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Least-cost Optimisation Models for CO_2 Capture and Sequestration

An update on results

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Summary of recently concluded study

- The global objective: To add relative realism to discussions on CO_2 capture costs and early deployment of carbon capture technology in the UK.
- The present study proposes a methodology for determining the least-cost options of introducing carbon capture technology under the overarching assumption of increasingly stringent emission caps on fossil-fuelled power plants, which are universally recognised as large point sources of carbon emission.
- The approach entails formulating and solving an optimisation model with clearly stated goals, and, explicit provisions for the various regulatory, technological and market conditions which offer opportunities and/or restrict corporate decision-making and action-taking, while using public-domain data on selected power plants' proposed CO_2 capture investment programmes combined with relevant data available in the literature.
- More specifically, the objective of the study is to minimize the cost of CO_2 capture, using the well-tested optimizing techniques of linear programming to scan through all the possible cost-output combinations before selecting a particular combination as being the optimal. The model is applied to the UK but has a wider applicability.

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Results and future plans

- Determination of the nature of the CO_2 capture cost curve.
- Establishment of a dynamism in the cost relativities of alternative carbon capture technologies.
- Establishment of the importance of Government incentives.
- Demonstration of the need for increasingly stringent emission allocation rights, to enhance and sustain the universal profitability of CO_2 capture operations.
- The immediate future plan is to formulate and solve a transportation problem that would determine the least-cost option of matching the supply of the captured CO_2 at the power plants with the demand for CO_2 at the sinks, for value-added (EOR, ECBM) and non-value added (permanent storage) uses.

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A summary of the model

Formally, the objective is to minimise the generalised environomic cost function:

$$C_t = \frac{k_t\left(\sum a_{it}x_{it} + \sum b_{it}u_{it}\right) + \sum\sum f_{it}y_{it} + \sum\sum e_{it}y_{it} + \left(\sum\sum m_{it}v_{it} - \sum\sum h_{it}q_{it}\right) - \sum\sum g_{it}\left(q_{it}\right)}{\left(1+r\right)^t}$$

Where:

- k_t = capital recovery factor of plant type at time *t*
- a_{it} = unit CAPEX of the core power generating plant type *i* at time *t*
- x_{it} = effective electricity generating capacity of plant type *i* at time *t*
- b_{it} = unit CAPEX of the CO2 capture equipment of plant type *i* at time *t*
- u_{it} = installed CO2 capture capacity in plant type *i* at time *t*
- f_{it} = unit fuel OPEX of plant type *i* at time *t*
- y_{it} = the operating level (or output) of plant type *i* at time *t*
- e_{it} = unit non-fuel OPEX of plant type i at time t
- h_{it} = unit CO2 capture OPEX
- q_{it} = amount of CO2 capture in plant type *i* at time *t*
- m_{it} = unit emission penalty cost to plant type *i* at time *t*
- v_{it} = excess CO2 emission in plant type *i* at time *t*
- g_{it} = unit Government intervention (tax or subsidy) rate in plant type *i* at time *t*
- r = discount rate
- *t* = time in years

A summary of model (continued)

- The aforementioned objective function is minimized subject to the satisfaction of a number of constraints determined by demand, supply, technological and capacity factors. These can be summarized broadly into two sets of constraints namely,
- Supply and/or maximum capacity constraints:

$$\sum s_{it} x_{it} \leq z_i$$

- Demand and/or minimum capacity constraints:

$$\sum d_{it} x_{it} \geq w_i$$

Application to the UK

- Time horizon

5-year expansion period	Median year
2008 – 2012	2010
2013 – 2017	2015
2018 – 2022	2020
2023 – 2027	2025
2028 – 2032	2030

Application to the UK (continued)

The selected power plants with likely CCS schemes

Town	Nominal capacity (MW)	Technology	Fuel	CO_2 capture ($MtCO_2$/yr)	Estimated capital cost £m	Estimated Start-up date	Year first commissioned
Peterhead	475	CCGT	Natural gas	2	700	2009[2]	1980
Teesside	850	PCSCFGD	Coal	5[4]	1,000	2010/2011	2010
Killingholme, Lincolnshire	450	IGCC	Coal	(2)[6]	550	(2012)	1992
Tilbury, London	1,000	PCSCFGD	Coal	(3)	800[7]	2016	1968
Ferrybridge, West Yorkshire	500	PCSCFGD	Coal[9]	2[10]	350[11]	2011/2012	1966
Kingsnorth, Kent	800	PCSCFGD	Coal[13]	(5)[14]	1,000	2012	1970
Longannet, Fife	2,304	PCSCFGD	Coal	(7)	(1,500)	(2012)	1970
Selby, North Yorkshire	3,960	PCSCFGD	Coal	(15)	(2,000)	(2012)	1974
Total	10,339			44	7,900		

[1] BP pulled out of the scheme in May 2007 but it is included for comparative purposes.
[2] (a) captured CO_2 to be used from 15 to 20 years for Miller field life extension; (b) Pipeline length (Peterhead to Miller) = 240 km.
[3] Centrica and Renew Tees Valley Ltd. Source: Guardian Unlimited Wednesday November 8, 2006
[4] The company plans to capture 100 $MtCO_2$ over an assumed plant lifetime of 20 years.
[5] Press Release May 24 2006 and Annual Report 2006
[6] Authors own estimates in brackets.
[7] Source: http://www.ndtcabin.com/articles/power/0603014.php#art_k1x
[8] Project collaborators include Doosan (formerly Mitsui) Babcock Energy, UK Coal, Siemens and Heriot-Watt University (design and implementation of carbon capture technology). Source: Scottish and Southern Energy PLC, 2006, Powerful Opportunities, Annual Report 2006 p. 16
[9] To be sourced mainly from the nearby Kellingley mine.
[10] The supercritical plant/process would itself save 500,000 tonnes of carbon dioxide per annum (Press Release).
[11] Of which £250 million is for the supercritical plant and £100 million for the capture equipment (Source: SSE Press Release: "Plans for the UK's First Cleaner Coal Power Plant at Ferrybridge Power Station")
[12] Source: Press Releases: 11 October 2005; 11 December 2006.
[13] Co-generation envisaged (i.e. coal + energy crops)
[14] "The supercritical units could reduce CO2 emissions by up to 1.08m tones a year."

Application to the UK (continued)

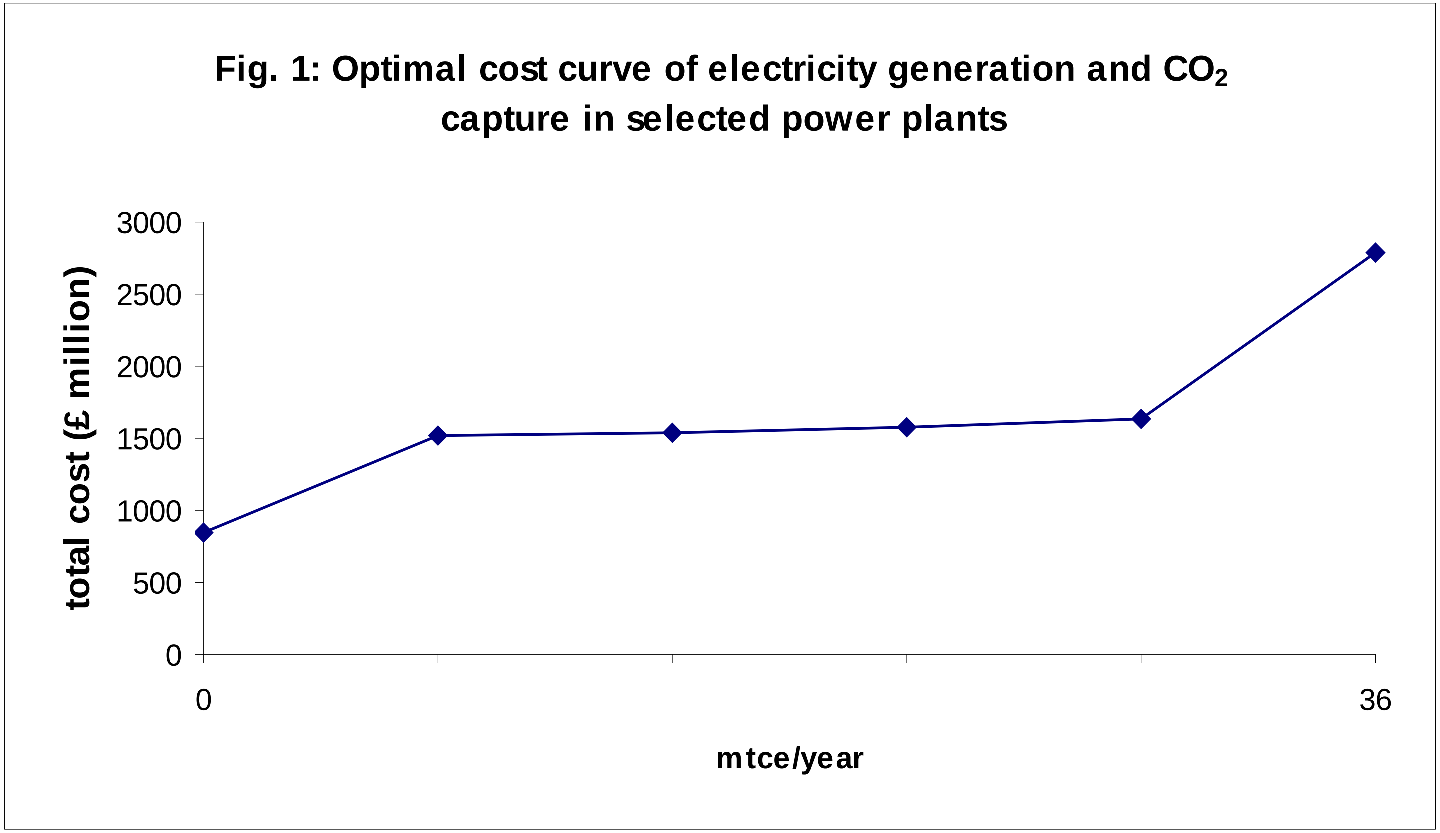
Data sources and key assumptions

- Company data (public domain)
- The National Grid
- DTI
- UKCCSC
- IEA-GHG

Variable	Value	Source
1. Full load hours	8000 hours	Gibbins, 2006a
2. Plant lifetime	25 years	Gibbins, 2006b
3. CO_2 capture OPEX	£11.20/tCO_2 (or $20/t$CO_2$)	IPCC, 2006
4. Fuel cost: 500/750 MW supercritical plant	1.5p/KWh	Chalmers, 2006
5. Efficiency loss due to the parasitic effect of CO_2 capture	10 – 20 %	Leci (1996), BP (2006)
6. Levelised plant capacity factor	85%	IEA-GHG, 2006
7. Fuel costs	80% of OPEX	DTI
8. Excess emission penalty	€40 (or £26.85)/tCO_2	EU Commission
9. Annual increase in emission penalty	4%	Authors' own estimates
10. Emission allocation ratio[1]: PCSCFGD plants	70%[2]	Authors' own estimates
11. Emission allocation ratio: IGCC plants	80%[3]	Authors' own estimates
12. Emission allocation ratio: CCGT plants	90%	Authors' own estimates
13. Yearly reduction in the emission allocation ratio for all plant types.	5.5%	Authors' own estimates
14. Carbon price	€21 (or £14)/tCO_2	Point Carbon (2007)
15. Annual increase in carbon price	4%	Authors' own estimates
16. Improvements in plant efficiency reflected in the reduced cost of fuel per net KWh generated		IEA-GHG, 2006
17. A load duration curve divided into "peak" and "off-peak" loads		Authors' own estimates.

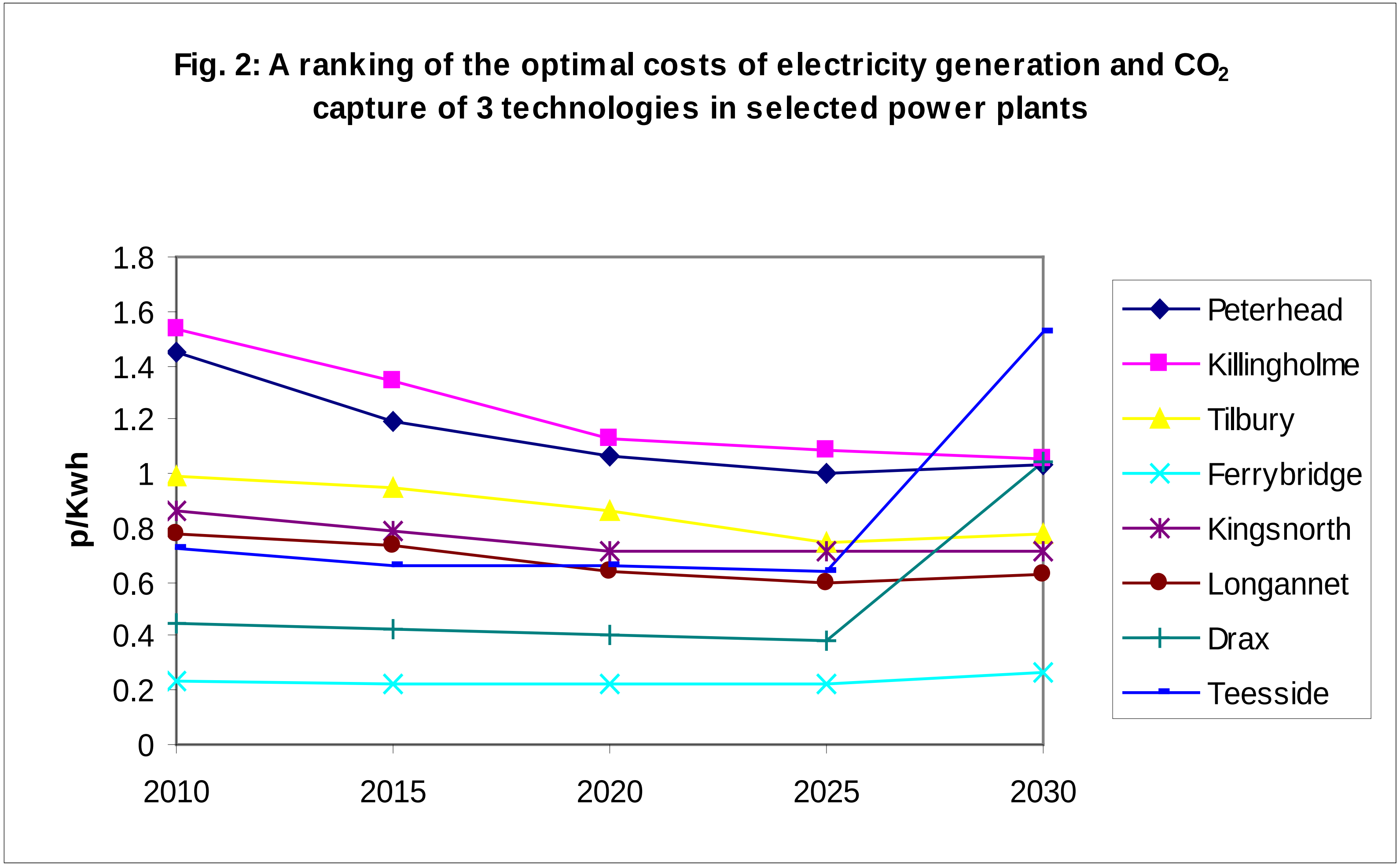
[1] That is, emission allocation as a percentage of the historic amount of emission required to produce a given level of power output.
[2] This was the actual emission allocation ratio of Drax in 2005.
[3] The less polluting plants (i.e. IGCC and CCGT) are assumed to be allocated a higher proportion of their required emission rights than the more polluting PCSCFGD plants.

Application to the UK (continued)
Key results (1)



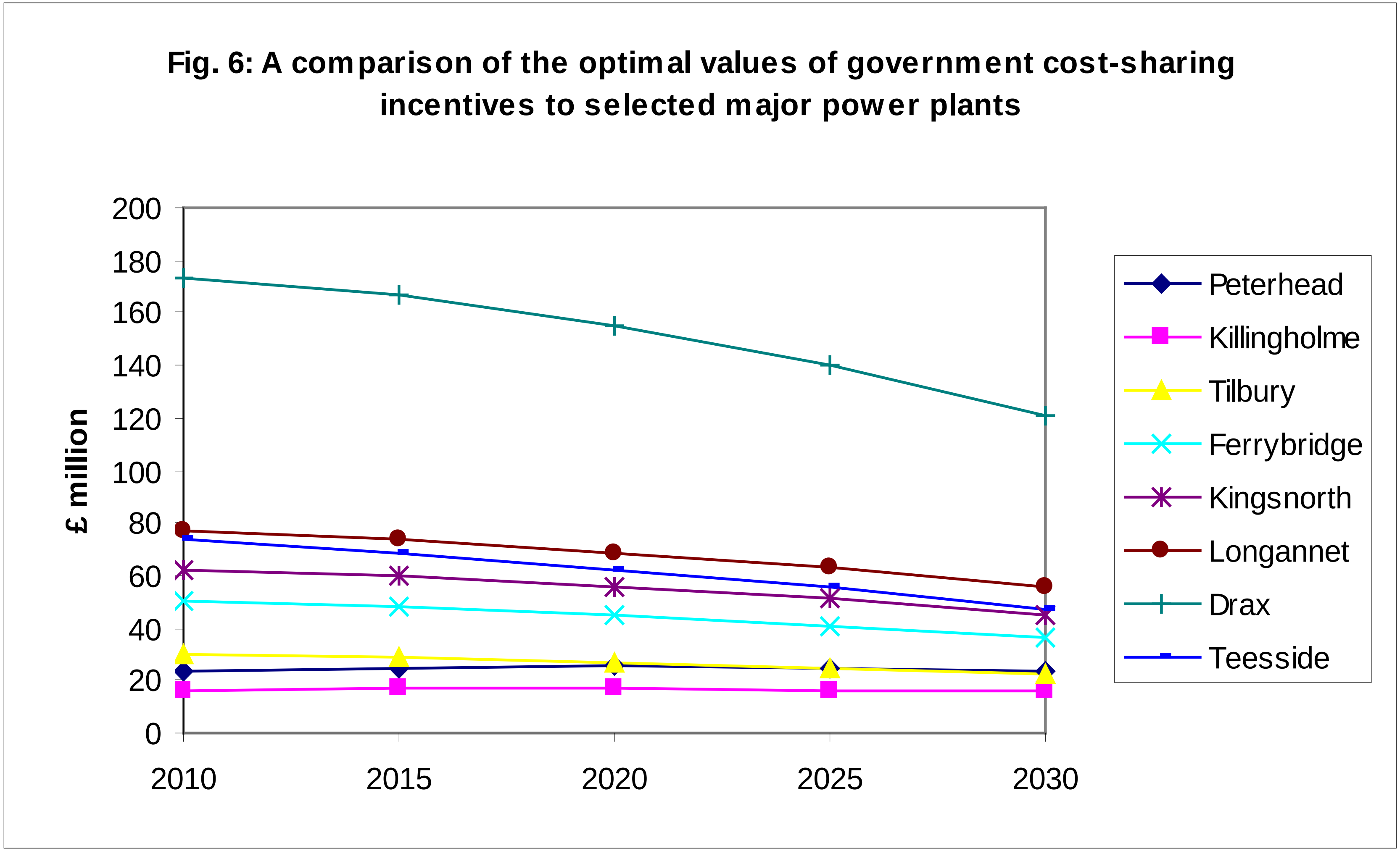
Application to the UK (continued)

Key results (2)



Application to the UK (continued)

Key results (3a)



Application to the UK (continued)
Key results (3b)

	Cost of Government support (p/KWh)								Aggregated
	Peterhead	Killingholme	Tilbury	Ferrybridge	Kingsnorth	Longannet	Drax	Teesside	total (£M)
2010	0.39	0.33	0.27	0.65	0.74	0.32	0.38	0.81	506.08
2015	0.26	0.22	0.16	0.27	0.29	0.17	0.21	0.29	488.65
2020	0.22	0.19	0.14	0.23	0.24	0.15	0.18	0.24	456.33
2025	0.20	0.16	0.12	0.19	0.19	0.12	0.15	0.20	416.18
2030	0.17	0.14	0.09	0.15	0.16	0.10	0.12	0.16	366.88