Characterisation of UK Industrial Clusters and Techno-Economic Cost Assessment for Carbon Dioxide Transport and Storage Implementation

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UKCCSRC Spring Conference
Cardiff 28-29 March 2023

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What is the impact of introducing a new CO_2 transport and storage sector into the economy?

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“Introducing a Scottish CO_2 Transport and Storage industry with an overseas export base could deliver sustained gains in UK GDP, jobs, real take-home pay and income tax revenues.” [2]

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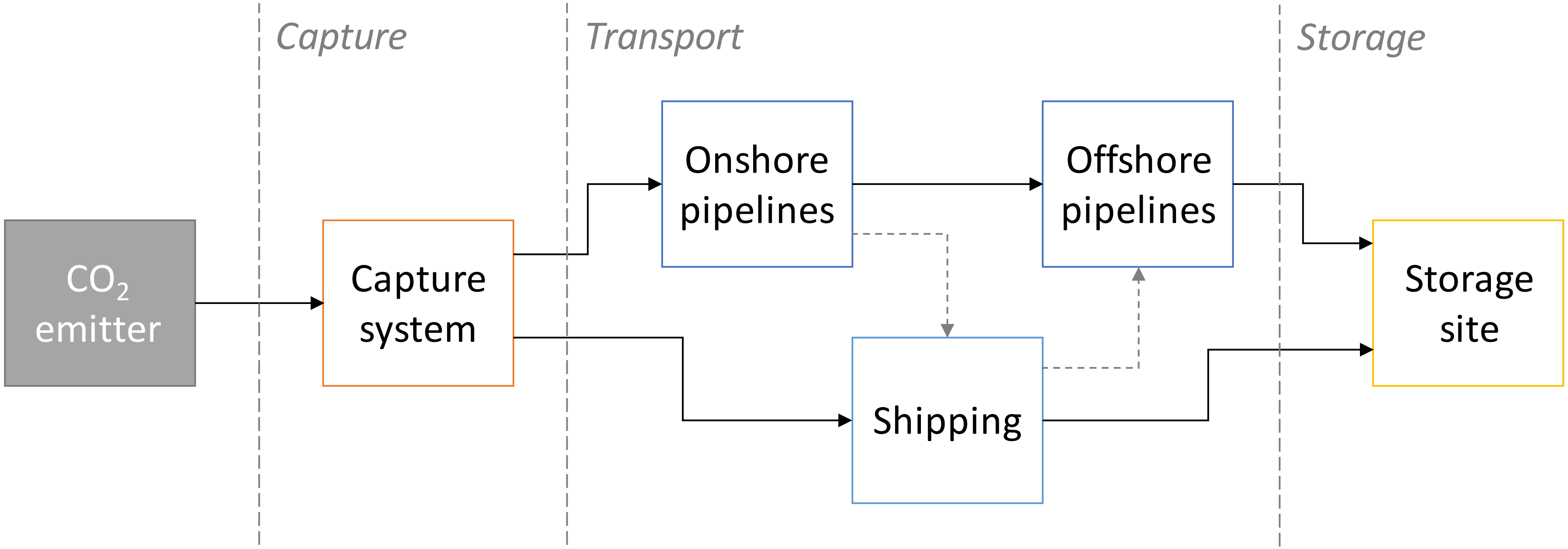
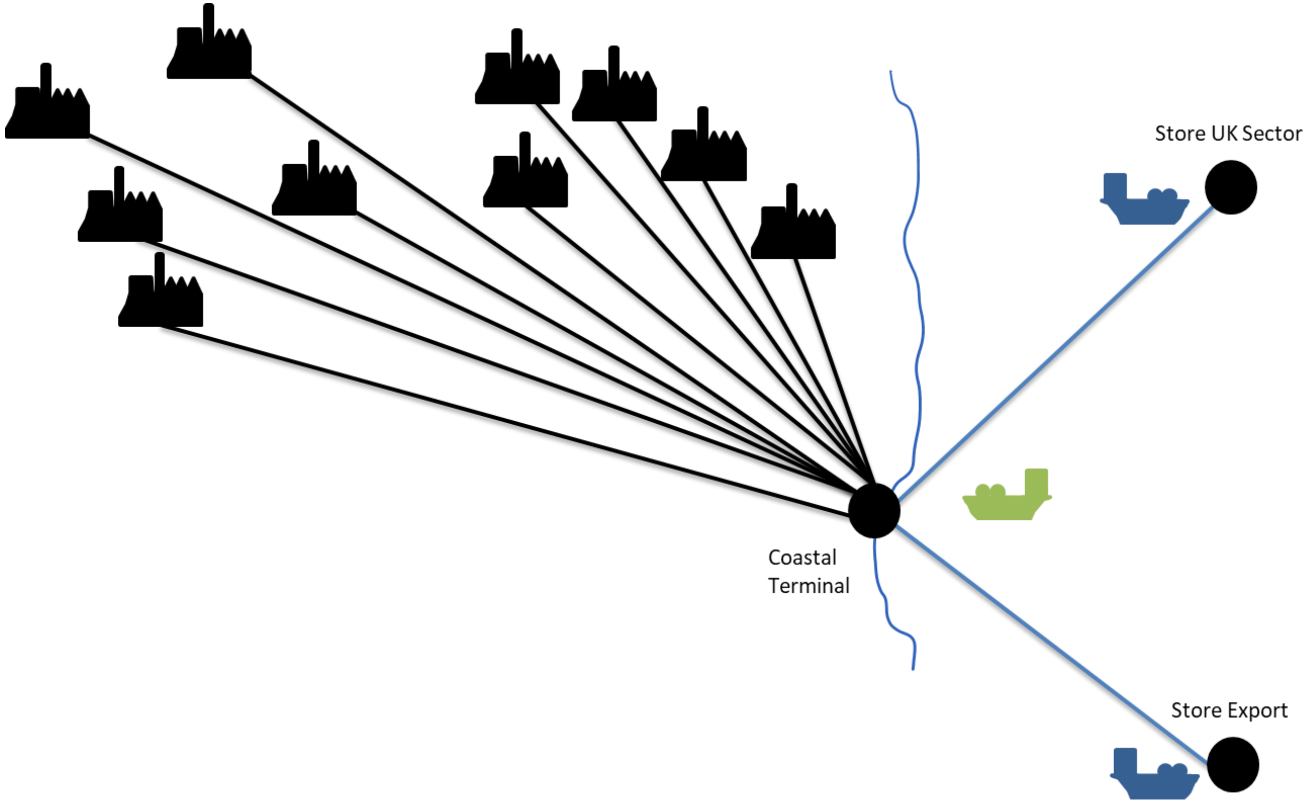
T&S Sector Definition



Scenario Design
"Each to their own"

- In this scenario every emitter builds a separate onshore pipeline to the coast.
- This is the most expensive option and is considered to be impractical due to the size of the infrastructure required and the subsequent permissions and rights of way that would need to be acquired.
- Considered to be the least risky option as every emitter will be responsible for the quality of their own CO_2 and pipeline operation (ref BEIS Business Model Contract Risks).
- The offshore infrastructure is considered to be shared. It is not feasible due to pipeline landfall restrictions to have separate offshore pipelines in this context.



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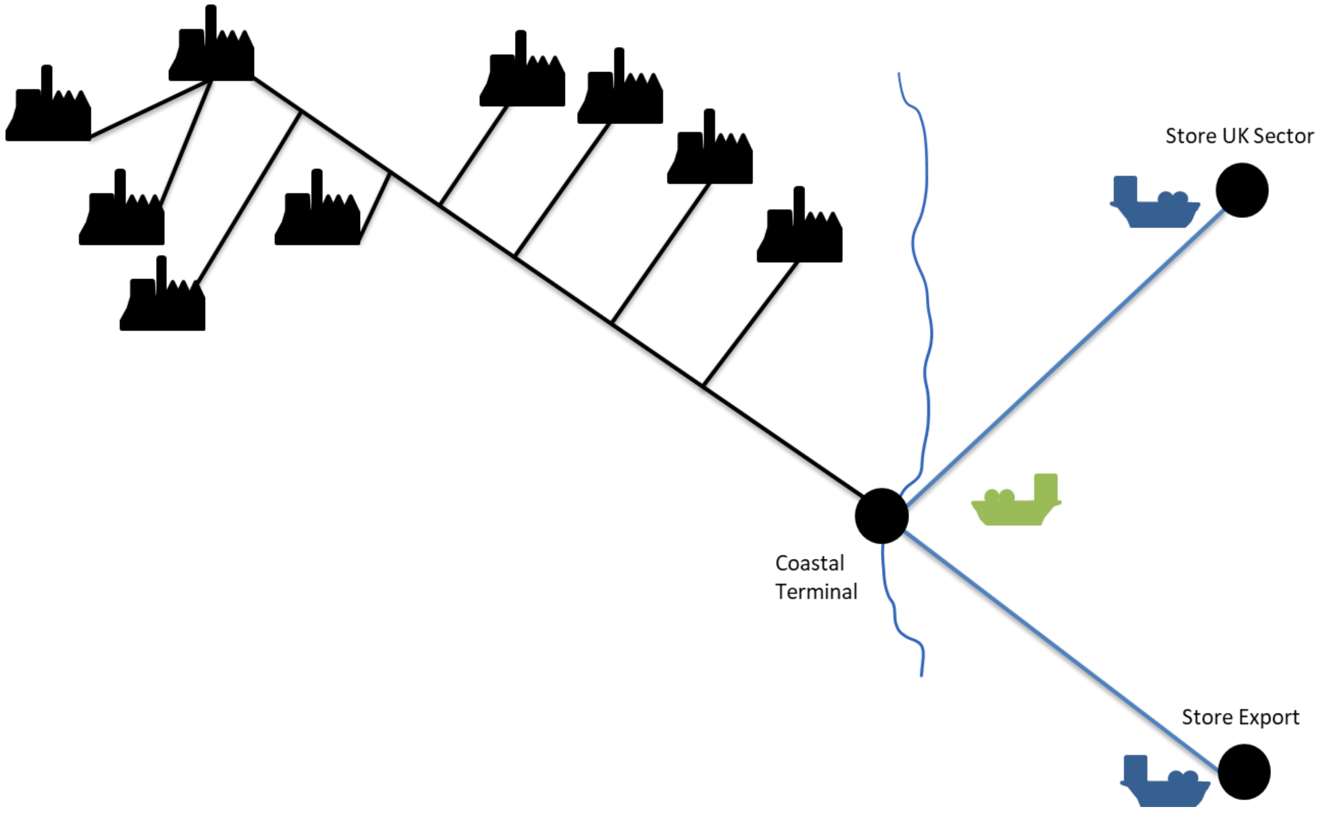
Scenario Design

“Build it & they will come”

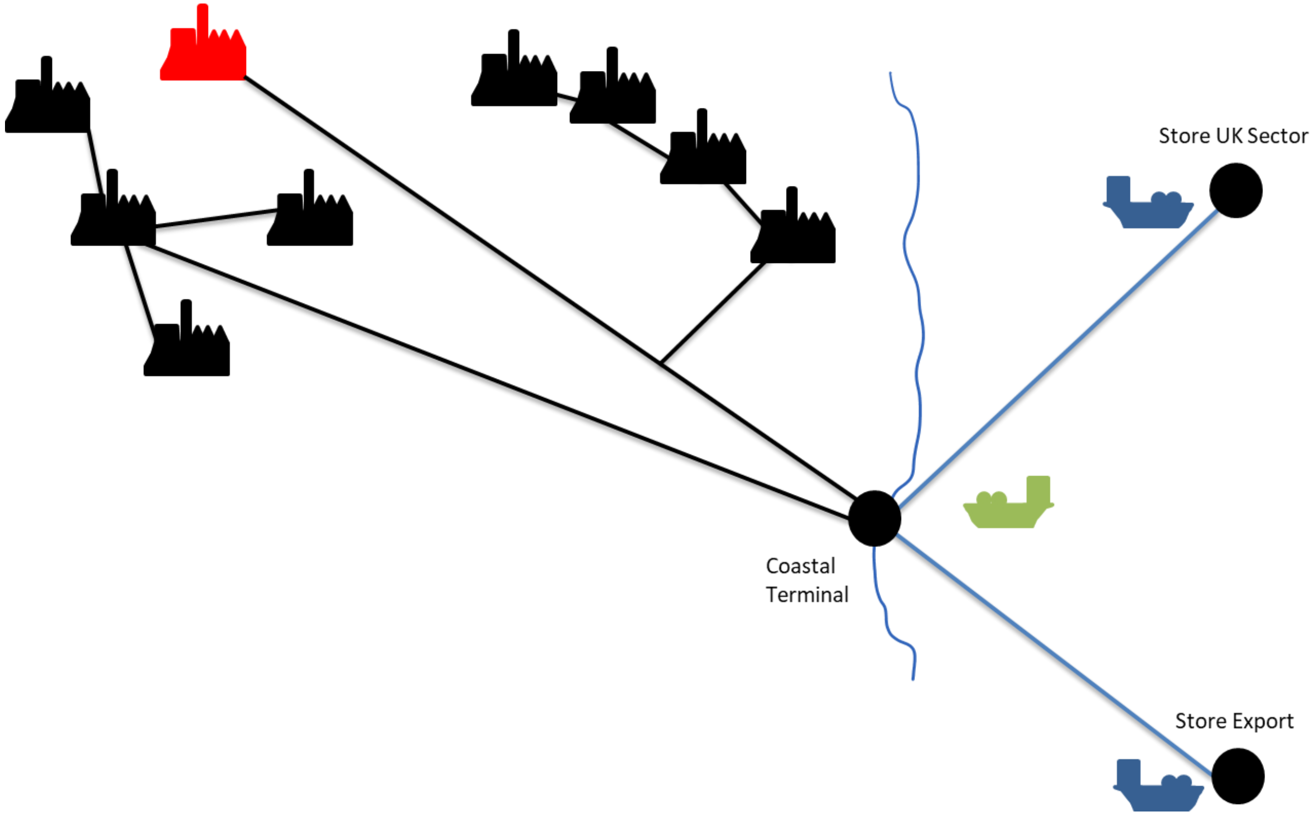
- In this scenario there is a central pipeline into which all of the emitters feed.
- As it is envisaged that each emitter will come on stream at different times then the main trunkline pipeline would have to be oversized to accommodate increasing demand.
- The phasing of the entrants into the system is therefore important in terms of the operation efficiency of the network.
- The risk in this option is that “they don’t come” but this risk is decreasing with the drive to net zero
- Offshore part of the infrastructure considered to be shared as per Scenario 1



Scenario Design

“Early adopter/collaborator”

- In this scenario there is one early adopter (highlighted in red)
- There are then separate trunk lines to the source but industries collaborate in a gathering network to feed into that network.
- This is a half-way house scenario between 1 and 2 and reduces the risk of the early adopter being left stranded with an oversized pipeline
- It will be potentially more expensive than scenario 2



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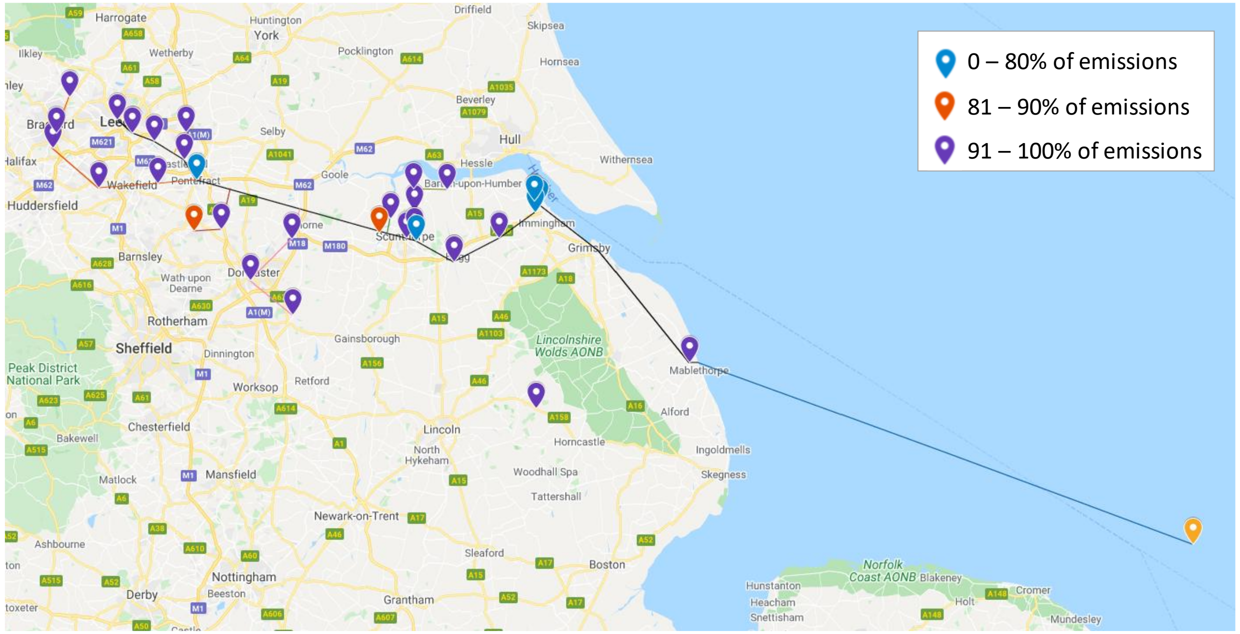
Assumptions for cluster activity in CCS

North Humber and Teesside

South Humber



Methodology for Cost Calculation

- Collate total emission data for a cluster (UK local authority and regional carbon dioxide emissions national statistics)
- Mapping of the emitters geographically to create an onshore pipeline network and identify landfall locations for offshore pipelines, ports and storage sites
- Can be used to explore reuse of infrastructure options
- Development of CAPEX and OPEX costs using models described or project data
- Translate model data to GBP for 2020
- Results for all seven clusters obtained

Explanations of models
Onshore and offshore pipeline

- Key parameters for determining the CAPEX costs are the CO_2 mass flow or pipeline diameter and the average distance between sources and sinks
- Two types of cost models in literature diameter-based models – weight based or quadratic fits to cost data[3]

$$CAPEX_{onshore} = FL * \ FT * 10^6 * \left[(0.057L_{onshore} + 1.8663) + (0.00129L_{onshore}) * D_o + (0.000486L_{onshore} - 0.000007) * D_o^2\right]$$

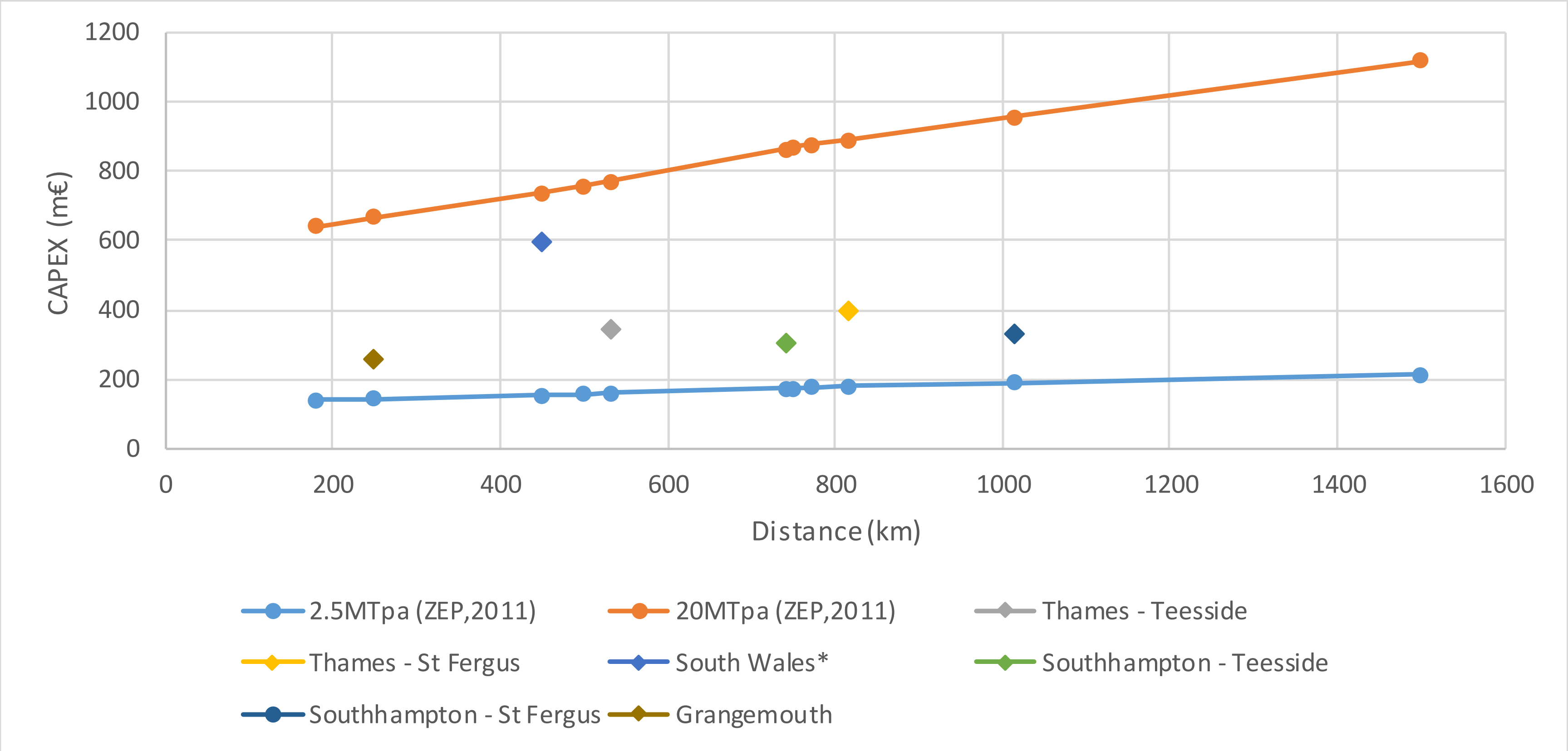
and mass flow rate models[4]

$$C_{cap} = 9970 \ \times \ \left(m^{0.35}\right) * \left(L^{0.13}\right)$$

$$CAPEX_{onshore} = FL * FT * L * C_{cap}$$

3. Ghazi, N., & Race, J. M. (2013). Techno-Economic Modelling and Analysis of CO_2 Pipelines. *The Journal of Pipeline Engineering*, *12*(2), 83–92. https://doi.org/10.1115/IPC2012-90455
4. McCollum, D. L., & Ogden, J. M. (2006). *Techno-Economic Models for Carbon Dioxide Compression, Transport, and Storage & Correlations for Estimating Carbon Dioxide Density and Viscosity*. https://escholarship.org/uc/item/1zg00532

Explanations of models Shipping



Zero Emissions Platform (ZEP). (2011). *The costs of CO_2 transport: Post-demonstration CCS in the EU*. https://www.globalccsinstitute.com/resources/publications-reports-research/the-costs-of-co2-transport-post-demonstration-ccs-in-the-eu/

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Explanations of models Storage

- Available literature in storage cost models more limited
- Most studies present FEED analyses using linear cost models
- Other studies present cost analyses of specific CO_2 storage projects, combining offshore pipeline transport and storage e.g. Pale Blue Dot[6]

Linear cost model example[5]

$$CAPEX_{storage} = W * (C_d * H + C_w) + C_{sf} + C_{sd}$$

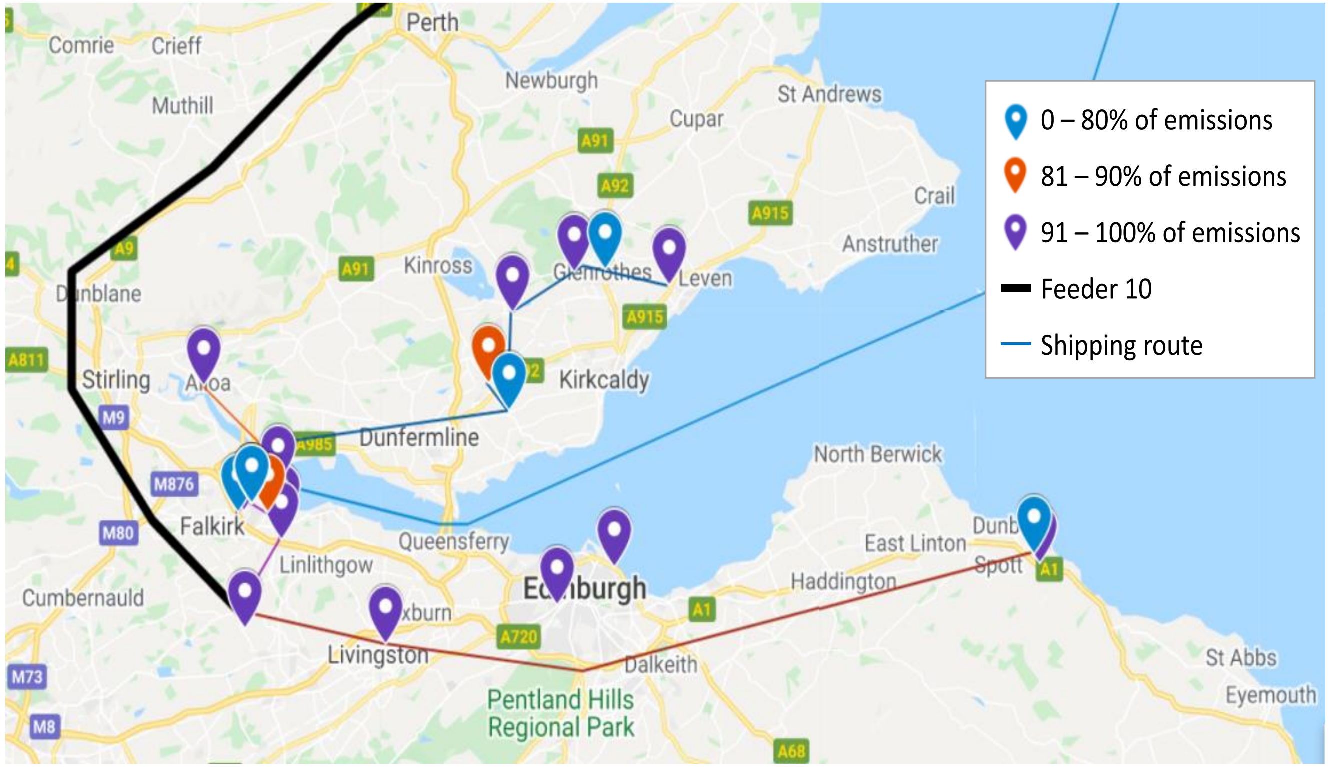
- W= number of wells per sink;
- Cd = drilling costs (€ per meter); if old wells can be re-used, Cd = 0;
- H = the drilling distance being the depth of the reservoir starting at the bottom of the sea plus the thickness of the reservoir (in meter);
- Cw = fixed costs per well (in €).
- Csf = investment costs for the surface facilities on the injection site and investments for monitoring (e.g. purchase and emplacement of permanent monitoring equipment) (in €).
- Csd = investment costs for the site development costs. E.g. site investigation costs, costs for preparation of the drilling site and costs for environmental impact assessment study (in €).

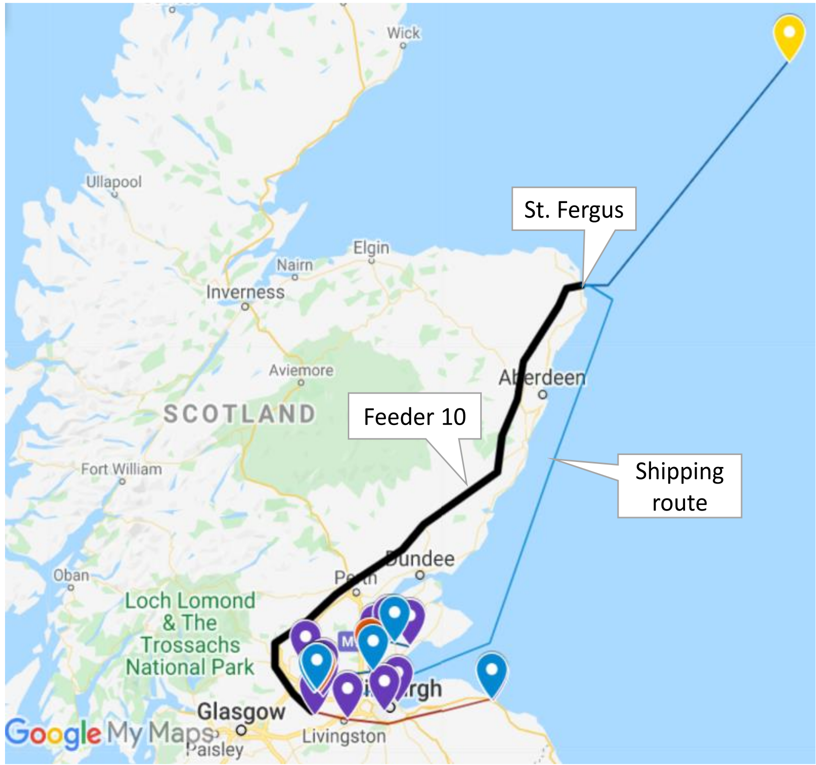
5. van den Broek, M., Ramírez, A., Groenenberg, H., Neele, F., Viebahn, P., Turkenburg, W., & Faaij, A. (2010). Feasibility of storing CO_2 in the Utsira formation as part of a long term Dutch CCS strategy: An evaluation based on a GIS/MARKAL toolbox. *International Journal of Greenhouse Gas Control*, *4*(2), 351–366. https://doi.org/10.1016/j.ijggc.2009.09.002
6. Pale Blue Dot. (2016). *Progressing Development of the UK’s Strategic Carbon Dioxide Storage Resource*. https://s3-eu-west-1.amazonaws.com/assets.eti.co.uk/legacyUploads/2016/04/D16-10113ETIS-WP6-Report-Publishable-Summary.pdf

Methodology for Cost Calculation

	Onshore pipeline	**Offshore pipeline**	**Storage**	**Shipping**
Cost models set a	(McCollum & Ogden, 2006)	(Pale Blue Dot, 2016)		(ZEP, 2011)
Cost models set b	(Ghazi & Race, 2013)	(Ghazi & Race, 2013)	(van den Broek, Ramírez, et al., 2010)	(ZEP, 2011)
O&M factor set a	2.5%	3 – 8%*		15 – 20%*
O&M factor set b	3%	3%	5%	15 – 20%*

Example for Grangemouth





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Cost Models

CAPEX costs (2020 M£)

	Onshore pipeline	Offshore pipeline	Storage	Shipping/ Feeder 10	Total
Option 1.a	115.61	314.12		64.70	494.43
Option 1.b	84.29	112.05	83.39	64.70	344.43
Option 2.a	115.61	314.12		313.36	743.09
Option 2.b	84.29	112.05	83.39	313.36	593.09

OPEX costs (2020 M£)

	Onshore pipeline	Offshore pipeline	Storage	Shipping/ Feeder 10	Total
Option 1.a	2.89	12.47		2.59	17.95
Option 1.b	2.53	3.36	4.17	2.59	12.65
Option 2.a	2.89	12.47		53.55	68.91
Option 2.b	2.53	3.36	4.17	53.55	63.61

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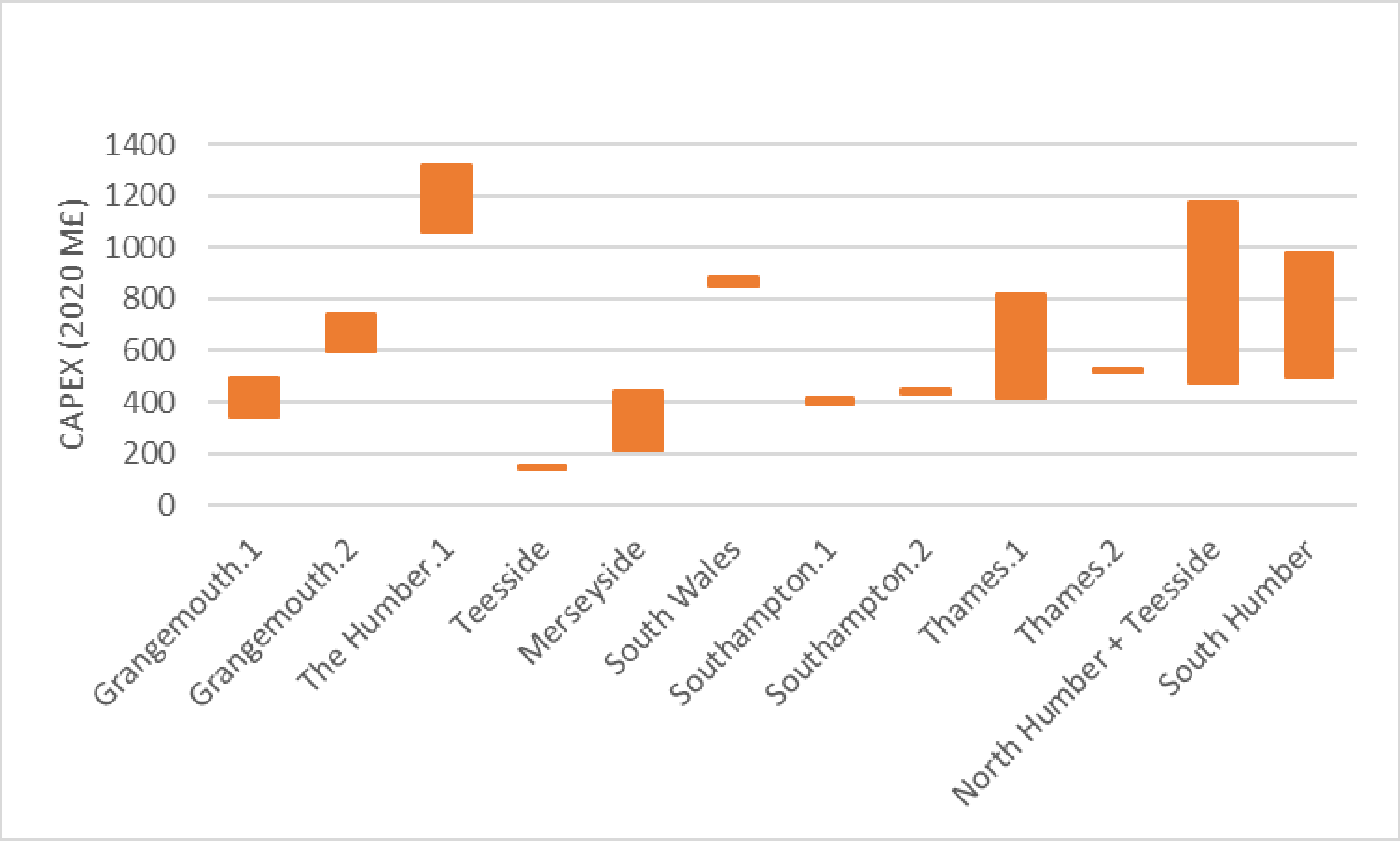
Results – T&S Capex

- Costs strongly align to size of the cluster, the volume of CO_2 and the complexity of the system
- Wide variation in costs depending on modelling approaches used



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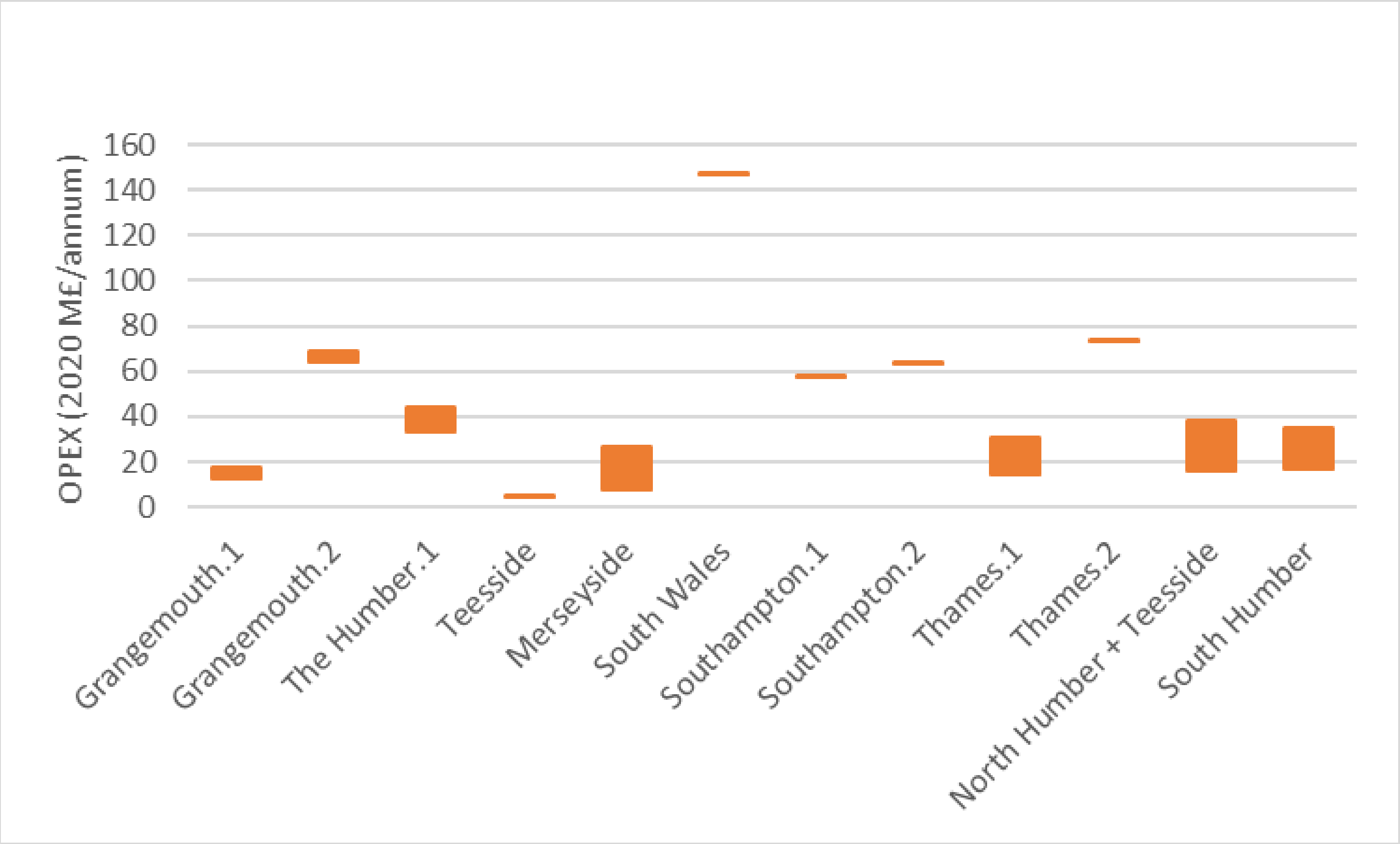
Results – T&S Opex

- Shipping OPEX considerably larger than alternative offshore pipelines (see Thames 1 (offshore pipelines) vs Thames 2 (shipping))

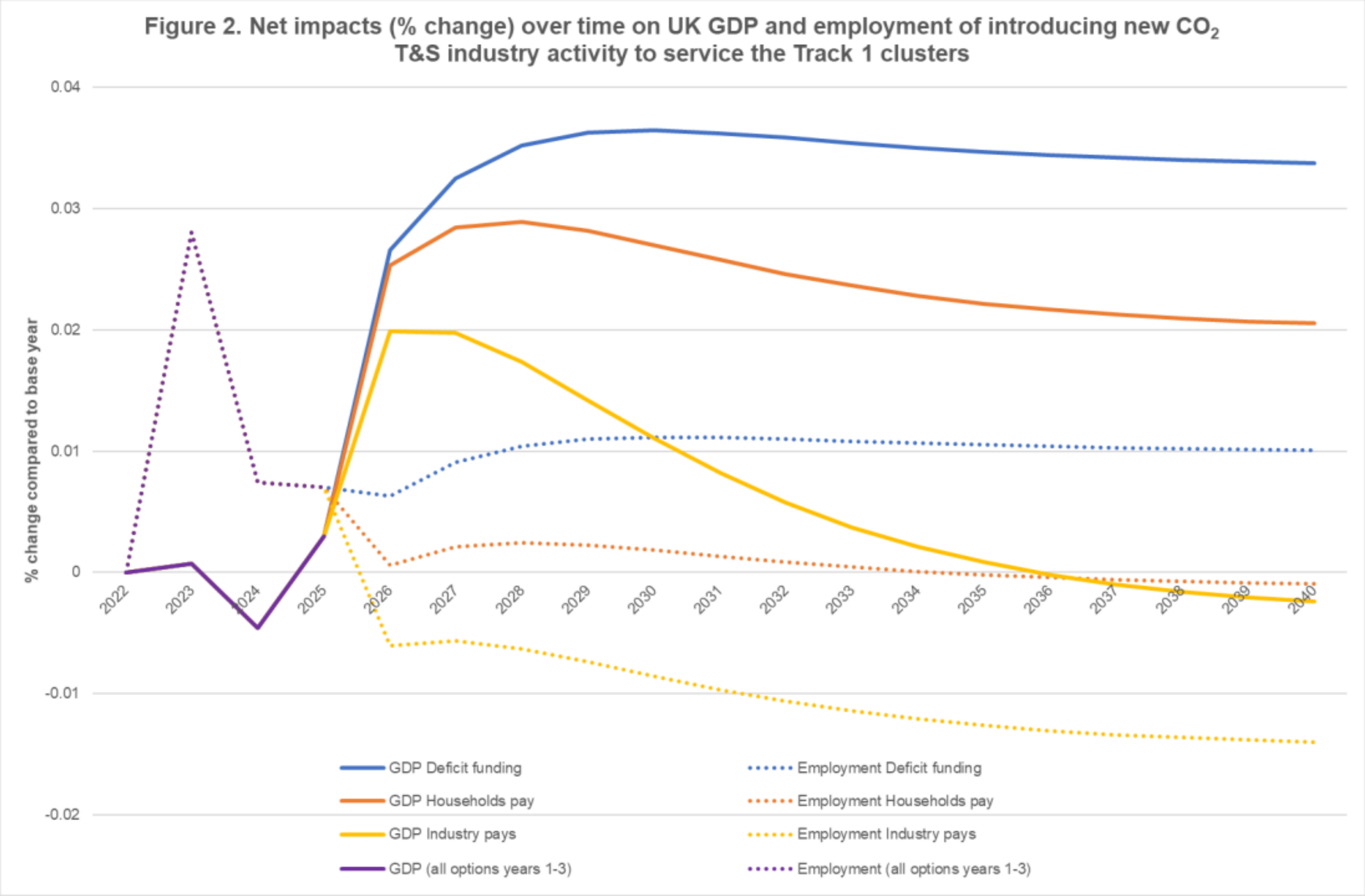


Impact in economy wide modelling

- Transport and storage of CO_2 will constitute a new sector in the economy
- Assume that the new sector shares supply chain structure with existing UK Oil and Gas, but is initially oversized – challenge of guaranteeing demand (thereby inducing required infrastructure investment)
- Need to understand the size of the sector and the investment required through techno-economic models that feed into economy-wide models
- Who pays for the new sector?
    - Government - by running a deficit?
    - UK households as taxpayers – socialising costs (simple lump sum tax)
    - Or does the polluter (the capture industry) pay? (indirect business tax)

Impact in economy wide modelling

- Even with labour supply constraints, investment and rollout of a CO_2 T&S industry is likely to trigger a sustained wider economy expansion
- Expansion is more constrained at investment/project delivery stage
- Question of ‘who pays’ to ensure utilisation of capacity really matters going forward



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1

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"If you build it, they will come."
-Field of Dreams (1989)

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