenario in 2050:

- All countries have CO_2 capture (role varies significantly)
- NL, NO, DK store CO2 at Utsira (UK also if low energy prices are taken into account)
- NL has largest share of storage at utsira (105 Mt/yr)
- Lower energy prices increase the total amount of CO2 stored in Utsira

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WHAT DOES THE MODELING AT THE REGIONAL LEVEL INDICATES?

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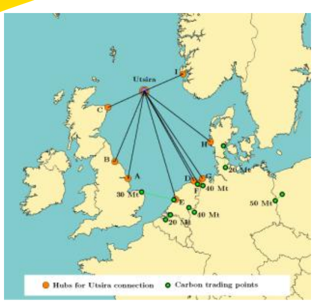

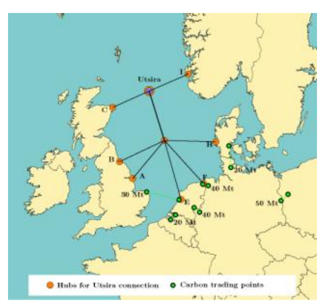

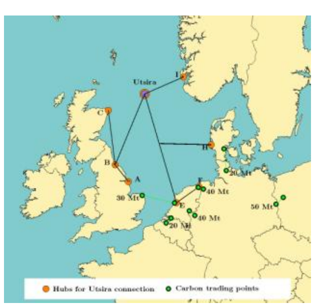

Possible transport networks

Role of CCS?

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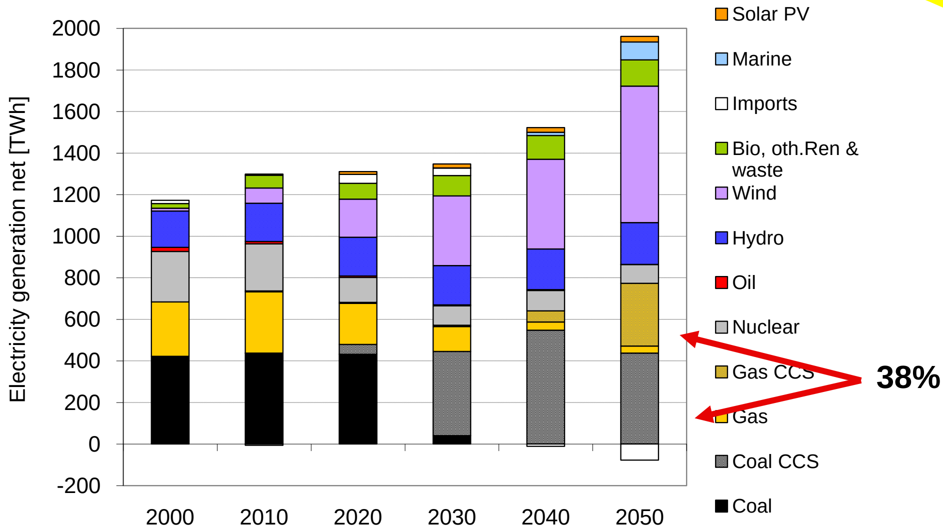

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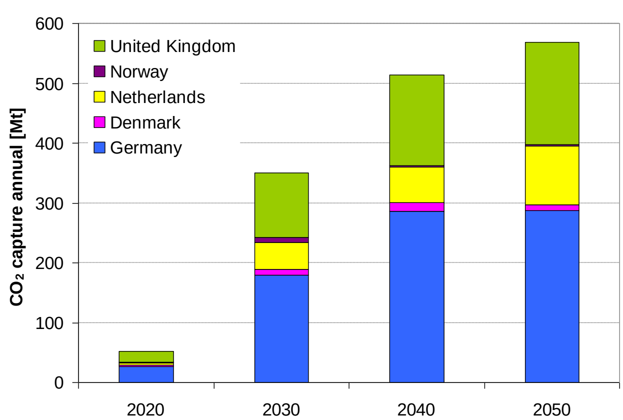
CO_2 capture in the neighbouring countries of the North Sea by country



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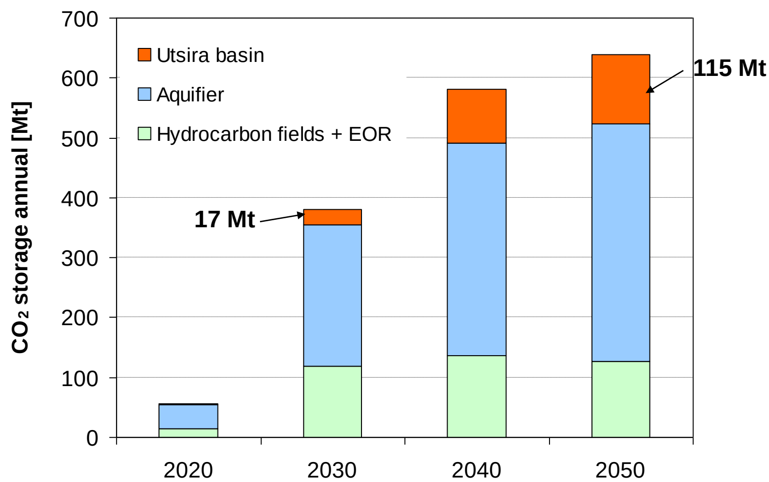
Where is CO_2 stored?



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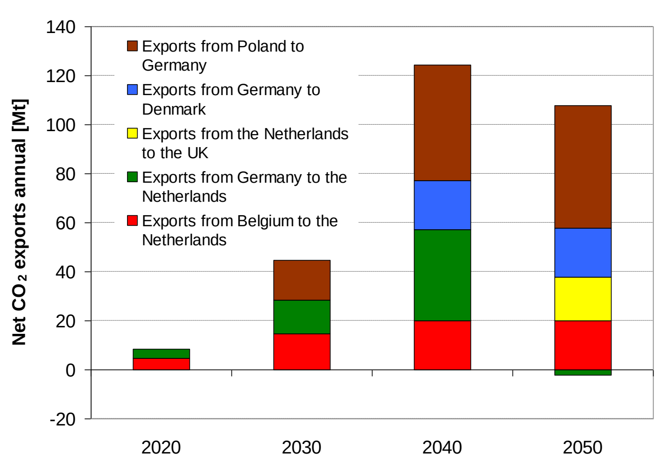
Cross boundary CO_2 exchange



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Total CO_2 captured

Regional (Infra I)	Regional model (infrastructure type I)	National model
United Kingdom	171.8	*53.0*
The Netherlands	97.5	144.7
Germany	287.6	*264.0*
Norway	2.2	2.9
Denmark	9.8	9.4
Total	**568.9**	**474.0**

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CO_2 storage at Utsira

Country	2030	2040	2050
Regional (Infra I)			
United Kingdom	**12.3**	**56.4**	**73.5**
The Netherlands	**4.6**	**34.4**	**41.4**
Germany	**0.0**	**0.0**	**0.0**
Norway	**8.7**	**1.7**	**2.2**
Denmark	**0.0**	**0.2**	**0.0**
Total	**25.7**	**90.0**	**116.2**
National			
United Kingdom	**0.0**	**0.0**	**0.0**
The Netherlands	**0.0**	**2.4**	**105.2**
Germany	**0.0**	**0.0**	**0.0**
Norway	**0.7**	**0.0**	**2.9**
Denmark	**0.0**	**2.0**	**1.4**
Total	**0.7**	**4.4**	**109.5**

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Conclusions

- Under a tight climate policy, CCS appears as cost-effective measure for all countries
- Scenarios with lower energy prices increases the share of CCS in the system
- Nuclear energy appears as its main competition option
- CO2 storage at Utsira appears as cost-effective option for UK, NL and NO.
- Time line is dependent on the scenarios assumed and the level modeled
- Trade of CO2 in an early stage increases the cost effectiveness of storage at Utsira
- The models at the national level assumed that the whole capacity of Utsira will be available, but if all results are put together the max injection rate would be excedeed. Need to consider Utsira in a regional context
- Geographical scale have a significant impact on the results, partly due to differences in input and level of detail but also to differences in the spectrum of meaasures that appear as cost-effective

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THANK YOU FOR YOUR ATTENTION

QUESTIONS?