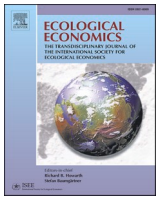
Ecological Economics 233 (2025) 108587

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon



ANALYSIS

# Regional employment implications of deploying $CO_2$ transport and storage to decarbonise the UK's industry clusters

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ARTICLE INFO

*Keywords:*
Jobs and skills
Industrial decarbonisation
CCUS
Economic modelling
Regional impacts
$CO_2$ transport and storage

ABSTRACT

The decarbonisation of UK industrial clusters via CCUS can support jobs and gross value-added (GVA). However, worker and skills shortages have been identified as a common challenge across UK clusters, and the net zero space, with average wage rates increasing as different sectors compete for a limited pool of labour. This paper employs multi-sector economy-wide CGE scenario simulations and linked regional mapping to examine how constrained labour market responses can affect potential outcomes of investing and deploying the $CO_2$ transport and storage element of CCUS networks in UK industry clusters. The analysis concentrates on the location and nature of labour demand and wage cost-driven jobs displacement. Findings suggest transitory annual peaks of over 11,000 jobs in the construction sector set against job displacement peaks of around 5200 concentrated in sectors such as retail, services and hospitality. Regional mapping suggests that southern regions may be particularly affected by displacement effects, given the concentration of service sectors set against less direct benefit from the introduction of $CO_2$ transport and storage (T&S) sector activity. Overall, the key finding is that net economy-wide gains are constrained by congestion of investment activity even with the relatively small scale of investment in T&S capacity and associated competition for resources.

## 1. Introduction

The International Energy Agency (IEA, 2020) and national institutions like the UK's Committee on Climate Change (Committee on Climate Change, 2019) present evidence indicating that it is unrealistic to deliver on the 2050 net-zero objectives without carbon capture, utilisation and storage (CCUS). CCUS involves the storage of $CO_2$ emissions captured during the use (or conversion) of fossil fuels in industrial or energy production processes, with transportation to storage sites, generally involving offshore reservoirs that previously held hydrocarbons (Serin, 2023).

CCUS is, therefore, likely to have a role in the net zero and economic transition plans of many nations, especially those with $CO_2$ sequestration capability and capacity developed in hosting oil and gas industries. In Europe, this includes Denmark, Norway, the Netherlands and the UK, with potential for development of cross-country CCUS networks and emergence of international trade in $CO_2$ transport and storage (T&S) services (European Commission, 2022).

In the UK, through the Prime Minister's 'Ten Point Plan for a Green Industrial Revolution (UK Government, 2020a) and subsequent net zero strategy (UK Government, 2021), a policy objective has emerged to have four operational CCUS clusters (i.e., clustered capture industries linked to T&S networks) capturing and sequestering around 20-30Mt$CO_2$ by 2030. 2021 saw initial steps taken with the announcement of two 'Track 1' CCUS clusters, in Merseyside (HyNet) and Teesside/North Humber (the East Coast Cluster) (DESNZ, 2021a). Early in 2023, the UK Government renewed its commitment to CCUS through the announcement of £20 billion funding for early deployment of CCUS in the UK Government's spring 2023 'Powering Up Britain' announcement (UK Government, 2023). In July 2023, the UK Government announced the selection of the Scottish Acorn project (a reserve cluster on Track 1) and South Humber Viking $CO_2$ T&S systems as the Track 2 CCUS clusters, subject to final decisions, due to their ability to meet the Track 2 criteria (DESNZ, 2023a). More recently, in the Autumn budget 2024, the UK Government further showed its commitment to CCUS by adding an extra £3.9 billion for 2025/2026 to advance Track-1 projects and secure contracts with 11 green hydrogen producers (HM Treasury, 2024).

The decarbonisation of UK industrial clusters via the development of CCUS networks and supply chains has been associated with supporting jobs and gross value-added (GVA) across multiple sectors of the

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https://doi.org/10.1016/j.ecolecon.2025.108587
Received 25 June 2024; Received in revised form 28 February 2025; Accepted 4 March 2025
Available online 20 March 2025

economy. For example, the UK Government estimates that CCUS could create up to 50,000 jobs in the UK (DESNZ, 2021b), including 10,000 associated with the current domestic-facing activity of sequestering emissions from the UK's regional industry clusters. However, the timeframes involved are not clear, where deployment through Track 1 and Track 2 will involve a range of activities and different labour demands across an extended and dynamic time frame. Moreover, existing estimates do not address how wage responses in the supply-constrained UK labour market – characterised by both worker and skills shortages – may manifest in net total employment impacts involving potential displacement of jobs and activity in other sectors and across regions (CCC, 2023; CCSA, 2023; Skidmore, 2023). Crucially, potential congestion of nascent activity in the net zero space could exacerbate resource and skills competition across all sectors, impacting not only deliverability of CCUS projects but the dynamics of the wider transition.

Research on the wider economy impacts of nascent CCUS activity is limited, with most available CCUS studies focusing on carbon reduction potential (e.g., Fan et al., 2021), and other techno-economic analysis (e.g., van der Spek et al., 2020), including plant-level abatement costs (e.g., Fan et al., 2022). There are also studies looking at barriers to uptake (e.g., Budinis et al., 2018) and firm-level issues around the importance of capture readiness to ease retrofitting processes (e.g., Ding et al., 2020). CGE modelling tends to be the dominant methodology for economy-wide scenario simulation analysis around new or emerging activities, including CCUS, but with a limited number of examples (e.g. see Le Treut et al., 2021; Vennemo et al., 2014). This is a crucial gap given increasing policy focus - particularly in those nations with capability and capacity developed through oil and gas extraction – on generating new supply chain activity and jobs linked to the emergence of CCUS (DESNZ, 2021b). Here, there is a particular need to understand the likelihood of temporary employment peaks, potential labour market pressures, job displacement, and the sectoral and regional implications thereof.

This paper aims to contribute to addressing these gaps, with specific focus on estimating the national and regional labour market implications of the deployment and operation of a nascent $CO_2$ T&S sector in the UK economy that emerges in the form of four regional subsectors that, at least initially, focus on servicing sequestration demand from industry actors located within the Track 1 and 2 clusters (DESNZ, 2021a, p. 1, DESNZ, 2023a). The objective is, through multi-sector economy wide CGE scenario simulations and linked regional mapping analyses, to identify and understand the regional employment implications of such nascent sector activity, with particular emphasis on the timing, location and nature of labour demand and how the potential movement of workers may involve displacement of jobs and activity across different sectors and regions of the UK economy.

We conduct comparable scenario simulations introducing each regional T&S subsector in isolation, to allow comparison of potential wider economy outcomes across each of the regional T&S subsectors linked to the Track 1 and Track 2 CCUS developments. However, we also simultaneously simulate the staged introduction of all four Track 1 and Track 2 clusters to better capture the dynamic nature and impacts of potential congestion effects in the supply-constrained UK economy. The outcome is delivery of consistent assessments of employment requirements and economic impacts of a national T&S emerging through four regional sub-sectors linked to the Track 1 and 2 CCUS clusters. This speaks to the policy need identified by UKRI (2023) for a consistent methodology to permit better understanding of net zero opportunities and challenges and comparisons to be made across projects.

Thus, in addition to contributing to filling a gap in the research literature, this work provides a timely and relevant insight to policy makers, industry and other stakeholders. With no intervention, the relocation of skilled labour could significantly affect wage rates and labour costs across the CCUS networks and other UK sectors requiring similar skillsets and competing for the same pool of labour. This could have wider public policy implications, not least in terms of regional disparities and 'just transition' agendas.[1]

## 2. Methodology

### 2.1. Introducing a new sector to a national CGE model

The choice of a CGE modelling method is motivated by its strength in capturing the impacts of supply-side responses and price changes across the wider economy. This complements the focus on understanding the potential national and regional labour implications of introducing and operating a new sector that provides $CO_2$ T&S services through the staged emergence of four regional subsectors. Nascent T&S activity is introduced in the context of a persisting national labour supply constraint, with price impacts triggered via wage bargaining responses likely to drive the outcomes. In the absence of the necessary regional economy data for the UK to inform a multi- or inter-regional CGE model, a national CGE model is utilised with scenarios built around the staged introduction of regional components of a national T&S industry (see Section 2.3) with regional mapping of results based on regional workforce data (see Section 2.4).

The UK CGE model used, UKENVI, is calibrated on a social accounting matrix (SAM) incorporating the 2018 industry-by-industry (IxI) input-output (IO) tables, the most recent and sectorally detailed at the time of undertaking the applied work. Here, the 105 UK sectors identified by ONS (2022a) are aggregated to identify 33 domestic sectors (and competing imports), retaining the originally reported data for a number of energy supply and consumption sectors (see Appendix B for a listing).

In considering new $CO_2$ T&S activity (a nascent sector not yet represented in published IO data or underlying survey data) we introduce a new (34th) sector. This is assumed to share the input structure of the existing oil and gas extraction industry, on the assumption (in absence of better information) that a new sector transporting $CO_2$ for offshore storage may share supply chain characteristics of the existing industry that extracts fossil fuels from similar geological reservoirs.

However, it is assumed that, despite servicing implicit demand for $CO_2$ T&S in privately owned, energy-intensive (and regionally clustered) industry, demand for its output must initially be guaranteed by the national government. This aligns with the UK Government strategy on CCUS deployment for industrial decarbonisation (DESNZ, 2023b), where T&S costs are likely to be covered until at least 2035. Due to uncertainties regarding which industries within each cluster will capture $CO_2$ and engage with the nascent T&S sector, we develop scenarios based on all potential emissions in each cluster being sequestered; this exceeds the UK objective of 20–30 $MtCO_2e$ by 2030 (DESNZ, 2023b; DESNZ, 2021b).

In calibrating the CGE model, the new T&S sector is introduced at the minimal scale the model will solve for (here equating to a scale equivalent to 0.2 % of the Oil and Gas proxy); the investment and full

[1] The UK Government and its devolved nations have set just transition agendas. The Scottish Government defines it as 'Just transition is how we get to a net zero and climate resilient economy, in a way that delivers fairness and tackles inequality and injustice.' In terms of jobs, the aim is to develop, across the whole economy, 'a workforce employed in good, green jobs with Fair Work practices built in to support greater equality, diversity, security, and an effective voice for all workers'. (Scot Gov just transition ref)

deployment of the new sector are detailed in Section 2.3.

To isolate the T&S sector driven impacts, all results are compared with an unchanging baseline, abstracting from any projected changes in technical progress, economic growth and/or population change. This involves taking the 2018 SAM[2] as representing the real economy structure in the pre-CCUS base year of 2022 (with reporting in 2018 prices). This is a necessary assumption as 2022 IO data are not currently published; a typical lag in publishing the complex IO data internationally, including the UK. The main implication is the abstraction from subsequent changes in the structure of key sectors and the wider economy, not least those associated with impacts of the COVID pandemic, Brexit and war in Ukraine.

### 2.2. Summary of main specification of the UKENVI CGE model

#### 2.2.1. Production and investment

A nested CES production function determines the output of all production sectors, involving substitution between domestically produced and imported intermediates, including different types of energy supply, and labour and capital. In the existing 33 sectors, a recursive dynamic process is used to endogenously determine the adjustment of sectoral capital stocks on a year-by-year basis. Investment in the nascent T&S industry (the 34th sector) is exogenously determined, at the simulation stage (see Section 2.3). One of the long-run equilibrium conditions across all sectors is that the actual equals the desired capital stock with gross investment limited to offsetting depreciation.

#### 2.2.2. Labour market

The total national labour supply is assumed fixed, with limited flexibility in total employment through a pool of unemployment. In the absence of sectoral data on skills/occupations, labour is assumed to be fully mobile across sectors with competition for the constrained labour supply reflected through the specification of a bargained real wage (BRW) function (Blanchflower and Oswald, 1989). This involves an inverse relationship between unemployment ($u_t$) and the real wage rate ($w_R$):

$$ln[w_R] = \omega - \varepsilon ln(u_t) \quad (1)$$

In the base year (full-time equivalent, FTE) unemployment rate is 4.1 % (in line with ONS data[3]). The bargaining power of workers is determined by the elasticity, $\varepsilon$, of wages relative to the unemployment rate, with the implication that workers have greater bargaining power as the unemployment rate falls and vice versa. The central value of $\varepsilon$ is set at 0.113 based on the work of Layard et al. (1991) and reinforced by Blanchflower and Oswald (2005) and Allan et al. (2021) for the UK. We can reformulate the bargaining function to demonstrate the link between real wages and employment ($L$) (given the fixed labour assumption):

$$\dot{w}_R = 2.65\,\dot{L} \quad (2)$$

#### 2.2.3. Trade

The UK is modelled as a small open economy that trades with an exogenous rest of the world (ROW) region. The price of externally produced commodities is fixed across all timeframes and all scenarios, effectively providing the model numeraire. UK exports and imports are driven by changes in UK prices, with domestically produced and imported commodities assumed to be imperfect substitutes in all UK production and consumption under an Armington (1969) assumption.

#### 2.2.4. Household consumption

An aggregate household group/single representative household is assumed, whose consumption is determined by its disposable income (excluding taxes and savings). The SAM gives the initial consumption distribution, which then endogenously responds to changes in income levels and relative prices. Total household income is determined by earnings from employment, capital income and government transfers (assumed fixed in real terms), with a fixed marginal propensity to save across all timeframes and scenarios.

#### 2.2.5. Government

The government budget ($GB$) is given by:

$$GB_t = GY_t - GEXP_t \quad (3)$$

$GY$ is government revenue, including income and other taxes, including indirect business taxes, capital revenue and foreign remittances at a fixed exchange rate. $GEXP$ represents the nominal government expenditure:

$$GEXP_t = GQ_t \bullet Pg_t + TRG_{hh} \bullet CPI_t + TRG_{firm} \bullet CPI_t \quad (4)$$

$GQ$ is (fixed) real government spending on goods and services, with nominal spending adjusting to changes in the government price index $Pg$. Government also makes fixed real transfers to households ($TRG_{hh}$) and firms ($TRG_{firms}$), where nominal spending adjusts for changes in the consumer price index ($CPI$). The long-run equilibrium conditions do not require a balanced budget. Therefore, any government payments required to guarantee the demand for T&S services are reflected in the value of $GB$ via changes to $GQ$.

### 2.3. Scenario analysis approach

The basis of our analyses is the simulation of the investment and operation of a nascent UK $CO_2$ T&S sector emerging to service sequestration requirements in regionally clustered industries identified as Track 1 and 2 CCUS clusters (DESNZ, 2023a, DESNZ, 2021a, p. 1). Track 1 involves potential capture industries and T&S projects in clusters located at the northeast and northwest of England. Track 2 introduces activity aligned with the Scottish cluster, spanning across the east coast of Scotland, while the Viking CCS project covering part of the South Humber region of northeast England.[4] One challenge for regional analysis is where these clusters span over multiple regional areas for which ONS report data.

Scenario data on investment draw on Calvillo et al. (2022) updated to take into consideration the emissions reported in the UK emissions inventory (UK Government, 2020b) and relevant recent cluster publications updating clusters definitions and characteristics[3]. In the absence of data on which firms and industries in each cluster will participate in CCUS activity, and on whether there may be cross cluster T&S provision/activity, we consider scenarios where investment in T&S capacity is sufficient to sequester all and only the emissions of the industries identifiable for each Track 1 and 2 cluster.

Table 1 summarises emissions serviced and our assumptions regarding capital and exogenous investment requirements. It also

[2] The SAM used here is publicly available at: doi: 10.15129/67521ce7-3184-47bf-8d63-4764ae5d1951

[3] Data on the UK's annual unemployment rate can be sourced at https://www.ons.gov.uk/employmentandlabourmarket/peoplenotinwork/unemployment/timeseries/mgsx/lms

[4] We characterise the $CO_2$ T&S requirements based on the emissions and locations identified by the UKRI Industrial decarbonisation challenge. For Track 1 clusters, we consider industrial emitters located around north of the Humber area, Tees Valley, Merseyside and the North West, roughly aligned to CCUS projects identified in those areas (e.g. HyNet, Net Zero North West (NZNW), Humber Industrial Cluster Plan (HICP), Zero Carbon Humber, Net Zero Teesside, etc.). For Track 2, we consider industrial emitters along the North East of Scotland and Grangemouth, and in the South Humber area, roughly aligned to the Scotland Net Zero Roadmap and Viking CCS projects. See Calvillo et al., 2022, https://doi.org/10.1016/j.ijggc.2022.103695 for full detail on the methodology used to characterise clusters and $CO_2$ T&S needs.

**Table 1**
UK regional cluster emissions sources and interventions/impacts of linked $CO_2$ Transport and Storage capacity.

| Key T&S industry investment and operational characteristics | East Coast cluster | North West cluster | Scottish cluster | Viking cluster | All Clusters |
|---|---|---|---|---|---|
| Total capital stock created (£m) | 1162 | 437 | 499 | 587 | 2685 |
| Pre-operation investment (£m) - Evenly distributed over the investment period | 1458 | 549 | 582 | 685 | 3274 |
| Ongoing additional annual investment (£m) | 174 | 66 | 75 | 88 | 403 |
| Total output/demand serviced (£m) | 402 | 151 | 173 | 203 | 929 |
| Direct employment (FTE) | 175 | 66 | 75 | 88 | 404 |
| Value added (GDP) (£m) | 254 | 96 | 109 | 128 | 587 |
| **Total emissions serviced (Mt, millions of tonnes of $CO_2$)** | 22 | 9 | 7 | 12 | 50 |

reports the implied value of T&S output (equating to required demand), direct employment and value-added generated, where capital and labour intensities are given by the oil and gas benchmark.

In terms of timing of investment and deployment, we assume:

- Track 1 clusters start developing their infrastructure from year 1 (2023), with year 4 (2026) being the last year of investment; investment is spread equally over the 4-year period. The full capital stock is established by year 5 (2027) and the sector starts operating in that year.
- Track 2 clusters start developing the necessary infrastructure in year 5 (2027) and conclude the investment in year 7 (2029), again spreading the investment equally over 3 years. The capital is in place by year 8 (2030) and the full cluster becomes operational with an implied demand that is the sum of the output produced across all four clusters.

Herein, we first conduct comparable scenario simulations introducing each regional T&S sector in isolation, followed by one simultaneously simulating the staged introduction of all four. The former allows us to compare economy-wide outcomes of introducing each subsector, while the latter permits consideration of how potential congestion, manifesting through greater competition for labour market resources in particular, may affect economy-wide outcomes.

All investment in T&S is modelled as an exogenous investment shock. Once each regional subsector of the UK T&S sector becomes operational, additional annual investment offsets depreciation of the newly introduced capital. We assume that the demand for all T&S output is guaranteed by government, modelled for simplicity as government purchases, which aligns with the provisions in the current UK Government's CCUS Business Models (BEIS, 2022). We note that it would be equally appropriate to run the simulations with fully subsidised industry demand, but potentially without substantial impact on the outcomes focussed on here.[5]

### 2.4. Employment impacts - regional mapping approach

The outputs of the national CGE analyses (see Sections 2.1 and 2.2) inform, in terms of economy-wide impacts, on sectoral and total jobs and other outcomes at UK-wide level (i.e. as a single region). However, the regional as well as sectoral location of labour demand in different time periods is likely to be important for workforce planning and the successful delivery of $CO_2$ T&S services and other industrial decarbonisation actions (UKRI, 2023), hence we extend to a regional mapping of employment impacts.

This involves mapping the national level employment impacts (from the CGE model) to different regions using ONS data on 'Workforce jobs by region and industry' (ONS, 2022b). We introduce a weighting factor to allocate a higher share of employment changes around cluster regions for the construction and T&S sectors, where activity is likely to be physically concentrated around the clusters. See Appendix A for a more detailed description of the regional mapping approach.

## 3. Results and discussion

### 3.1. Economy-wide outcomes by 2035

We start by exploring the economy-wide implications of introducing the new UK $CO_2$ T&S sector that emerges through regional subsectors linked to the industrial clusters identified as part of Track 1 and Track 2 of the CCUS sequencing process.

It is instructive to consider the likely new long run equilibrium conditions once the economy has fully adjusted to the introduction of the new T&S sector. Here, we would expect to observe a constrained expansion of the UK economy, with a sustained boost to GDP and employment. However, given our assumption of a persisting national labour supply constraint, increases in employment in expanding sectors involves movement of labour from the pool of unemployed labour and across sectors. Here, cross sector competition for workers and associated impacts on nominal wage rates faced by all producers involves real wage bargaining in the UK labour market.

Thus, the new long-run equilibrium will be characterised by increases in producer and consumer prices, which will cause some displacement of activity across both the sectors of the economy and the components of GDP that they service. Given the domestic focus of initial UK T&S activity and government expenditure thereon, set against emerging price pressures, the composition of UK GDP can be expected to shift away from export production, with domestic GDP gains eroded by CPI pressures. In terms of the net public budget impacts, we assume that CPI increases translate to increases in nominal government spending to meet real spending commitments, thereby offsetting the positive impacts of additional revenues on the public budget.

A fuller set of simulations not reported here suggest that the economy will fully adjust by around 2040 (given the relatively small scale of the investment and new sector shocks). However, given the current UK policy position (as set out in the 2023 CCUS Vision: DESNZ, 2023b), our assumption that government guarantees demand for all nascent T&S sector output may only be valid to 2035. Thus, Table 2 reports key macroeconomic impacts for that year, focussing on outcomes of publicly supporting this nascent industry deployment. In terms of % changes relative to the 2022 baseline, in Table 2 all the macroeconomic variables have adjusted (to the 3 decimal places reported) to their long-run values,

[5] We note that the simulations extend beyond the (as yet not fully defined) timeframe of government support – which is likely to end by the early 2040s at the latest – in identifying the properties of long-run equilibria. Thus, longer term results should be considered with caution.

**Table 2**
Key 2035 macroeconomic impacts in the UK of introducing the T & S industry in Track 1 and Track 2 clusters.

| | East Coast | North West | Scottish Cluster | Viking | UK-wide (additive) | UK-wide (simultaneous) |
|---|---|---|---|---|---|---|
| GDP (£million) | 393 | 146 | 168 | 199 | 906 | 893 |
| GDP (% change) | 0.021 % | 0.008 % | 0.009 % | 0.010 % | 0.047 % | 0.047 % |
| Employment (FTE) | 1813 | 668 | 773 | 919 | 4173 | 4088 |
| Employment (% change) | 0.006 % | 0.002 % | 0.003 % | 0.003 % | 0.014 % | 0.014 % |
| Unemployment (% change) | −0.144 % | −0.053 % | −0.061 % | −0.073 % | −0.331 % | −0.324 % |
| Nominal wage - index to 1 (% change) | 0.030 % | 0.011 % | 0.013 % | 0.015 % | 0.070 % | 0.070 % |
| Real wage - index to 1 (% change) | 0.016 % | 0.006 % | 0.007 % | 0.008 % | 0.037 % | 0.037 % |
| CPI - index to 1 (% change) | 0.014 % | 0.005 % | 0.006 % | 0.007 % | 0.033 % | 0.034 % |
| Total investment (£million) | 247 | 94 | 109 | 128 | 578 | 580 |
| Total investment (% change) | 0.036 % | 0.014 % | 0.016 % | 0.019 % | 0.084 % | 0.085 % |
| Total exports (£million) | −154 | −59 | −68 | −79 | −360 | −366 |
| Total exports (% change) | −0.027 % | −0.010 % | −0.012 % | −0.014 % | −0.064 % | −0.065 % |
| Total imports (£million) | 213 | 81 | 91 | 107 | 492 | 495 |
| Total imports (% change) | 0.035 % | 0.013 % | 0.015 % | 0.017 % | 0.080 % | 0.081 % |
| Real household consumption (£million) | 287 | 107 | 122 | 144 | 661 | 658 |
| Real household consumption (% change) | 0.022 % | 0.008 % | 0.009 % | 0.011 % | 0.051 % | 0.051 % |
| Net government revenue (£million) | −306 | −116 | −132 | −154 | −708 | −713 |

with only small differences in absolute values (e.g., the long-run GDP change is £5 million larger than reported for 2035 in the final column of Table 2, while total employment is 24 FTE units higher). However, the 2035 picture should not be taken as a sustained long-run outcome as the expansion would dissipate quickly if government support were withdrawn from 2036 and/or (more likely) change if a shift to an 'industry pays' market mechanism were invoked from that time.

By 2035, outcomes are entirely driven by the impacts of operating the new T&S sector. We begin by focussing on the UK-wide picture in the final column of Table 2, where all four regional components of T&S are simulated alongside one another (according to the time paths set out in Section 2.3). The boost to GDP is 0.047 % per annum over what it would be in the absence of the T&S rollout (the 2022 baseline). This equates to a per annum uplift of £893 million and supports a net additional 4088 FTE jobs.

With the national labour supply assumed fixed, the increase in employment is achieved through a reduction (just over 0.3 %) in unemployment but involving an increase in the average nominal wage rate (of 0.07 %) faced by all producers, driven by real wage bargaining in the labour market. The average real wage rate increases by 0.037 %, eroded

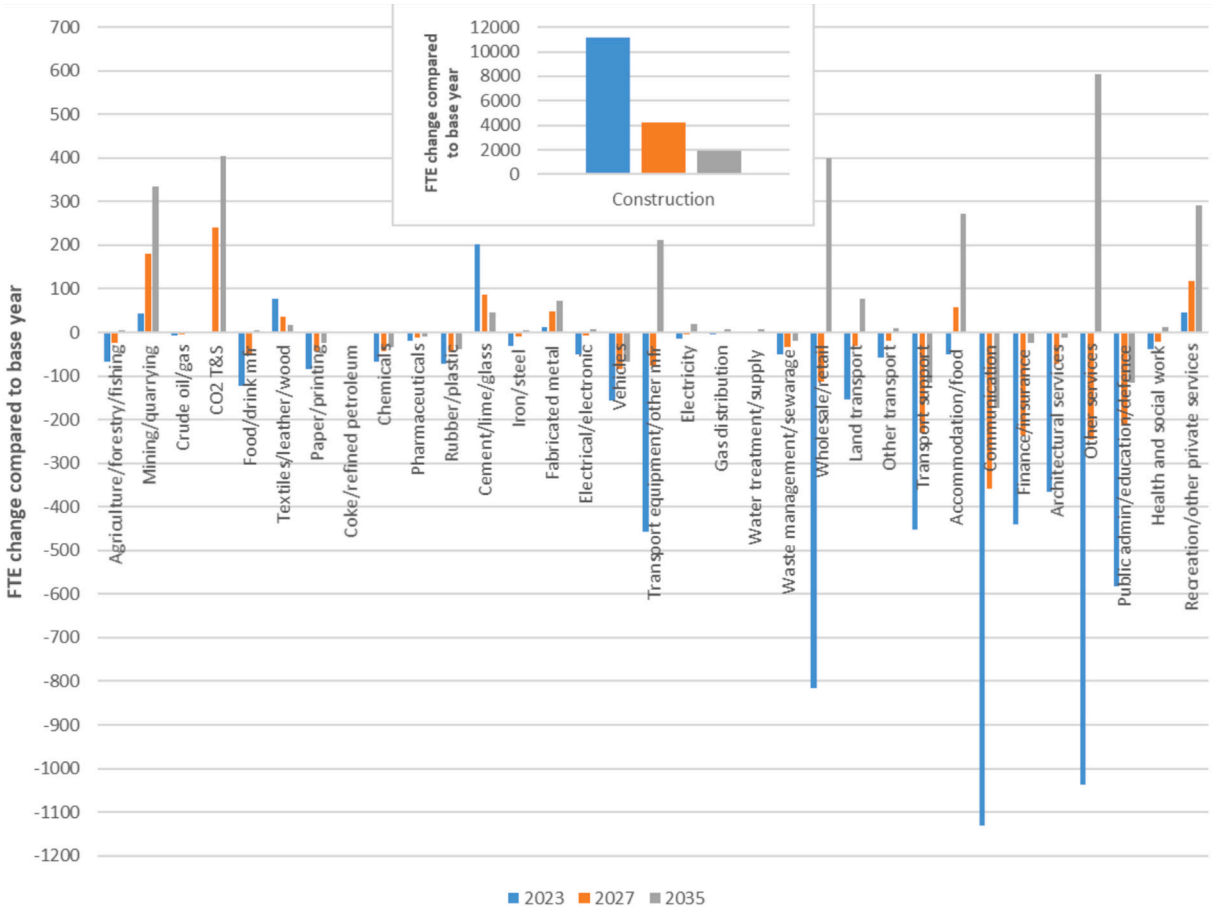


**Fig. 1.** Sectoral breakdown of employment impacts due to the introduction of a new UK-wide T&S industry (simultaneous simulation).
Note that the construction sector has been separated from the other sectors, due to the significant difference in the scale of changes.

by upward pressure on the CPI (+0.033 %), which constrains real household consumption gains (0.051 %). The CPI increase also erodes the offsetting effect of additional revenue gain in determining the net public budget impact of supporting the deployment of the nascent T&S sectors.

The increase in labour costs across the economy triggers some displacement of activity, particularly in labour or wage intensive sectors enjoying little or no boost from introducing the new T&S sector. Here, the 2035 bar in Fig. 1 reflects how net displacement impacts are concentrated in sectors like Public Administration and Communications. Other sectors expand less than they would in the absence of wage pressure in the UK labour market and the CPI pressure that emerges as a result.

The first four data columns of Table 2 show how the economy would adjust in response to any one of the regional T&S sectors deploying around the T&S systems planned for each of the Track 1 and 2 clusters. Note that the UK-wide picture in the final column is not a straightforward summation of the four components, as reflected in the fifth column (additive results), with some further general equilibrium impacts as the greater expansion across all four occurs in the context of the labour supply constraint. The differences between the additive vs simultaneous simulation approach are small by 2035, as economic transition paths begin to merge, and these are further reduced in the long-run. For example, total employment (FTE) by 2035 in the additive case is 4173, whereas UK-wide (simultaneous case) is 4088 FTEs. However, in the dynamic economy-wide adjustment pre-2035, where labour market constraints 'bite harder' the differences can be significant (this is explored in the next section).

Looking at the results in the first four columns of Table 2, for each individual subsector simulation, the 2035 results for each regional case are qualitatively similar, with the scale of the resulting UK-wide expansion depending partly on the size of the regional T&S system being introduced. For example, East Coast sequesters the largest share of emissions in Table 1 and supports a proportionate share of the expansion in Table 2. However, it also depends on the characteristics of each T&S system and what these imply in terms of the investment requirement, and the resulting value of infrastructure developed, and economic output and income generation supported by the capital stock created.

Given that we assume (in the absence of better national and/or regional data) the input structure given by the oil and gas (extraction) industry benchmark applies in all four cases, differences in the extent of expansion and shares of income generating activity depends on things like the geographical spread of the emissions sources that the regional T&S system can/will service. This is what determines the level of investment in infrastructure and the extent of economic activity and output to be serviced and guaranteed by the UK Government.

Thus, there are some trade-offs for policymakers in considering and assessing the comparative picture across the regional T&S industry cases in Tables 1 and 2. The more geographically concentrated the regional T&S system, the lower the investment requirement and the average cost to the public purse per physical unit of emissions sequestered. On the other hand, a larger share of the required investment, for example in the Scottish case (18 %), delivers a more than proportionate share of the value of new UK T&S sectoral activity and associated employment, GVA and government revenue gains (broadly around 19 %) relative to the share of emissions sequestered (14 %).

Such differences also impact what we find in the regional mapping analysis in Section 3.4. However, first, we consider how outcomes evolve through the transitory stage of the staggered pre-operational investment stage.

### 3.2. Dynamic economy-wide adjustment

Tables 3a and 3b shows key employment and economic outcomes of developing and operating the T&S sector for 2023 and 2027 as key years for the onset of investment activity in the Track 1 and Track 2 T&S systems respectively (as detailed in Section 2.3).

In 2023 (and until 2026) investment activity is concentrated in the Track 1 cases. As discussed above, the largest share of investment activity and wider economy impacts are associated with the East Coast T&S subsector. Again, differences in location of emissions equate to differences in investment requirements and the capital stock created and output supported, here with East Coast developed to sequester 71 % of Track 1 emissions but requiring 73 % of the total pre-operational investment and delivering 74 % of the employment gains in the first year.

However, the greater extent of near-term activity in the East Coast case generates more immediate wage-driven cost and price pressure across the economy, displacing other activity to the extent that there are almost no economy-wide GVA gains. In Fig. 1, the 2023 bar reflects how the increase in Construction sector employment (in particular) displaces jobs across a range of more labour and/or wage intensive service sector activities due to the 0.064 % increase in the average nominal wage.

A similar pattern is observed in Table 3b in considering 2027, when the development of Track 2 clusters begins in year 5. However, a key difference is that by this point the Track 1 T&S systems are fully invested and operational, so that further construction requirements to those regional T&S sectors are in maintaining the capital developed as the new operational industries begin to produce output. This also invokes the direct public spending requirement in guaranteeing demand for that output.

Considering the evolution of impacts from the wider emerging UK T&S sector, comparing the final column of Table 3b first with earlier

**Table 3a**
Key year 1 (2023) macroeconomic impacts in the UK of introducing the T & S industry in Track 1 and Track 2 clusters.

| | East Coast | North West | Scottish Cluster | Viking | UK-wide (additive) | UK-wide (simultaneous) |
|---|---|---|---|---|---|---|
| GDP (£million) | 6 | 1 | 0 | 0 | 8 | 10 |
| GDP (% change) | 0.000 % | 0.000 % | 0.000 % | 0.000 % | 0.000 % | 0.001 % |
| Employment (FTE) | 2988 | 625 | 0 | 0 | 3613 | 5211 |
| Employment (% change) | 0.010 % | 0.002 % | 0.000 % | 0.000 % | 0.012 % | 0.018 % |
| Unemployment (% change) | −0.237 % | −0.050 % | 0.000 % | 0.000 % | −0.287 % | −0.414 % |
| Nominal wage - index to 1 (% change) | 0.064 % | 0.013 % | 0.000 % | 0.000 % | 0.078 % | 0.113 % |
| Real wage - index to 1 (% change) | 0.027 % | 0.006 % | 0.000 % | 0.000 % | 0.032 % | 0.047 % |
| CPI - index to 1 (% change) | 0.038 % | 0.008 % | 0.000 % | 0.000 % | 0.045 % | 0.066 % |
| Total investment (£million) | 234 | 110 | 0 | 0 | 344 | 273 |
| Total investment (% change) | 0.204 % | 0.043 % | 0.000 % | 0.000 % | 0.246 % | 0.356 % |
| Total exports (£million) | −363 | −76 | 0 | 0 | −439 | −634 |
| Total exports (% change) | −0.064 % | −0.013 % | 0.000 % | 0.000 % | −0.078 % | −0.112 % |
| Total imports (£million) | 598 | 125 | 0 | 0 | 723 | 1046 |
| Total imports (% change) | 0.097 % | 0.020 % | 0.000 % | 0.000 % | 0.118 % | 0.170 % |
| Real household consumption (£million) | 417 | 87 | 0 | 0 | 504 | 728 |
| Real household consumption (% change) | 0.032 % | 0.007 % | 0.000 % | 0.000 % | 0.039 % | 0.056 % |
| Net government revenue (£million) | 82 | 17 | 0 | 0 | 99 | 143 |

**Table 3b**
Key year 5 (2027) macroeconomic impacts in the UK of introducing the T & S industry in Track 1 and Track 2 clusters.

| | East Coast | North West | Scottish Cluster | Viking | UK-wide (additive) | UK-wide (simultaneous) |
|---|---|---|---|---|---|---|
| GDP (£million) | 312 | 108 | 2 | 3 | 425 | 449 |
| GDP (% change) | 0.016 % | 0.006 % | 0.000 % | 0.000 % | 0.022 % | 0.023 % |
| Employment (FTE) | 1216 | 403 | 1056 | 1376 | 4051 | 3046 |
| Employment (% change) | 0.004 % | 0.001 % | 0.004 % | 0.005 % | 0.014 % | 0.010 % |
| Unemployment (% change) | −0.096 % | −0.032 % | −0.084 % | −0.109 % | −0.321 % | −0.242 % |
| Nominal wage - index to 1 (% change) | 0.033 % | 0.012 % | 0.023 % | 0.030 % | 0.098 % | 0.074 % |
| Real wage - index to 1 (% change) | 0.011 % | 0.004 % | 0.009 % | 0.012 % | 0.036 % | 0.027 % |
| CPI - index to 1 (% change) | 0.022 % | 0.009 % | 0.013 % | 0.017 % | 0.062 % | 0.046 % |
| Total investment (£million) | 361 | 131 | 148 | 169 | 809 | 873 |
| Total investment (% change) | 0.058 % | 0.021 % | 0.072 % | 0.094 % | 0.244 % | 0.168 % |
| Total exports (£million) | −240 | −92 | −128 | −167 | −628 | −483 |
| Total exports (% change) | −0.043 % | −0.016 % | −0.023 % | −0.030 % | −0.111 % | −0.086 % |
| Total imports (£million) | 224 | 88 | 211 | 275 | 798 | 557 |
| Total imports (% change) | 0.036 % | 0.014 % | 0.034 % | 0.045 % | 0.130 % | 0.091 % |
| Real household consumption (£million) | 243 | 91 | 147 | 192 | 672 | 513 |
| Real household consumption (% change) | 0.019 % | 0.007 % | 0.011 % | 0.015 % | 0.052 % | 0.040 % |
| Net government revenue (£million) | −346 | −133 | 29 | 38 | −413 | −437 |

outcome in Table 3a then the 2035 results in Table 2, observe that the upward pressure on wage costs and the CPI peaks as the start of Track 2 investments coincide with the start of T&S operations in Track 1. However, the net employment and GDP impacts continue to build, with only 50 % of the annual GDP gain in 2035 realised by 2027.

While, in absolute terms, the total employment impact in 2027 is 75 % of what is observed in 2035, this masks the dynamic adjustment at play. Comparing the 2027 and 2035 bars in Fig. 1, observe that there is markedly more displacement of employment while upfront investment activity continues in 2027, despite the minor net impact on the average nominal wage rate (+0.074 % compared to +0.070 in 2035).

In 2027 more labour-intensive construction is the dominant draw on the constrained labour supply, but with a smaller drop in unemployment and rise in the average real wage rate than is observed later. Over time, as the rollout of the more capital-intensive operational T&S sector becomes the main driver of the expansion, the combination of reduced CPI pressure and less displacement/more expansion in more labour/wage intensive activities support an expansion characterised by more jobs at a higher real wage and other sources of domestic income generation.

Here, it is important to note that we have mostly focused on the results emerging from the simultaneous introduction of the UK T&S sector via the staged introduction of all four regional subsectors (i.e., running the four individual scenarios in a single simulation). However, both Table 2 and Tables 3a and 3b also report the additive results of the individual simulations of the four T&S systems. As pointed out in Section 3.1, the differences between the additive and the simultaneous simulation results in 2035 are relatively small and become negligible as we move closer to a new long-run equilibrium. However, as shown in

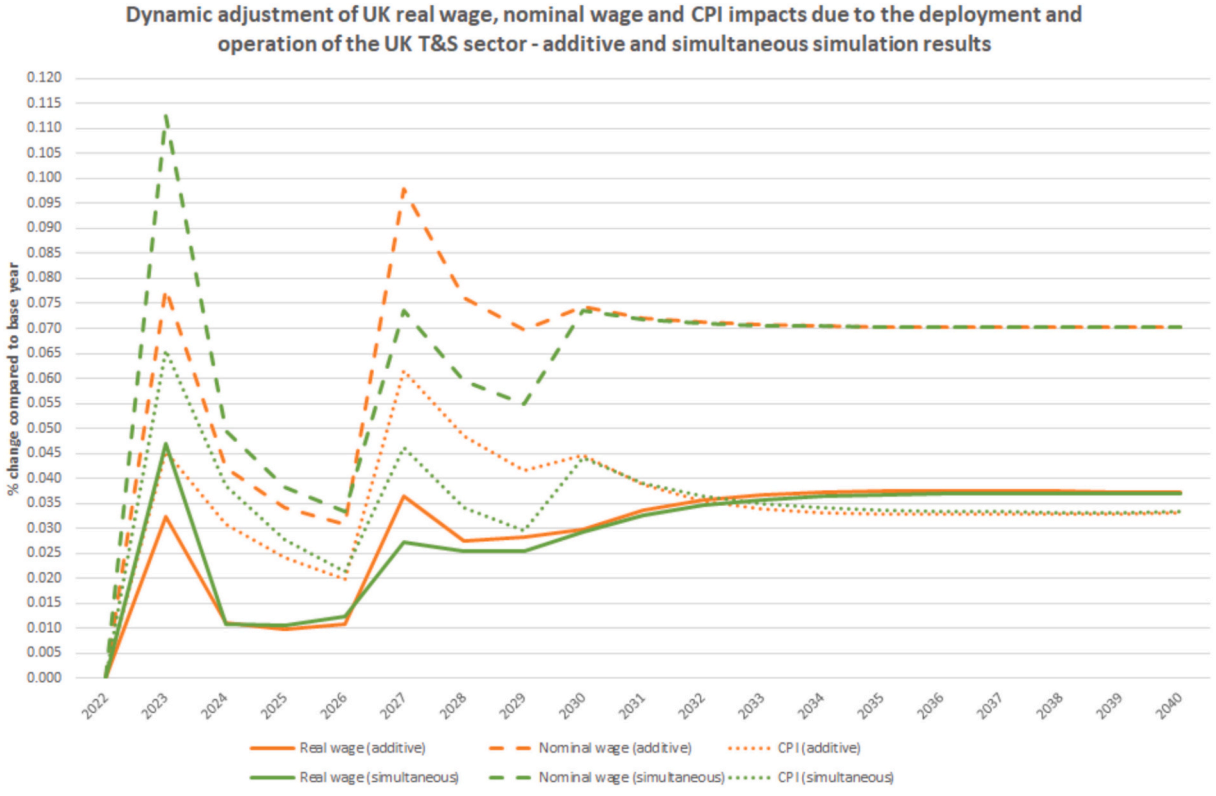


**Fig. 2.** Dynamic adjustment of UK real wage, nominal wage and CPI impacts due to the deployment and operation of the UK T&S sector – additive and simultaneous simulation results.

Tables 3a and 3b, this is not the case in the years prior and immediately after the full operation of the nascent T&S sector.

The underlying driver of this discrepancy between the additive and the simultaneous simulation results is the resource competition associated with more extensive nascent sector activity occurring in the same broad timeframes. Effectively, the implementation of investment projects could lead to congestion, where the different projects strive to secure the necessary labour from an already constrained labour market, which in turn may exacerbate cost and price pressures, and the impacts thereof, beyond a simple summation of component elements. This, to our knowledge, constitutes a first, albeit small scale, test of how the potentially crowded net zero space could be associated with an accumulation of pressures on constrained resources. The outcomes for UK T&S (likely to be one of the smaller nascent sector activities emerging through the net zero transition) are reflected in Figs. 2 and 3, where we compare our core 'additive' and the additional 'simultaneous' case, where we show how key macroeconomic variables adjust to the 2035 outcomes we focus on.

Fig. 2 reports the dynamic real wage response as the four regional T&S subsectors are first invested then become operational. Note that the initial spike, in 2023, as investment in the two Track 1 cases begins, is greater in the simultaneous case, which triggers greater nominal wage impacts for producers and CPI impacts for consumers. This is in line with the strong link between real wages and employment, which we discuss in Section 2.1. In Fig. 3, while the larger transitory real wage increase induces a more substantial gain in employment, the cost-price effects cause a temporary slump in gross value added (GDP) in the simultaneous simulation case.

By the time investment begins in the two Track 2 regional T&S systems in 2027, the slightly faster expansion in activity across the economy in the additive case causes the labour supply constraint to 'bite' a bit more, so that the real wage driven cost-price pressure becomes greater than in the simultaneous simulation case. This causes the respective GDP and employment transition paths to begin to merge so that, by the time the economy adjusts past the 2035 period that we focus on here, there is little difference between the two cases (translating to around 85 FTE jobs and £13 million in annual GDP).

Nonetheless, the results reported here are important for policymakers to consider. In terms of the nascent T&S sector case we focus on here, it suggests that even if the regional T&S subsectors do not compete directly with each other, for resources or demand (which we constrain them from doing here with the exogenous introduction of T&S activity and government demand guarantee), the impact of staged simultaneous investment and deployment will have important wage-driven cost price impacts that are likely to, at least initially, constrain but generally influence the trajectory of the wider economic expansion.

This underpins a key finding for the work reported here. This is that the simultaneous staged introduction of what are effectively four regional subsectors of a nascent UK T&S sector is likely to introduce some degree of congestion in the labour market, and for resources more generally. This manifests in the exacerbation of resource competition across all sectors, which constrains the value (represented by GVA in Fig. 3) of a larger employment peak. However, over time, the slower subsequent expansion in activity and associated labour demand picked up by simultaneous simulation avoids the type of potential exaggeration of the likely expansionary power of later investment activity observed in our additive simulation trajectory in Fig. 3 (and the underlying real wage pressure/gains to workers in Fig. 2).

While the congestion impact is relatively small for T&S alone, the kind of dynamic resource competition pressures highlighted here are likely to become more important if a greater number of net zero infrastructure and nascent activities happen in the same/similar timeframes. This implies not only a need for policy leadership in mitigating congestion impacts but also for research of the simultaneous study of how different activities will affect the wider national economy. Moreover, there is a need to explore the impacts and implications of varying

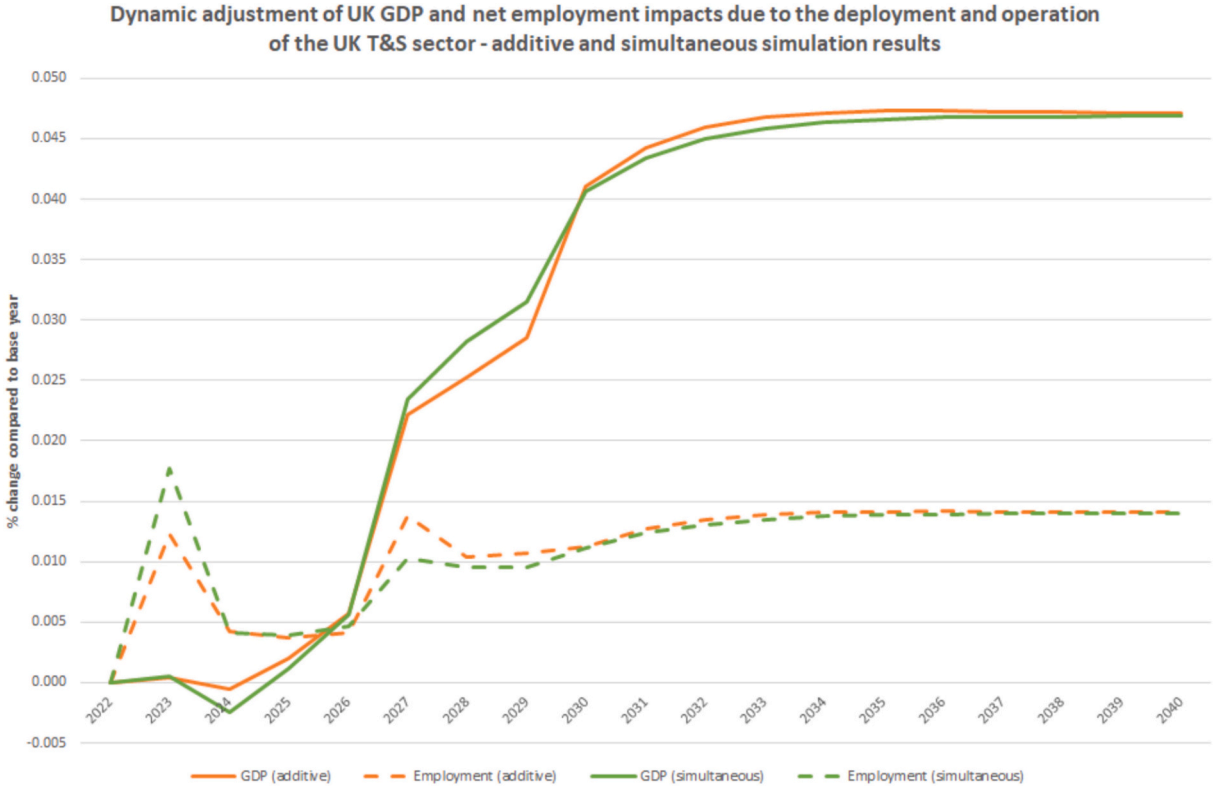


**Fig. 3.** Dynamic adjustment of UK GDP and net employment due to the deployment and operation of the UK T&S sector – additive and simultaneous simulation results.

distribution and displacement of employment across regions therein.

### 3.3. Regional employment impact mapping and analysis

Fig. 56 show the regional mapping of employment changes linked to the deployment of the T&S sector servicing the Track 1 and Track 2 clusters in the three key years (2023, 2027 and 2035) considered above. Impacts are grouped to focus on those sectors where employment impacts are concentrated at the investment and deployment stages – i.e., the Construction sector and nascent T&S sector – and all others. The first frame in Figs. 4–6 identifies the regions considered, the second and third show the distributed employment outcomes across sector groupings and regions, for the additive case in the second frame and the simultaneous simulation case in the third.

If we start with the longer-term picture by 2035 (Fig. 4), here the economy has started to stabilise, and (as discussed above) the difference in total employment outcomes between the additive and simultaneous simulation cases greatly decreases. Comparing Fig. 4.a and b respectively, we observe that this also the case for regions not hosting CCUS clusters (e.g. southern England). However, while congestion impacts in the labour market are netting out at the national level, residual impacts persist somewhat in the regions where most congestion and displacement has been experienced.

Overall, however, by 2035 Fig. 4 shows that introducing T&S does ultimately drive net positive employment changes across regions. Note, however, that the higher level of sectoral employment changes reported in Fig. 4 nets out several net negative sectoral impacts reported in Fig. 1 for 2035 (e.g. transport support, communications, public services, etc.), implying that some more detailed investigation of impacts at sectoral level may be merited.

Here, we elect to focus on how the dynamic regional picture varies even at the level of sectoral aggregation reported in Figs. 4–6. Let us consider 2023 (Fig. 5) as the first employment peak year identified in Figs. 1 and 3, with the underlying wage dynamics shown above in Fig. 2. Whether we consider the additive simulation picture (Fig. 5a) or the simultaneous one (Fig. 5b), investing in T&S capacity to decarbonise the East Coast and North West clusters drive high employment requirements in the construction sector, of over 3000 FTEs for each of the Yorkshire and the Humber, and North East regions, and over 1000 FTE jobs in the North West region. This triggers wage pressures that affect all sectors of the economy and a picture of regional and sectoral job displacement manifests. This is concentrated in more wage/labour intensive activities and the regions where they are more prevalent, e.g. London and southern regions. In 2023, no activity has begun around the Track 2 projects (Scottish and Viking), so that employment impacts, most notably in Scotland (as the region more remote from the rest of the wider emerging T&S sector) are limited.

While qualitatively similar, more notable quantitative variations between the additive and simultaneous simulation cases start to emerge. As reported in Fig. 2 for total employment, in 2023, the simultaneous simulation does not yet show the congestion effect (which is picked up in later years) meaning that the simultaneous results in Fig. 5b overestimate the net construction industry employment gains around the Yorkshire and the Humber, North East and North West regions. These gains are concentrated across these host regions (noting there are no employment impacts in the nascent T&S industry, which is not yet operational).

On the other hand, Fig. 5a results may underestimate the extent of job displacement, reflected in net employment losses in other regions and sectors being smaller than in Fig. 5b, while underestimating the construction industry gains in the host regions (that is, overestimating the displacement of construction activity outside host regions). However, in this first simulation year, both the additive and simultaneous results fail to fully pick up the greater wage cost-driven price pressures shown in the simultaneous simulation trajectories for later timeframes in Fig. 2.

Moving onto 2027, the start of Track 2 investment activity, Figs. 2 and 3 have already shown that the subsequent slower expansion following the greater early congestion impact causes the additive simulation to overestimate employment demand (and associated wage-cost price pressures) in the 2027 peak. Fig. 6 reflects how the regional picture also flips (in terms of quantitative outcomes) in comparing the second and third frames.

In either simulation case, 2027 sees employment demand spikes, concentrated in construction, in the regions hosting the Track 2 clusters. In Fig. 6a (additive case) the results suggest that investment in Scottish T&S activity requires over 2300 construction jobs in Scotland, and about 3300 jobs linked to Viking CCS, located between Yorkshire and the

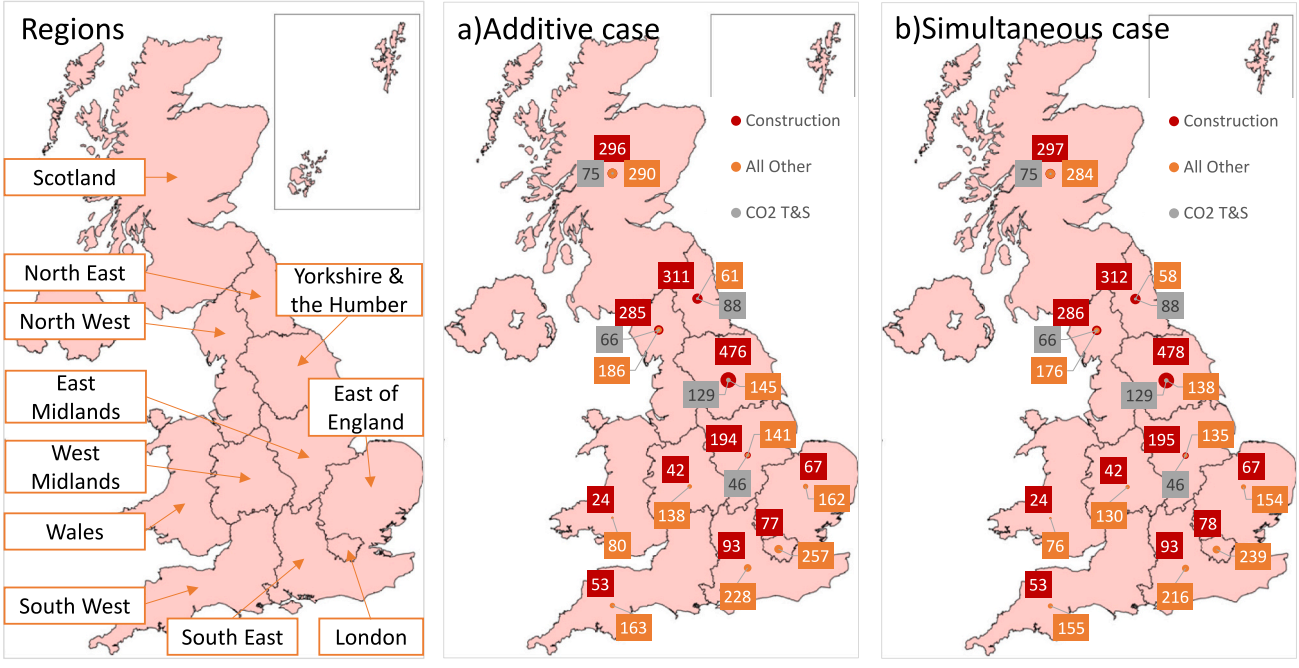


**Fig. 4.** Regional employment changes (FTE) at year 2035 relative to baseline – focus on key activity sectors: construction and $CO_2$ Transport & Storage.

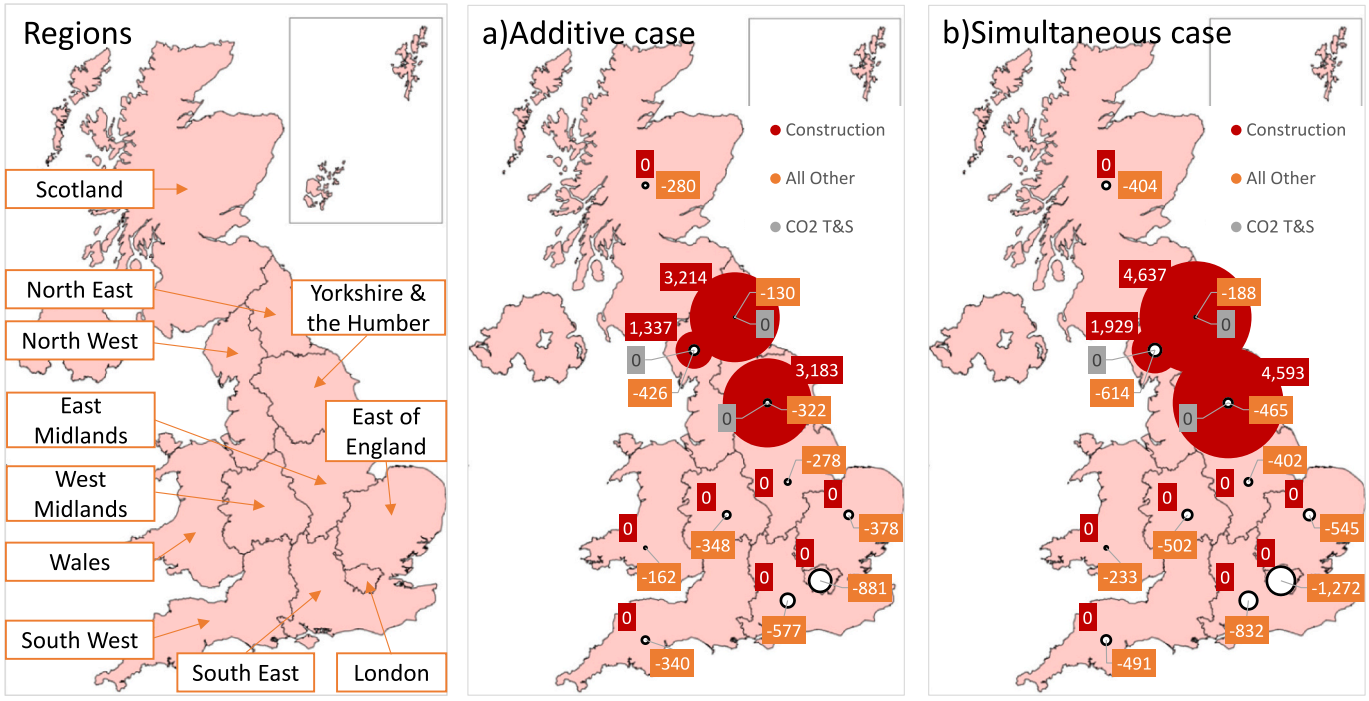


**Fig. 5.** Regional employment changes (FTE) at year 2023 relative to baseline – focus on key activity sectors: construction and CO2 Transport & Storage.

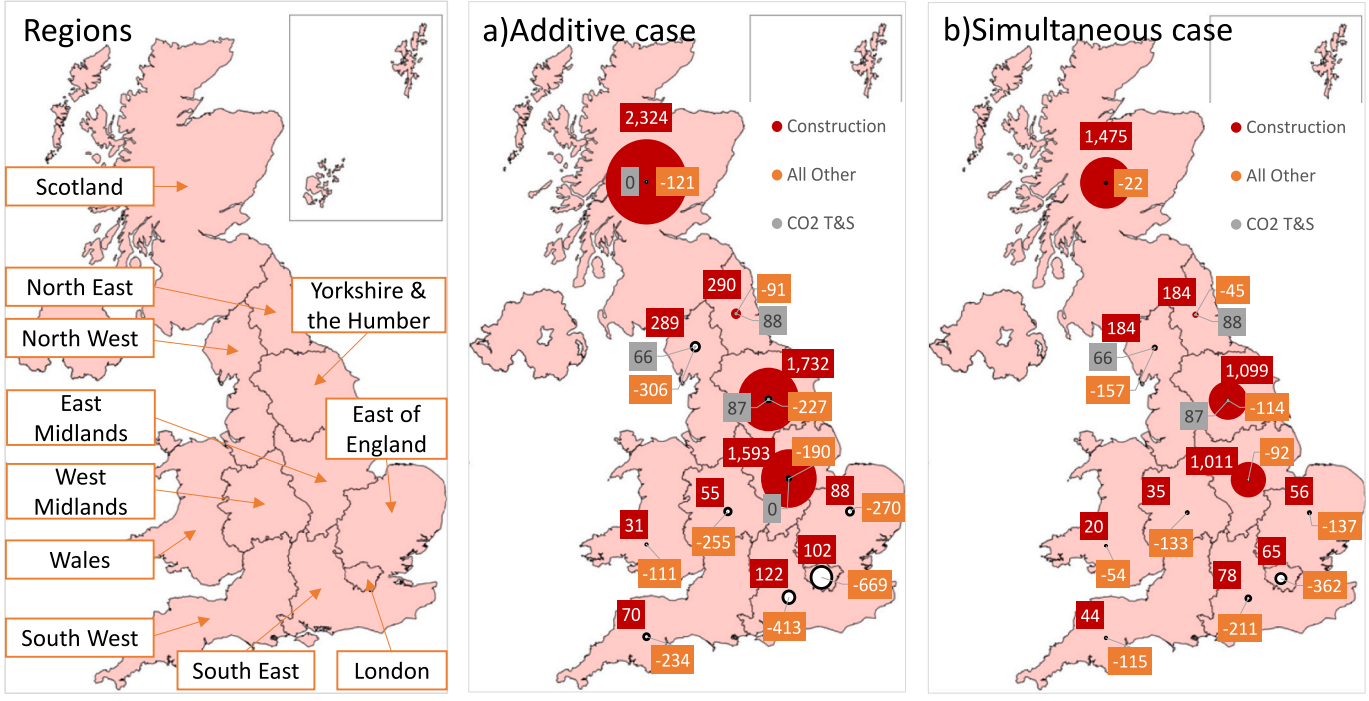


**Fig. 6.** Regional employment changes (FTE) at year 2027 relative to baseline – focus on key activity sectors: construction and CO2 Transport & Storage.

Humber and the East Midlands regions. By his time, Track 1 cluster construction activity has significantly reduced, and is mainly linked to the maintenance of the previously introduced capital, where the Track 1 T&S subsectors are now operational and adding to labour demand requirements and wage pressure. Overall, but particularly due to the greater boost in employment requirements in construction, job displacement is observed in other sectors and regions.

However, examination of the simultaneous simulation case in Fig. 6b suggests that the construction industry gains in the Track 2 cluster regions are over-estimated, as is the extent of displacement that delivers net negative impacts in other sectors and regions, and depresses construction gains in regions that do not host the clusters. Indeed, the net positive regional and sectoral employment impacts in 2027 are notably larger in the additive case in Fig. 6a than in the simultaneous simulation reported in Fig. 6b (e.g., Scotland gains 2324 construction jobs in the former and only 1475 in the latter jobs in Fig. 6.b).

As discussed above in the context of Figs. 2 and 3, the difference in outcomes when we move from the additive to the simultaneous

simulation approach is that labour demand across the wider economy is more subdued in the latter case by the time of the second investment-driven peak/the beginning of Track 2 because of the negative impacts of congestion following the first peak. Thus, while congestion, wage pressure, and displacement in the labour market are present in the picture presented in Fig. 6b, net gains and losses are more muted (outside of the construction sector in regions not hosting clusters, where the displacement effect manifests as a reduced positive impact).

## 4. Conclusions

The decarbonisation of UK industrial clusters via the development of CCUS networks and supply chains can support jobs and gross value-added (GVA) across multiple sectors of the economy. Moreover, the deployment of CCUS could have positive regional economic development outcomes in parts of the country where is needed, supporting the UK Government levelling up agenda (UK Government, 2022), and also delivering important co-benefits to the environment, air quality and helping to provide reliability and resilience to a decarbonised power sector (DESNZ, 2024; IEA, 2020).

However, worker and skills shortages have been identified as a common challenge across the UK clusters, as well as more generally in the net zero space and for the UK economy. Our analysis shows that these shortages, and the concurrent implementation of different net zero projects, may introduce congestion and wage cost pressures in the labour market. This could affect the deliverability of projects such as the $CO_2$ T&S networks considered here, and (differentially) impact the dynamic adjustment trajectories of the subsequent wider economic and net employment expansions. Crucially, our results demonstrate that net employment gains involve wage competition and price pressures that trigger jobs displacement across sectors and regions.

Five key messages emerge from our research, which have important implications for industry and policy stakeholders.

1. Likely transitory peaks in job creation in the UK construction sector, during the development of a new $CO_2$ Transport and Storage sector, need to be factored into CCUS deployment and broader net zero delivery planning.
2. Addressing worker and skills shortages can help mitigate the risk of job displacement across UK regions and sectors and ensure that the maximum potential positive economy-wide benefits of establishing a new $CO_2$ Transport and Storage sector are realised.
3. The simultaneous staged introduction of what are effectively four regional subsectors of a nascent UK T&S sector is likely to trigger congestion effects that exacerbate resource competition across all sectors and, thereby, constrain wider economy gains in the early stages, despite a slight boost in near term jobs gains.
4. While the congestion impact is limited here and eases over time (due to the relatively small supply-side shock generated by nascent T&S activity), that it occurs at all points to challenges for the wider net zero transition, which will involve many new (and in some cases significantly larger) infrastructure investment and nascent activities emerging in a constrained economic landscape.
5. Consistent assessments of employment requirements and economic impacts across the UK's CCUS cluster developments, coupled with scenario analyses to identify potential congestion effects emerging through the planned sequencing process, are necessary to inform action on addressing and mitigating labour shortages and other potential negative economic outcomes.

In terms of this fifth point, a limitation of, already published, (non-academic) work on the potential impacts of T&S systems on the regional and wider UK economies, is the significant variation on the approaches utilised. Here, a UKRI (2023) report that reviews the relevant analyses highlights the discrepancies in terms of the methodologies used, the types of jobs and timelines reported, as well as the limited detail on the location of expected impacts.

One aim of our research has been to begin to respond directly to these recommendations, utilising an already peer-reviewed economic modelling approach (Turner et al., 2024; Turner et al., 2023) that allows for a consistent individual cluster and aggregated economic and employment needs analysis for industrial decarbonisation activity for the cluster efforts. Crucially, the analyses presented here highlight the importance of getting an accurate picture of the labour requirements and the need to coordinate project delivery to limit the negative impacts of congestion, where the consequent boost to wider economy gains could help justify/compensate any costs of potential rescheduling to individual projects.

In terms of how the research presented here needs to develop, there are a range of applied issues, not least in terms of fuller and more accurate specification of scenarios around the industrial capture and T&S activity likely to be invested and emerge through Track 1 and 2 in the UK. This is not just in terms of the domestic 'own-cluster' facing element we have considered here, where there may be export opportunities involved with CCUS technologies development and wider (domestic and overseas) markets for T&S. There is also a need to revise and update our assumptions on emitters, level of emissions and timelines, as policy evolves (e.g. recent additional funding commitments to track 1, may change plans and timelines for track 2 clusters (HM Treasury, 2024)), and to move beyond our terminal date of 2035 as it becomes clearer exactly when the UK government aims to end the type of direct support reflected in our scenarios and move to the market-based approach clearly aimed for in the CCUS Vision (DESNZ, 2023b). How this later stage of fully operational nascent T&S activity develops will also depend on developments in the wider domestic and international policy and economic landscapes (e.g., around carbon pricing mechanisms).

However, even for the focus of analysis here, there is a need for more sophisticated approaches to determining regional economic impacts and implications, which may include (but are not limited to) development of interregional CGE modelling frameworks. Furthermore, more advanced and detailed approaches need to be developed to translate the economy-wide implications, reported by our CGE model or any other relevant modelling approach, onto regional impacts. Similar needs are likely to apply in other geographical contexts, where regional impacts may spread across borders, e.g., in the context of CCUS projects around the Port of Rotterdam, where capture industry activity may be in a different country (e.g., Germany) to storage destinations in the Dutch and/or Norwegian North Seas, implying international T&S networks. Moreover, these could ultimately compete with the nascent UK T&S sector, not least in terms of UK demand outside of the identified Track 1 and 2 clusters, but also in terms of how particularly the Track 2 Viking and Scottish T&S subsectors may look to expand to utilised greater potential storage capacity. Finally, the future operation of a T&S sector might differ significantly compared to what we assume in this paper. It is important then to revisit the analysis once more information become available on how T&S sectors might interact with the rest of the economy, for how long and whether it will pursue to transform T&S services to a primarily commercial, out-facing, activity.

## CRediT authorship contribution statement

**Christian Calvillo:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Antonios Katris:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Julia Race:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Hannah Corbett:** Writing – review & editing, Visualization, Validation, Project administration, Investigation, Data curation. **Karen Turner:** Writing – review & editing, Validation, Project administration, Methodology, Funding acquisition, Formal analysis,

Conceptualization.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Karen Turner reports financial support was provided by Industrial Decarbonisation Research Centre. Karen Turner reports financial support was provided by Innovate UK. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

This research was undertaken as part of the Industrial Decarbonisation Research Centre, IDRIC (EPSRC Grant Ref: EP/V027050/1) under one of the IDRIC Wave 2 Projects. We also acknowledge support from the UKRI (InnovateUK) through the 'ISCF Decarbonisation of Industrial Clusters Phase 2' initiative, under the project 'Scotland's Net Zero Infrastructure (SNZI) Onshore' (Grant ref.: 75989). For the purpose of Open Access, the authors have applied a CC licence to any Author Accepted Manuscript (AAM) version arising from this submission.

## Appendix A. Employment impacts regional mapping approach

Our regional mapping of employment impacts is based on primary and secondary data processing and analysis, where we map national level employment impacts generated by the CGE model (single region representing the whole UK) to different regions, using ONS available data 'Workforce jobs by region and industry' (ONS, 2022b), based on the following steps:

1. Aggregate economic sectors from CGE model to match ONS data sectors (See Table 4, below, for the detail on the sector aggregation and matching)
2. Calculate current proportion of jobs across industries and regions (from ONS data, 2022 values) – for example, the percentage of construction jobs in each region.
3. Map CGE employment impacts to the proportionate breakdowns calculated in (2), distributing employment changes across the different regions.
4. The exception is where certain activities linked to the deployment of T&S sector are likely to take place around the industrial clusters. Here, we focus on construction sector activity linked to the implementation of the T&S infrastructure, and the emerging $CO_2$ T&S sector itself, with construction sector employment linked to the operation and maintenance of the sector). To account for this, the distribution of employment changes on the construction and $CO_2$ T&S sectors emerging via step 3 is weighted across different regions as follows:
   - **Cluster and non-cluster weighting**. Although construction activity is likely to be concentrated on the clusters' regions, the growth in the sector is likely to also be experience in other regions, albeit at a smaller scale. The weighting on cluster and non-cluster is based on investment on the construction sector relative to total investment, see Table 5. Note that $CO_2$ T&S jobs are assumed to be directly linked to the cluster regions, as the operation and maintenance activity is likely to take place around the deployed infrastructure.
   - **Within cluster region weighting**. Some of the industrial clusters and the T&S infrastructure are located across regional borders. For example, the east coast cluster is located across the North East and Yorkshire and The Humber regions. We distributed the within cluster employment changes for the construction and $CO_2$ T&S sectors based on the assumed length of onshore and offshore pipeline network required, as described in Table 6. The pipeline network is assumed following the methodology developed in (Calvillo et al., 2022).

**Table 4**
Sectoral aggregation and mapping between CGE model and ONS workforce data sectors.

| CGE sectors | Sector aggregation on workforce data (ONS, 2022b) | SIC 2007 section |
|---|---|---|
| S1 | Agriculture, forestry & fishing | A |
| S2 – S3 | Mining & quarrying | B |
| S4 | $CO_2$ T&S | (new added sector) |
| S5 - S17 | Manufacturing | C |
| S18,S19 | Electricity, gas, steam & air conditioning supply | D |
| S20,S21 | Water supply, sewerage, waste & remediation activities | E |
| S22 | Construction | F |
| S23 | Wholesale & retail trade; repair of motor vehicles and motorcycles | G |
| S24, S25, S26 | Transport & storage | H |
| S27 | Accommodation & food service activities | I |
| S28 | Information & communication | J |
| S29 | Financial & insurance activities | K |
| S30, S31 | Real estate activities | L |
| | Professional scientific & technical activities | M |
| | Administrative & support service activities | N |
| S32 | Public admin & defence; compulsory social security | O |
| | Education | P |
| S33 | Human health & social work activities | Q |
| S34 | Arts, entertainment & recreation | R |
| | Other service activities | S |
| | People employed by households, etc | T |

**Table 5**
Cluster/non-cluster weighting parameters for construction sector employment changes.

| Cluster weighting | | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2035 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| East coast | cluster | 100.0 % | 75.1 % | 74.7 % | 77.4 % | 48.2 % | 56.2 % | 62.0 % | 65.8 % | 70.5 % | 70.4 % | 70.3 % |
| | non-cluster | 0.0 % | 24.9 % | 25.3 % | 22.6 % | 51.8 % | 43.8 % | 38.0 % | 34.2 % | 29.5 % | 29.6 % | 29.7 % |
| North West | cluster | 100.0 % | 90.0 % | 84.3 % | 83.9 % | 49.9 % | 56.8 % | 61.8 % | 65.1 % | 70.0 % | 70.3 % | 70.2 % |
| | non-cluster | 0.0 % | 10.0 % | 15.7 % | 16.1 % | 50.1 % | 43.2 % | 38.2 % | 34.9 % | 30.0 % | 29.7 % | 29.8 % |
| Scottish cluster | cluster | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 100.0 % | 85.8 % | 81.3 % | 44.1 % | 68.7 % | 70.5 % | 70.3 % |
| | non-cluster | 100.0 % | 100.0 % | 100.0 % | 100.0 % | 0.0 % | 14.2 % | 18.7 % | 55.9 % | 31.3 % | 29.5 % | 29.7 % |
| Viking | cluster | 0.0 % | 0.0 % | 0.0 % | 0.0 % | 100.0 % | 83.3 % | 79.6 % | 43.5 % | 68.8 % | 70.6 % | 70.3 % |
| | non-cluster | 100.0 % | 100.0 % | 100.0 % | 100.0 % | 0.0 % | 16.7 % | 20.4 % | 56.5 % | 31.2 % | 29.4 % | 29.7 % |
| UK Wide | cluster | 100.0 % | 68.4 % | 70.6 % | 75.2 % | 75.9 % | 78.7 % | 80.3 % | 57.2 % | 69.5 % | 70.3 % | 70.3 % |
| | non-cluster | 0.0 % | 31.6 % | 29.4 % | 24.8 % | 24.1 % | 21.3 % | 19.7 % | 42.8 % | 30.5 % | 29.7 % | 29.7 % |

**Table 6**
Assumed $CO_2$ T&S pipeline network length (in km).

| Region | East coast | North West | Scottish cluster | Viking | UK wide Track 1 | UK wide Track 2 |
|---|---|---|---|---|---|---|
| North East | 217.9 | 0 | 0 | 0 | 217.9 | 0 |
| North West | 0 | 209 | 0 | 0 | 209 | 0 |
| Yorkshire and The Humber | 215.8 | 0 | 0 | 108 | 215.8 | 108 |
| East Midlands | 0 | 0 | 0 | 118 | 0 | 118 |
| West Midlands | 0 | 0 | 0 | 0 | 0 | 0 |
| East of England | 0 | 0 | 0 | 0 | 0 | 0 |
| London | 0 | 0 | 0 | 0 | 0 | 0 |
| South East | 0 | 0 | 0 | 0 | 0 | 0 |
| South West | 0 | 0 | 0 | 0 | 0 | 0 |
| Wales | 0 | 0 | 0 | 0 | 0 | 0 |
| Scotland | 0 | 0 | 292.8 | 0 | 0 | 292.8 |
| *Total* | *433.7* | *209* | *292.8* | *226* | *642.7* | *518.8* |

## Appendix B. The sectors in the UKENVI CGE model

**Table 7**
Sector aggregation in CGE model and link to SIC2007 codes.

| Sector Number | Sector Name | SIC code |
|---|---|---|
| S1 | Agriculture, Forestry and Fishing | 01–03 |
| S2 | Coal, Mining and Quarrying | 05 & 08–09 |
| S3 | Crude Oil and Gas | 06–07 |
| S4 | $CO_2$ Transport & Storage | new sector |
| S5 | Food, Drinks and Tobacco | 10–12 |
| S6 | Textile, Leather and Wood | 13–16 |
| S7 | Paper and Printing | 17–18 |
| S8 | Coke and Refined Petroleum Products | 19 |
| S9 | Chemicals | 20 |
| S10 | Pharmaceuticals | 21 |
| S11 | Rubber and Plastic | 22 |
| S12 | Cement, Lime and Glass | 23 |
| S13 | Iron, Steel and Metal | 24 & 25.4 |
| S14 | Manufacture of Fabricated Metal Products, excluding weapons & ammunition | 25.1–3 & 25.5–9 |
| S15 | Electrical Manufacturing | 26–28 |
| S16 | Manufacture Of Motor Vehicles, Trailers And Semi-Trailers | 29 |
| S17 | Transport Equipment l and Other Manufacturing (incl Repair) | 30–33 |
| S18 | Electricity | 35.1 |
| S19 | Gas Distribution | 35.2–3 |
| S20 | Natural Water Treatment and Supply Services | 36 |
| S21 | Waste Management and remediation | 37–39 |
| S22 | Construction - Buildings | 41–43 |
| S23 | Wholesale and Retail Trade | 45–47 |
| S24 | Land Transport | 49 |
| S25 | Other transport | 50–51 |
| S26 | Transport support | 52–53 |
| S27 | Accommodation and Food Service Activities | 55–56 |
| S28 | Communication | 58–63 |
| S29 | Financial and Insurance Services | 64–66 |
| S30 | Architectural Services | 71 |
| S31 | Services | 68–70 & 72–82 |
| S32 | Public administration, Education and Defence | 84–85 |

(*continued on next page*)

**Table 7** (*continued*)

| Sector Number | Sector Name | SIC code |
|---|---|---|
| S33 | Health and Social Work | 86–88 |
| S34 | Recreational and other private services | 90–98 |

## Data availability

Data will be made available on request.

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