

MOVING EARLY IN

CARBON CAPTURE & STORAGE

Opportunities and challenges
for delivering 'green growth'
and 'just transitions'



Corradenkoff

FOREWORD



The world is facing a climate emergency. With time running out to mitigate the worst effects of climate change, it is clear that decisive action cannot be delayed. Some countries, like the UK, are setting out plans to meet net zero emissions by the mid-century and have put targets in statute. With ambition laid down in law, attention must turn to delivery and how to manage the transition in a sustainable and equitable way, with the need to focus on ensuring prosperity and a 'just transition' for all citizens.

At the Centre for Energy Policy (CEP), we recognise that meeting net zero ambitions really is a public policy challenge. Although some tests do remain in scaling up new low carbon technologies and infrastructure, the real challenge lies in designing a framework for delivery that is holistic and robust in an ever changing political environment.

Knowing that urgent action must be taken to reduce emissions, this report seeks to identify the opportunities and challenges of delivering new large scale infrastructure, taking the example of carbon capture and storage in an industrial setting. We consider economic opportunities that do not rely on intangible or far stretching assumptions, instead focussing on fundamental assumptions that we consider feasible and key in determining outcomes. Where our robust wider economy modelling highlights very real economic challenges, such as tensions between 'green growth' and regional 'levelling up' agendas, we suggest actions that could be taken by policymakers to mitigate unfavourable outcomes. Our report also underlines the importance of understanding 'who *really* pays, how and when' – taking account of how costs are ultimately passed on and transmitted to

different regions, sectors, and actors in different economic settings – and highlights real implications for delivering 'just transition' and regional levelling up agendas across a range of net zero activities.

Using the expertise we have gained in undertaking the economy-wide scenario simulation work that underlies the research presented in this report, and in focussing on understanding the causal processes determining impacts on key metrics such as GDP, productivity, employment, and real wages, we will continue our engagement with Government departments tasked with the challenge of delivering public policy to meet net zero emissions in a political economy setting. We also hope that the results and findings can be used to inform decision makers around the world charged with decarbonising a range of sectors.

Ultimately, we hope our research and associated report will support an equitable and sustainable transition to a prosperous net zero economy.

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EXECUTIVE SUMMARY

The decarbonisation of industry in the UK and around the world is a key component of meeting essential mid-century net zero targets. However, implementing the transformative processes required to achieve net zero economies and industries therein will be all the more challenging if the transition delivers outcomes that do not involve continued and growing economic prosperity in ways that are regarded as 'just' by citizens, communities, workforces, and businesses. Avoiding 'carbon poverty' challenges arising through new price pressures in a transitioning economy, generating new and sustainable economic opportunities, and safeguarding or improving employment and worker conditions will be critical.

Delivering a 'just transition' requires a new understanding of the relationship between the public and private sector, potentially shifting existing norms and paradigms in each respective role. For example, Governments may intervene in new ways to support emitting industries to decarbonise domestically. While these evolutions will have to take place primarily within nations, they will not happen in isolation. International shifts toward ever increasing cost pressures on polluting emissions are already underway¹, affecting trade patterns and the commerciality of existing production chains, along with associated jobs.

To successfully implement transformative processes that deliver new infrastructures for climate-improving technologies such as carbon capture and storage (CCS), and to create a competitive and viable operating environment for using those technologies, we need a better understanding of the consequences that different policy choices can have for the wider economy. How we decide to answer the question of 'Who pays?' ultimately effects 'Who benefits?'. The scale of a project, the evolution of a future market for new 'green' products and services, how consumer prices will be impacted by a combination of



decarbonisation costs and expansionary pressures, as well as domestic labour market conditions and international trade dynamics, are all factors that can decide over the actual costs and the rewards of the green transition.

Report rationale

In this report, we explore the key findings from important new research undertaken by CEP. The analysis examines the wider economy effects of differing types of policy choices and economic conditions for the delivery of industrial carbon capture and the transport and storage sector needed to service it (CCS). We use the UK as an example but draw important lessons for other nations where carbon capture and/or provision of CO₂ transport and storage services may be considered as decarbonisation and/or industrial transition solutions. Considering a broad range of scenarios, our analysis provides useful insight into the trade-offs and consequences of different broad policy approaches and allows exploration of potential impacts on the wider economy and specific sectors therein of introducing CCS solutions. Importantly our findings are framed around the context of

‘green growth’, delivering a ‘just transition’ and the challenges of ensuring regions where emitting activities are currently located are not disadvantaged by the introduction of decarbonisation solutions.

We focus on CCS in the specific context and challenge of industrial decarbonisation, where delivering a genuine transition to a net zero economy requires ensuring that the products that societies continue to need are themselves produced in clean and low emission, but ultimately still affordable ways. Crucially, an inability to decarbonise base industry sectors in their current locations brings the risk of simply shifting the location of global production and emissions, and offshoring jobs and investment.

This report seeks to set out not just the potential wider economy benefits of CCS, but also the risks and tensions associated with delivery of climate technologies and related infrastructure. Crucially we focus our scenario simulation analyses on the impacts of introducing CO₂ transport and storage and/or carbon capture in isolation and, thus, abstract from a multitude of other changes that may occur throughout the transition period modelled. This enables us to identify key drivers of the impacts emerging and the nature of the trade-offs associated with specific actions but also to allow important lessons to emerge for other net zero actions that share characteristics, such as in terms of how investment in infrastructure may need to be front-loaded and/or where adopting a solution may have implications for the efficiency of production processes.



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KEY FINDINGS:

CARBON CAPTURE AND STORAGE, 'GREEN GROWTH' AND 'JUST TRANSITIONS'

KEY FINDING 01

CCS as a source of 'green growth'

Deployment of CCS could lead to 'green growth' where it involves introduction of new industry activity to the economy.

Countries like the UK, Norway and the Netherlands, have significant offshore CO₂ storage capacity and linked onshore supply chain expertise, a legacy of oil and gas (O&G) industries that can be leveraged to provide new 'green growth' opportunities. The most obvious opportunity lies in new industry activity that supplies 'CO₂ transport and storage services' (T&S) to domestic or overseas firms that need to capture CO₂. **Repurposing existing supply chain capacity and providing continued or new job opportunities for workers currently employed in the O&G industry supply chains would**

also aid delivery of a 'just transition' for workers, households and communities currently dependent on the O&G industry.

We estimate that inducing the necessary upfront investment to develop and maintain initially oversized UK T&S infrastructure, needed to transport and store emissions from four of the nation's main regional industrial clusters stands in the order of £2.8 billion and requires that demand can be guaranteed for T&S output in the order of £2.2 billion per annum.

If this is forthcoming without sacrificing consumption elsewhere in the UK economy – for example

if government can guarantee the associated demand through deficit financing, and/or if an export base emerges for selling T&S services internationally – there is potential for net positive economic expansion. **The resulting 'green growth' could be associated with an additional £1.7 billion GDP per annum and up to 17,000 new full-time equivalent (FTE) additional UK jobs, including 5,630 T&S industry jobs, implying a multiplier of around three UK jobs per direct T&S industry job.**

However, achieving such gains requires that workers are appropriately trained to move into/between sectors and that firms currently associated with the O&G industry and supply chain are able and willing to transition their activity as required.

KEY FINDING 02

Implications of households paying for CO₂ transport and storage

'Green growth' outcomes will be eroded, and new challenges will emerge for the 'just transition', if action to support the T&S industry requires taxing households or emitting industries to pay from the outset.

In our UK case, if government cannot or chooses not to run an ongoing deficit to support the rollout of T&S, one option may be to 'socialise' the costs by passing the annual £2.2 billion burden to UK households. The key implication if UK households have to meet the costs of supporting the new T&S industry is a reduction in real disposable incomes available

for spending in other sectors of the economy. Particularly given how labour-intensive many of the service industries where people do much of their spending are, our findings suggest that the 5,630 direct jobs gain within T&S will be more than offset by losses in other sectors. Here the total net UK employment gain could fall from almost 17,037 to 3,464 by 2040.

We note that we examine the impacts of introducing T&S cost in isolation, abstracting from any potential increase in carbon prices that would otherwise affect wider decarbonisation costs falling on firms, households and/or the public purse. However, the key point is that **requiring households to pay clearly has implications for the justness of the transition, particularly for people whose incomes are dependent on service sector activities, which often involves those already on lower incomes.**



KEY FINDING 03

The risks of adopting an 'industry pays' approach

An 'industry pays' approach could lead to unanticipated negative economic outcomes for all but a few sectors, particularly those regions and communities most closely linked to the emitting industries.

Where the costs of operating the new T&S industry are passed to the emitting industries in the industrial clusters in our UK scenarios, the outcome becomes entirely negative for all but a few sectors of the national economy, particularly those located in and around the regional clusters. While activity directly associated with the T&S industry will be safeguarded,

the 'industry pays' approach risks the sustainability of the industry cluster activity that policy action aims to sustain within the UK regions. We find that the precise extent of negative implications to cluster industries from paying for T&S depends on the international market response to consequent rises in the prices of outputs produced by the cluster

industries. However, for our central case scenario, if potential capture industries are to cover the costs of supporting the roll-out of the T&S sector, **the net per annum impact on GDP is an estimated contraction of almost £1 billion. Almost 15,000 UK jobs could be lost by 2040**, with these spread across both the cluster industries themselves and those service sector industries where now unemployed workers formerly spent much of their disposable incomes. The 'just transition' challenges of such an outcome are exacerbated by the **tension with the UK Government's regional 'levelling up' agenda: where cluster job losses are suffered largely by people living in the cluster regions, the consequent impacts on activity and jobs in service industries are likely also to be concentrated in host regions.**

EXECUTIVE SUMMARY CONTINUED

KEY FINDING 04

Carbon capture and the competitiveness challenge

Operational carbon capture can reduce the capital efficiency of industrial firms with implications for returns on capital at the current production location.

In our central case scenario, we consider the impacts of introducing *carbon capture in the UK Chemicals industry – associated with capturing just over 5.8Mt or 30% of the 20Mt total that the new T&S industry is developed to service*. Again, we find that the magnitude of impacts depend on just how sensitive international trading conditions are to price changes associated with adopting carbon capture (with no other change in decarbonisation costs incurred), which involves using more operational capital/equipment to produce any given level of output. However,

in our central scenario the loss in competitiveness due to this capital efficiency loss alone **triggers a wider economy contraction associated with per annum GDP losses of around £2billion by 2040. This is accompanied by a net loss of 14,166 UK jobs, including 4,340 in the Chemicals industry. Thus, there is a risk that making industry pay for carbon capture will lead to an offshoring of Chemicals industry jobs and investment, along with the emissions that were formerly generated in the UK sector.**

Such outcomes are clearly not consistent with either the

spirit of international climate change ambitions, or with a 'just transition' in the UK. They also bring challenges for the UK Government's 'levelling up' agenda. **The regional 'levelling up' challenge is made more acute given that the almost 10,000 indirect/secondary job losses may also be quite heavily concentrated in the regional economies that host the industry clusters that UK CCS deployment focuses on sustaining.** Thus, there is an acute public policy need to consider how international market conditions may change for capture firms, and in particular focus on how any **timeframe for public support may be used to deliver better outcomes for industries, and for the wider regional and national economies.**

FUNDAMENTAL LESSONS FOR NET ZERO TRANSITIONS

Three key messages that emerge from our analysis of the economy-wide impacts of CCS as an industrial decarbonisation solution are essentially generic ones that will apply across the net zero domain and persist in more complex scenarios where a fuller range of policy actions and changes in economic conditions apply.



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LESSON 01

- Reducing carbon emissions to meet net zero targets will inevitably involve increased costs (here associated with capturing, transporting and storing CO₂) that will feed through to consumer prices and risk losses in GDP. Where one nation moves first in incurring and reflecting these costs in prices, it will lose competitive advantage in international markets in the near-term. However, a leading nation could potentially win this back through technological progress and efficiency gains over time.

KEY FINDING 05

Using policy support effectively for a 'just transition'

The timeframes where public support is provided can be used to deliver CCS in ways that better align with 'just transition' and 'levelling up' agendas.

Better outcomes emerge where international competitors follow in adopting carbon capture and face the associated (capital efficiency driven) costs. In our UK scenarios, this allows competitiveness driven losses to be eradicated to the extent that no UK 'Chemicals' job losses occur. However, there are still some slight negative impacts on the industry and wider economy, linked to pressures on the Consumer Price Index (CPI) of carbon costs being more fully reflected in commodity and product prices.

However, the real key to improving the mid-term

situation is increasing efficiency in operational CCS.

For first movers, this involves developing competitive advantage either through 'learning-by-doing' and/or further technical progress. In our scenarios focusing on carbon capture, we find that UK 'Chemicals' could ultimately enjoy net growth in its activity, employment and contribution to value-added if UK firms are more efficient than competitors who are later adopters of carbon capture. In particular, the industry would take on rather than lay off workers by 2040, with the offshoring

process effectively reversed, as reflected in our results where **UK 'Chemicals' industry exports rise by 5%** (£667million) **while imports of chemicals to the UK fall by 4.5%** (£296million).

Thus, policy support for CCS-related activities should be justified not only by sustaining economic activity through the net zero transition, but by using timeframes of support wisely to enable efficiency gains and, thereby, generate new future sources of value and jobs, with focus on enabling a 'just transition' for people in all regions.

LESSON 02

- Green growth' opportunities arising from opportunities to develop a new CO₂ transport and storage industry or building strong domestic supply chains servicing low carbon solutions – **could help offset cost-driven employment and other economic losses associated with decarbonisation costs.** However, like any form of economic expansion, 'green growth' in an economy characterised by constraints on labour supply and/or other 'factors of production', this is likely to involve consumer price pressures that can only be effectively and sustainably alleviated through productivity gains in supply and/or mitigated through increased efficiency in use.

LESSON 03

- Potential tensions between decarbonisation, 'green growth' and regional 'levelling up' agendas exist, where, depending on the policy approach and funding model adopted, the costs of delivering any one solution (here, CCS to decarbonise regional industry clusters) may be borne disproportionately by firms, workers and households in particular geographical regions within any one nation.

CCS IN EUROPE

Across Europe, CCS has been identified as an important tool to reduce emissions from process industries, such as cement, chemicals and steel. The UK Climate Change Committee (CCC) states that “CCS is required to deal with process emissions in industry and enables at-scale active removal of CO₂ from the air [...], a necessary feature of most pathways that reach global Net Zero CO₂ emissions”² In addition to the EU regulatory framework of the 2009 CO₂ Storage Directive and financial support through the Innovation Fund, several non-EU countries have also implemented, or are in the process of implementing, national CCS targets and policy support. Crucially, different countries will have varying degrees of opportunity to provide CO₂ T&S services and capacity domestically, with some having greater need to capture CO₂ from industrial process (and/or power generation) but rely on others to complete the CCS nexus (and vice versa).

FIGURE 01

MAJOR UK INDUSTRY CLUSTERS

% of emissions by sector, for each cluster

- Cement
- Iron & Steel
- Chemicals
- Refining
- Other

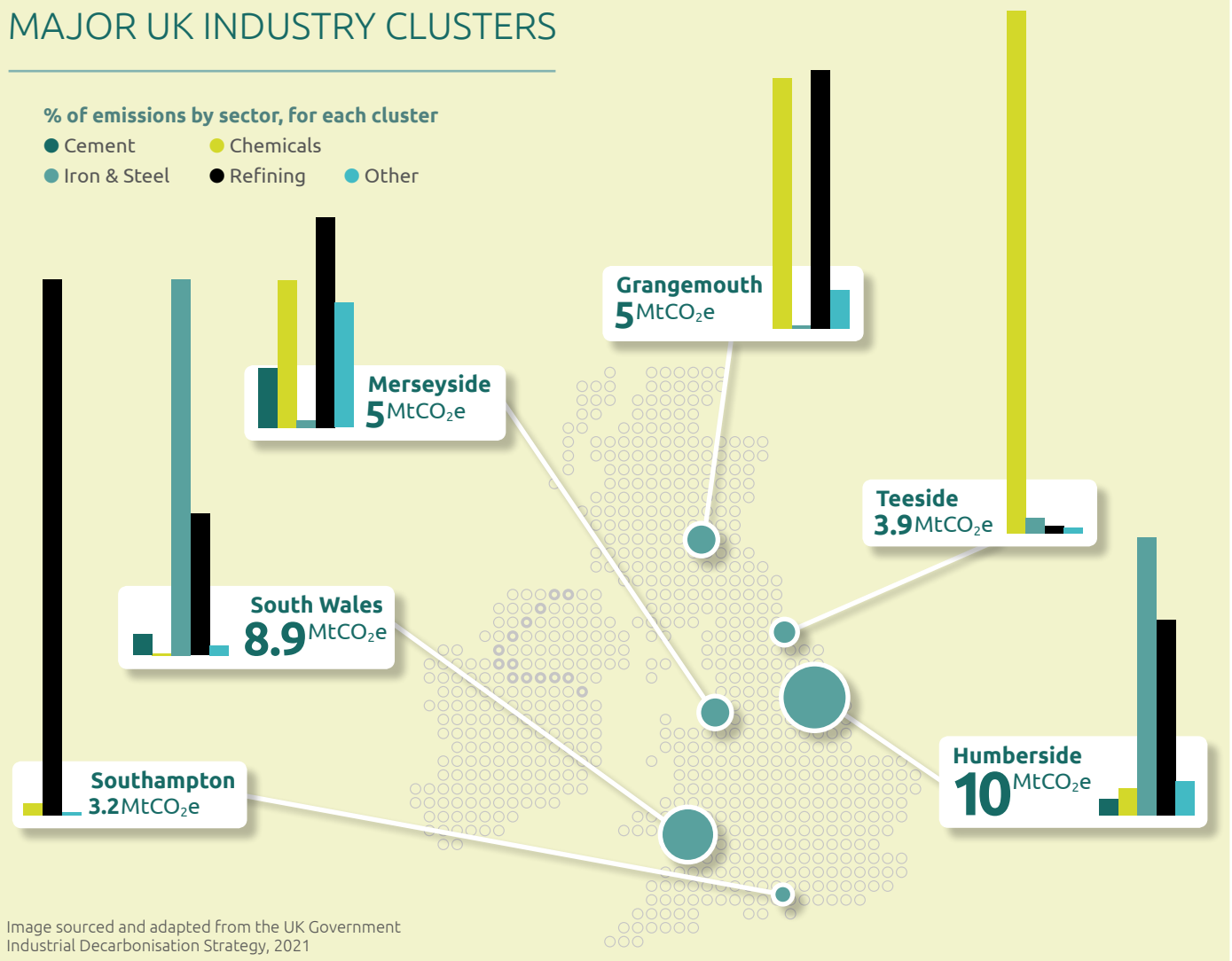


Image sourced and adapted from the UK Government Industrial Decarbonisation Strategy, 2021

Norway

With a 98% CO₂-free electricity generation and the highest global share of electric vehicles, Norway's biggest challenge is tackling emissions that cannot be reduced through electrification. The Norwegian full-scale CCS project, named 'Longship', supports the development of an open CO₂ T&S infrastructure that is connected to the Norcem Cement Plant on Norway's southern coast and Fortum's Waste to Energy Plant outside Oslo⁵. The transport and storage part of the project, Northern Lights, is a listed European Project of Common Interest (PCI) and open to receive CO₂ from source points outside Norway. To this end, the initial capacity is built for 1.5MtCO₂/year, about double the expected CO₂ from the initial two Norwegian capture projects. The provision of a CCS service to Europe, utilising Norway's vast geologic storage resources, is both a main motivator for the Norwegian government to launch 'Longship' and the key innovation of the project – see **Figure 02**.

Total expected capital costs for the project are NOK17billion (~£1.4billion/€1.5billion). The Norwegian Government will pay around three quarters of the total costs of the Northern Lights and Norcem parts of the project for the first 10 years. Many of project risks are also largely absorbed by the state, including risks of delay, cost over-run and leakage. Potential profits of Northern Lights after future expansion will partly be returned to the state. Other than the indirect holding via Equinor the state has no share-holding in the project. The project received State Aid clearance under European Economic Area (EEA) rules in July 2020.

The UK

The UK government has committed to capture 10Mt of CO₂ a year by 2030³, of which at least 3MtCO₂/year are to come from industrial sources.⁴ To this end, the UK government is directly investing £1billion up to 2025 to facilitate CCS deployment in at least four industrial clusters by 2030. Composition of process industries in need of CCS differs across regional clusters, with current Government estimates of the regional breakdown of all emissions (CO₂ equivalent) illustrated in **Figure 01**.

The UK Government is due to finalise its revenue mechanism to enable private sector investments in 2022. Current plans foresee Contracts for Difference (CfD) that provide payment per tonne of captured CO₂ to cover operational expenses, transport and storage fees, and a return on investment in carbon capture equipment. Free allowances for industrial emitters under the UK Emission Trading Scheme (UK ETS) are forfeited in proportion to capture volumes, but emitters are to receive compensation for this. A grant co-funding a portion of the capital costs of initial projects is intended to mitigate against risks. The government is currently evaluating the design and powers of a dedicated economic regulator for the delivery and operation of a CO₂ transport and storage infrastructure.

FIGURE 02

INDUSTRIAL DECARBONISATION – CO₂ STORAGE FOR EUROPE

Norwegian full-scale CCS (Longship project)



CO₂ capture from industrial plants, compressed & temporarily stored

Northern Lights project

Transport

compressed CO₂ transported by ship

Third party volumes



CO₂ from other emitters transported by ship

Onshore terminal



CO₂ received and temporarily stored, before exported via pipeline, to be stored in reservoir (approx. 3,000M below sea level)

Permanent offshore storage

100KM

2,600M

Image sourced and adapted from the Northern Lights CCS Longship Project

³ <https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution>

⁴ <https://www.gov.uk/government/publications/industrial-decarbonisation-strategy>

⁵ More information on Norway's Longship project design is available here: <https://bellona.org/publication/briefing-norways-longship-ccs-project>

Netherlands

Dutch 2030 targets require an annual reduction of 14 MtCO₂ from industry. CCS support exists for half of these emissions⁶. The 2019 Climate Agreement implemented two complementary measures:

- a feed-in contractual subsidy mechanism under the SDE ++ scheme rewards the most cost-efficient CO₂ reductions in industry. The system works like a CfD and covers the uncommercial part of investing and operating CCS on industrial plants
- a carbon tax, increasing gradually over the next decade and reaching at least €125/tonne(t)CO₂ by 2030.

The SDE framework has an embedded lowest-cost and market-based approach by holding auctions in which projects bid to offer. As part of a general climate action policy, CCS directly competes with other decarbonisation options. Free allowances under the EU ETS are retained by all emitters covered by the ETS. The carbon tax acts effectively as a floor price under the EU ETS, by topping up the allowance price when it is below the level of the tax. Through so-called dispensation rights, which exempt emitters from paying the tax for a gradually reducing share of emissions, industrial sites have something of a 'grace period' until the middle of the decade before the tax begins affecting them.

A new Dimension of European Climate Cooperation

Of course, other nations may adopt CCS solutions even where CO₂ storage capacity is not present domestically. In the absence of CCS or other deep decarbonisation solutions, industrial regions and supply chains across Europe risk rising investment uncertainty and offshoring risks as climate pressures mount.

European countries that require carbon capture and could benefit from integrating with cross-border T&S systems in the North Sea include major industry regions in Germany, France, Belgium, and Poland. Developing cross-border CCS systems as a strategic option for GHG mitigation will ultimately involve stimulating cooperation across countries, supporting development and provision of infrastructure and reducing the level of risk for firms that need and want to act to reduce emissions at their current locations.



Romanziariets

APPROACH AND RATIONALE

A key first step to enabling CCS development in the UK, Europe and beyond is to understand the ways in which engaging in CCS activity may impact at sectoral and economy-wide levels within nations. The aim of this report is to provide initial insight to inform this challenge, drawing on novel wider economy scenario simulations⁷ for the case of the UK, to draw generic lessons on the types of impacts and drivers of wider economy outcomes that may emerge from introducing carbon capture and/or T&S capacity and operability to the economic system.

We set the introduction of CO₂ T&S in the context of a new industry (initially servicing the transport and storage of CO₂ from four UK industry clusters) and consider carbon capture in an existing industry setting (here taking the example of the wider UK Chemicals industry). In either case, these are modelled as shocks to the UK economy, with the scenario simulation analyses focussing on exploring how different public funding mechanisms (involving government running a deficit or recovering costs from households or emitting industries) impact key indicators of policy interest, such as GDP, employment, the consumer price index (CPI), household spending and impacts (including exports and imports) across different sectors (and commodities/goods/services produced) on a dynamic year-by-year basis.

Crucially, we focus our scenario simulation analyses on the impacts of introducing CO₂ T&S or carbon capture in isolation. This is motivated by the need to: (a) understand the differential impacts of each; (b) abstract from a multitude of other changes that may occur throughout the transition period modelled, complicating outcomes without changing the underlying drivers of impacts. That is, our approach enables us to identify the causality and key drivers of the impacts emerging, along with the nature of the trade-offs associated with specific actions. Crucially, it also allows important lessons to emerge for other net zero actions that share central characteristics, such as where investment in infrastructure may need to be front-loaded and/or where adopting a solution may have implications for the efficiency of production processes.

Moving forward, other factors that could ultimately impact the economic outcome of introducing CCS in the UK, such as the introduction of a carbon price or the export of CCS services to other countries can be explored through layering further scenarios and assumptions into our simulations as and when appropriate data and clarity on potential deployment pathways emerge.



⁷ Details on modelling assumptions and scenario design used in the analyses are provided in Appendix of this report

CCS AS A SOURCE OF GREEN GROWTH

KEY FINDING 01

Deployment of CCS could lead to 'green growth' where it involves introduction of new industry activity to the economy

Countries like the UK, Norway and, to some extent, the Netherlands, have significant offshore CO₂ storage capacity and linked onshore supply chains and expertise. This is a legacy of O&G industries. In leveraging this expertise, the most obvious source of new 'green growth' for such countries is in establishing a new sector that supplies 'CO₂ T&S services' to domestic or overseas firms that need to capture CO₂.

In repurposing existing supply chain capacity and providing continued or new job opportunities for workers currently employed in the O&G industry and/or its supply chains, efforts to promote such 'green growth' could also help to meet 'just transition' ambitions, not least in terms of those communities and sectors currently heavily dependent on O&G industry activity.

Simulating the wider economy impacts of introducing a T&S sector to the UK economy

In the UK case, we considered the roll-out of a CO₂ T&S industry needed to facilitate the decarbonisation of the UK's four largest domestic industrial clusters (Grangemouth in Scotland, Merseyside in North West England and Teesside and Humberside in North East England). Capturing industrial emissions across these four industrial sites equates to capturing, transporting and storing almost 20Mt of CO₂ per year. Recognising that different industrial actors within clusters may connect and utilise T&S infrastructure at different times, this build-out initially leads to an 'oversized' T&S industry, potentially motivated by the linked issues of economies of scale in what is relatively indivisible infrastructure, and to build supplier and user confidence as costs reduce. Note that we focus here on isolating and analysing the impacts of introducing such T&S capacity, assuming that nothing else changes in the wider economic or decarbonisation landscape. We also make an important initial benchmarking assumption that the T&S industry shares the supply chain structure of the existing O&G industry.

Inducing the required investment to develop and maintain this initially oversized T&S infrastructure into the economy (estimated in the region of £2.8billion upfront and £0.35billion per annum thereafter) requires that demand can be guaranteed for T&S output in the order of £2.2billion per annum (values are in the 2016 prices of our simulation model).

UNDERSTANDING IMPACTS OF LABOUR MARKET CONSTRAINTS

Current issues associated with a shortage of workers in the UK labour market have reinforced the detrimental impact that 'constrained' labour markets can have on the economy. Using our economy wide scenario simulation model, we find that estimated employment and subsequently wider economy gains could be substantially higher if an assumption is made that the shortage of workers in the economy as a whole does not lead to wage pressures when a new industry like T&S is introduced and requires a workforce. While changing the scenario assumptions in this regard would not change the number of people employed directly in the new sector, it means that UK workers have much less or even no ability to negotiate higher wages when employer demand for labour rises and/or becomes more competitive across sectors. An absence of wage pressure across the economy would ultimately mean that the introduction of the new sector would have less of an effect on prices throughout the system even where the absolute size of the UK labour force is fixed with only a small pool of unemployed workers. The key implication being that the resulting wider economy expansion could be greater and more in line with what simple economic 'multiplier' metrics may predict.

If this is forthcoming without sacrificing consumption elsewhere in the UK economy, for example if government can guarantee the associated demand through deficit financing, and/or if an export base emerges, our scenario simulations suggest that **the resulting 'green growth' could be associated with an additional £1.7billion GDP per annum and up to 17,000 new full-time equivalent (FTE) additional UK jobs (including 5,630 within the new industry, implying a multiplier of around three UK jobs per direct T&S industry job).**⁸ This net employment gain is delivered even in the presence of an overall UK labour supply constraint, given a pool of unemployed labour, but does have consequent impacts on wage rates.

Moreover, achieving such gains requires that workers are appropriately trained to move into/between sectors and that firms currently associated with the O&G industry and supply chain are able and willing to transition their activity as required – see **Understanding Impacts** box, above right. Such 'green growth' outcomes are associated with **increased UK productivity (GDP per worker)**, mainly due to the T&S supply chain being relatively capital rather than labour intensive, reduced unemployment and higher household spending.

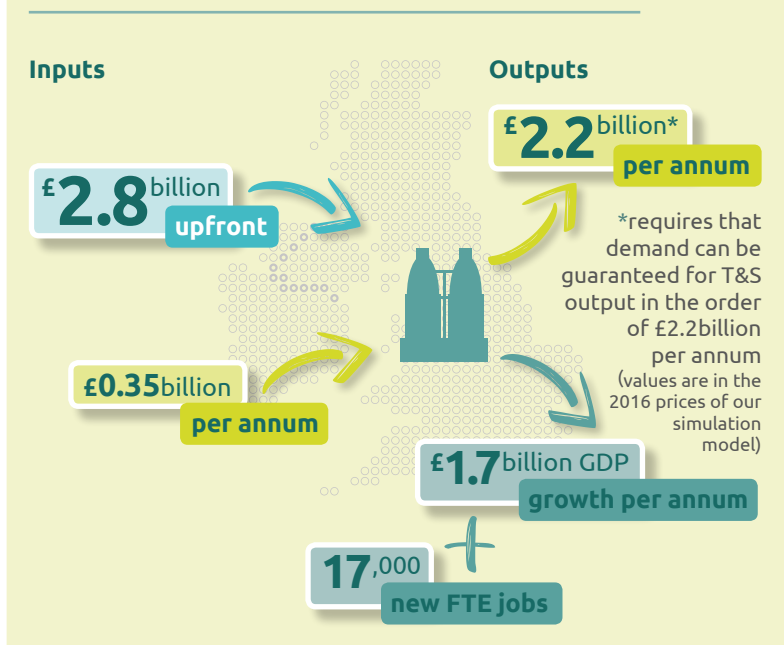
However, due to wage

pressures, a slight increase in the consumer price index (CPI) and **a slight contraction in exports from, and activity levels in, some other UK industries emerges, both of which could be challenging in broader 'just transition' concerns**

(i.e. in terms of the wider cost of living and jobs/income generation in other industries). On the other hand, with the expanding economy generating additional tax revenues, the net impact on the government deficit is reduced to £1.6billion, rather than the full £2.2billion required to guarantee demand for T&S output. This reflects the fact that the more 'green growth' opportunities can be effectively and efficiently exploited, returns to the public purse could potentially help balance the distribution of gains and losses.

FIGURE 03

UK T&S INVESTMENT & REWARD



⁸ For modelling set up and assumptions see Appendix

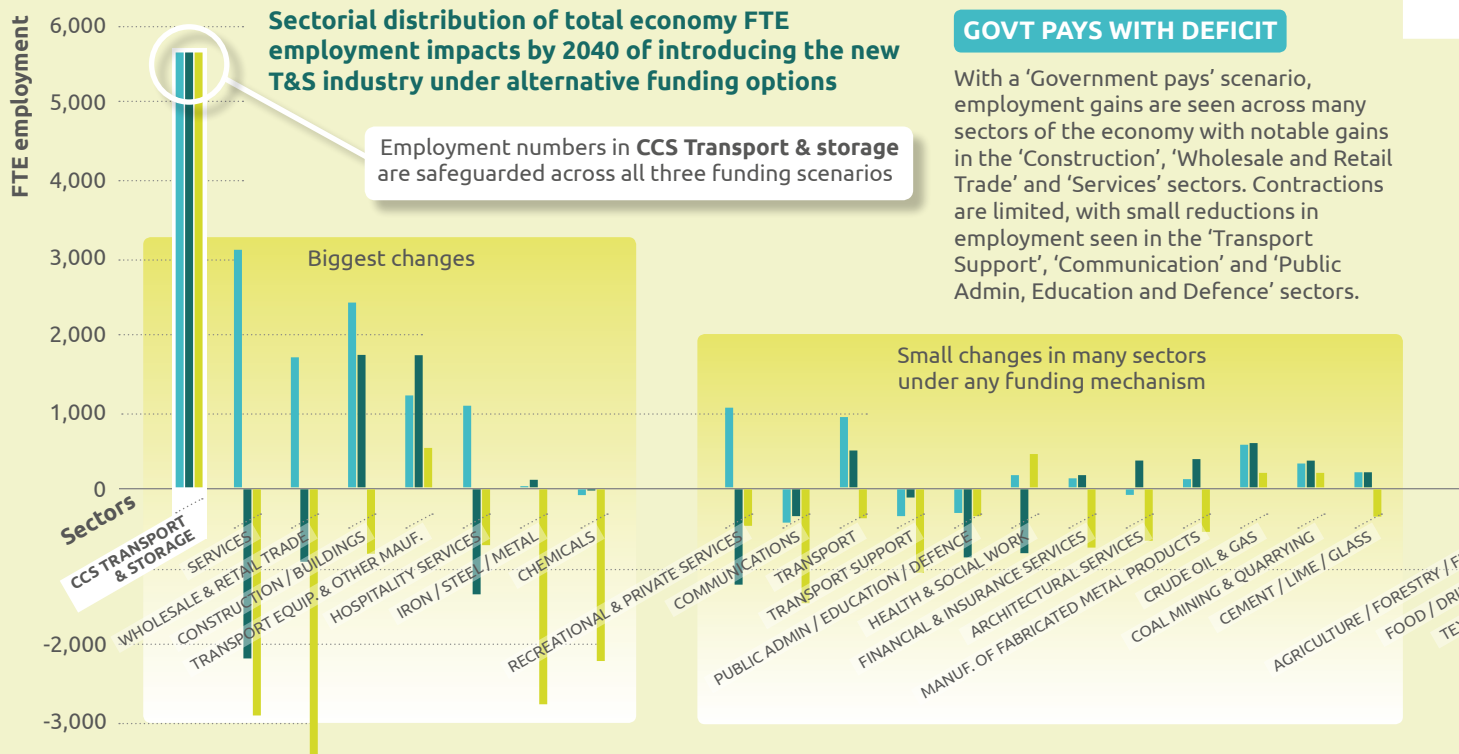
IMPLICATIONS OF HOUSEHOLDS PAYING FOR CO₂ TRANSPORT AND STORAGE

KEY FINDING 02

‘Green growth’ outcomes will be eroded, and new challenges emerge for the ‘just transition’, if action to support the T&S industry requires households or emitting industries to pay from the outset

FIGURE 04

UK EMPLOYMENT IMPACTS OF INTRODUCING THE T&S SECTOR BY 2040



HOUSEHOLDS TRANSPORT

For example, if government cannot or chooses not to run an ongoing deficit to support the rollout of T&S, one option may be to 'socialise' the costs by passing the annual £2.2billion burden to UK households. Our scenarios focus on the key implication of adopting a 'households pay' approach: if domestic taxpayers have to meet the costs of supporting a new T&S industry, households

across the nation will face a reduction in real disposable incomes available for spending in other sectors of the economy. Thus, transferring the costs to households introduces contractionary pressure, with the question being whether this is sufficient to entirely offset the gains from introducing the new T&S industry. In practice much will depend on exactly how the burden is transferred (and, in practise, the extent of the additional burden actually associated with rolling out T&S), for example with changes in income tax potentially introducing further distortionary pressure if workers attempt to bargain to restore real take-home incomes.

TABLE 01

KEY MACROECONOMIC OUTCOMES (2040)

Funding mechanism	GDP impact (% change)	CPI (% change)	Employment (% change)	Change in govt budget balance (£million)
● Deficit funding	£1.739billion (+0.099%)	+0.129%	17,037 FTE (+0.058%)	-1,586
● Household pays	£0.773billion (+0.044%)	+0.026%	3,464 FTE (+0.012%)	320
● Industry pays	-£0.977billion (-0.056%)	+0.159%	-14,912 FTE (-0.051%)	-766

In the absence of information on how costs may be transferred, and to focus on the central trade-off between spending on consumer goods/services and on the T&S industry, we consider a simple lump sum transfer. The outcome is one of eroded wider economy gains relative to a case such as the deficit funding one above or whether external (export) demand (for T&S services) may emerge.

Particularly given how labour-intensive many of the UK service industries where people do much of their spending (such as hospitality and retail sectors) are, our scenario simulation results suggest that the 5,630 direct jobs gain within the new T&S industry will be more than

offset by losses in other sectors, with the total net UK employment gain falling to 3,464 by 2040 – see **Figure 04** – sectoral breakdown. **Thus, requiring households to pay clearly has implications for the justness of the transition, particularly for people whose incomes are dependent on service sector activities, which often involves those already on lower incomes and who are now, indirectly, bearing decarbonisation costs associated with the roll out of CO₂ T&S capacity.**

Nonetheless, at the macroeconomic level, the introduction of the T&S sector in our UK scenarios still leads to limited productivity gains in the economy with albeit relatively small per annum GDP gains of £0.8billion by 2040 equating to a 0.044% per annum gain which exceeds that (0.012%) in employment (see **Table 01**). Moreover, without any direct deficit spending requirement, the more limited overall 'green growth' outcome delivers small annual gains (£0.3billion by 2040) to the public purse. CPI pressures and competitiveness loss in UK exports, that are associated with a much more limited domestic expansion, become even more negligible.

HOUSEHOLDS PAY

In this scenario, negative employment impacts are largely seen in service orientated sectors such as 'Hospitality Services', 'Services' and 'Public Admin, Education and Defence' and gains seen in the 'Transport Equipment and Other Manufacturing' and 'Construction' sectors.

INDUSTRY PAYS

With an 'industry pays' scenario, all but a few sectors see reductions in employment. Particular falls in employment are seen in sectors associated both directly and indirectly with industrial activity such as the 'Chemicals', 'Iron, Steel and Metal', 'Wholesale and retail trade' and 'Services' sectors.

Very little change in many sectors under any funding mechanism



THE RISKS OF AN 'INDUSTRY PAYS' APPROACH

KEY FINDING 03

An 'industry pays' approach could lead to negative economic outcomes for all but a few sectors, particularly those regions and communities most closely linked to the emitting industries

Our scenarios for the UK show that if the costs of operating the new T&S industry are passed to those emitting industries required to take decarbonisation action through carbon capture in the clusters, funded through an increase in indirect business taxes, the outcome becomes entirely negative for all but a few sectors of the UK economy. Moreover, losses are concentrated in those located in and around the regional clusters (see **Figure 04** for a sectoral breakdown of impacts on different UK sectors).

While activity directly associated with the T&S industry will be safeguarded for as long as it receives public support, the challenge is that an 'industry pays' approach risks the sustainability of the very activity – in the regional industry clusters – that Government aims to help sustain through the provision of public support. Dependent on where affected workers live and spend their incomes, service industry impacts in particular may also be regionally concentrated.

We find that the precise extent of negative implications to cluster industries from paying for T&S depends on the international market response to consequent rises in the prices of outputs produced by the cluster industries (largely commodity inputs to supply chains for other products). **However, for our central case scenario, and where UK cluster industries apply CCS ahead of international competitors, the net per annum impact on GDP is a contraction of almost £1billion. Almost 15,000 UK jobs are lost by 2040,** with employment losses spread across both the

cluster industries themselves, and those service sector industries where now unemployed workers formerly spent much of their disposable incomes (see **Table 01** for the impacts on household spending and employment, and **Figure 04** for the distribution of sectoral employment impacts).

The 'just transition' challenges of such an outcome are exacerbated by the **tension with the UK Government's regional 'levelling up' agenda: where cluster job losses are suffered largely by people living in the cluster regions, the consequent impacts on activity and jobs in service industries are likely also to be concentrated in host regions.**

In short, the somewhat perverse outcome is that jobs and GDP losses are more extreme in the 'industry pays' case than under 'household pays'. Crucially, wherever cluster industries bear additional costs, the resulting contractions are also more likely to be more concentrated in those regions that the T&S industry is deployed to help decarbonise, but with a key policy aim being to sustain local jobs and supply chains along with national prosperity.

Moreover, so far, we have not taken account of the cost of capturing CO₂ that are likely to ultimately fall on the regional cluster industries. This is likely to be a central challenge for any nation considering the sequestration of captured carbon as a deep decarbonisation solution, whether the capacity to deliver T&S services is available on a domestic basis or not, and it is the issue we turn our attention to next.

CARBON CAPTURE AND THE COMPETITIVENESS CHALLENGE

KEY FINDING 04

Operational carbon capture can reduce the capital efficiency of industrial firms with implications for returns on capital



Pichit Boonhuad

Particularly for nations that do not have the capacity for delivering CO₂ T&S services domestically, carbon capture may be the main cost element of adopting CCS solutions (depending on T&S fees that may be charged by actors in those nations that can provide/export such services). Carbon capture, or any decarbonisation action that involves firms installing and operating new equipment whilst producing the same output, brings a particular challenge. The need to run additional equipment to produce the same products without emitting the same emissions as before will reduce the capital efficiency of firms, with consequent implications for returns on capital invested. Of course, in practice, (and alongside factors such as how changes in carbon prices and/or other decarbonisation solutions, such as shifts to more sustainable fuels, affect production costs and/or processes) much will depend on where the 'factory gate' is for capture firms. That is, whether they need to pay for additional services or to use additional equipment themselves. Indeed, if a new industry were to emerge supplying 'capture services', this may not only create new domestic supply chain activity within the UK, but also reduce the additional capital requirements for capture firms.

Simulating the wider economy impacts of introducing carbon capture to the 'Chemicals' sector

At this stage, we focus our scenarios on the implications of reduced capital efficiency associated with deploying carbon capture in a way that requires firms to use additional equipment to produce the same output, with the implications for a mid-term 'industry pays' approach. While the magnitude of likely efficiency loss needs to be explored across all potential capture industries, discussions with actors from the UK Chemicals industry suggest that the capital efficiency loss may equate to an average 30% increase in the cost of equipment required to produce a given level of output. **Here the driver of competitiveness loss is not simply about passing on costs, rather the need to restore returns to capital for investors/owners of plants located in the UK that drives up capture industry prices.**⁹

As with our T&S scenarios, note that we isolate the impacts of introducing carbon capture on a 'nothing else changes' basis in order to focus on the drivers of outcomes associated with this solution. Crucially, we do not explicitly consider how carbon prices may otherwise change and/or other low-carbon product markets may emerge, either of which are likely to impact net impacts of on capture industry prices and the international trade response to relative competitiveness changes in particular ways that demand additional study (our research involves 'sensitivity analyses' around the extent rather than drivers of differing trade response to changing UK prices).

TABLE 02

INDUSTRY PAYS FOR CAPTURE

Impacts on key macroeconomic indicators and industry impacts of 'industry pays approach' for carbon capture

	2040	
Chemicals sector output price change associated with carbon capture*	+4.4%	
Chemicals exports	-8.2%	(-£1,061million)
Chemicals imports	+5.5%	(£358million)
Chemicals employment	-4.8%	(-4,340 FTE)
GDP	-0.117%	(-£2.053billion)
Total employment	-0.048%	(-14,166 FTE)
CPI*	+0.047%	
Household spending	-0.055%	(-£648million)

*relative to baseline numeraire of 1

In our central case scenario, we consider the impacts of introducing **carbon capture in the UK Chemicals industry – associated with capturing just over 5.8Mt or one-third of the 20Mt total that the new T&S industry is developed service per annum**. Again, we find that the precise impacts will depend on just how sensitive international trading conditions are to price changes. However, in our central scenario we find that the loss in relative competitiveness due to the capital efficiency loss alone **triggers a wider economy contraction associated with per annum GDP losses of around £2billion by 2040 – see Table 02.**

This is accompanied by a net loss of 14,166 UK jobs, 4,340 of which are in the Chemicals industry. Added to the 2,207 Chemical industry job losses associated with 'paying its share' of T&S costs above, in this UK case **the sum total is 6,547 total Chemical industry job losses associated with the deployment of carbon capture.** Moreover, while Chemical industry exports contract, by just over £1billion per annum by 2040, imports of chemicals rise, even in the contracting economy by about £0.4billion per annum.

Thus, there is a risk that making industry pay for carbon capture will lead to **an offshoring of Chemicals industry jobs and investment, along with the emissions that were formerly generated in the UK sector.**

Regional impacts depend on industry competitiveness

Moreover, we found that invoking a mechanism such as the commonly discussed 'carbon border tax adjustment' specifically focussed on matching or offsetting the domestic Chemical industry price rise, would not greatly help the industry itself (reducing the jobs loss by 200 jobs) and substantially worsen the wider economy outcomes (increasing the total UK jobs loss by more than 7,000). This is due to not only the UK Chemicals industry itself being heavily reliant on imported chemicals, but also numerous other sectors of the UK economy – see **box**, above right. Generally, there is always a risk of potentially unanticipated supply chain 'ripple' effects with any mechanism that increases prices faced by domestic producers and/or consumers.

Such outcomes are clearly not consistent with either the spirit of international climate change ambitions, or with a 'just transition' in the UK, in particular introducing challenges for the UK Government's regional 'levelling up' agenda, or for any policy objective focussed on ensuring those regions where production needs decarbonise do not disproportionately bear the costs of delivering net zero outcomes and reduced 'carbon footprints'

⁹ For details of modelling set up and assumptions see Appendix

CARBON BORDER ADJUSTMENTS

of a nation's consumption. **The regional 'levelling up' challenge is made more acute in the UK case given that the almost 10,000 indirect/secondary job losses may also be quite heavily concentrated in the regional economies that host the industry clusters that UK CCS deployment focuses on sustaining.**

Thus, in considering any policy action to offset the price and associated competitiveness implications of the capital efficiency loss (the apparent aim of the Industrial Capture Contract or tailored 'contract for difference', (CfD), mechanism being considered in the UK), there is an acute public policy need to consider how international market conditions may change for capture firms and how any supported timeframe may be used to deliver better outcomes. Such policy action would need to be transitory both from a public budget perspective and in terms of performance implications for firms, with focus on offsetting any competitive disadvantage experienced by firms engaging in first mover activity on CCS.

Simulating the wider economy impacts of a 'households pay' approach to carbon capture

For example, in our UK scenarios we considered a case where policy support is provided in the form of a taxpayer funded subsidy to the Chemicals industry just sufficient to offset the competitiveness loss associated with operating additional (capture) equipment in producing output. That is, the capital efficiency loss will still occur, and firms will still need to invest to support the additional equipment requirements, but the subsidy offsets the need to increase the price of output

to restore returns to capital. This is the fundamental aim of the type of CfD instrument being considered in the UK. We find that such an intervention will prevent contractions in domestic downstream and export demand for Chemicals industry output, and the and associated job losses within the regionally clustered industry and its supply chain.

However, as in the T&S case, even a non-distortive lump sum type tax on households will trigger consumer spending contractions particularly in service sectors of the economy. Thus, our scenario

simulations suggest that net losses in total UK employment and GDP should still be anticipated, but that these will be reduced relative to the industry pays case and associated with a reduction rather than an increase in the CPI as the economy contracts – see for example the outcomes by 2035 (five years after the uptake of carbon capture in the Chemicals industry is completed) in **Figure 05**. Moreover, while job losses associated with reduced household spending will be concentrated in service sectors, this will no longer be skewed in the regional economies where the Chemicals industry is clustered given that household spending reductions are spread across the tax base.

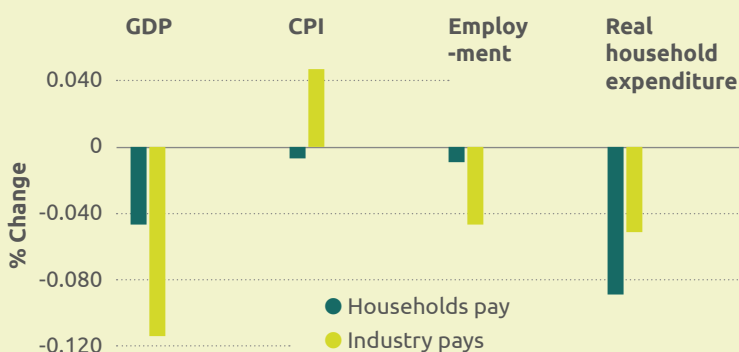
One commonly discussed solution to offset the impacts of UK prices rising ahead of the price of international competitors, is simply to impose some kind of import tax on the latter to 'level the playing field'. We experimented by adjusting the price of imported chemicals by an amount equal to the full (direct and indirect, or price multiplier) impact of the assumed 30% reduction in capital efficiency involved in operating capture equipment in the UK industry.

We found that when domestic chemicals became more expensive, both UK Chemical and the wide range of other UK industries that use chemicals in production processes had the option to import the chemicals they needed at a lower price, therefore maintaining their own competitiveness. However, as imported chemicals become equally expensive, this substitution option is removed with the implication that the production cost and, therefore, the prices of all UK sectors are increased. Hence, multiple UK sectors become less competitive and lose demand both domestically and abroad. The outcome is stark – the per annum GDP loss by 2040 rises from the -0.117% reported in **Table 02** to -0.153%, and the total UK employment loss from 14,166 to 21,757. The increased price pressure is reflected in the UK CPI increase by this time, 0.08% rather than the 0.05% increase.

FIGURE 05

SUPPORTING CARBON CAPTURE

Relative impacts on key macroeconomic indicators by 2035 of Household vs. Industry Pays approaches to introducing carbon capture in the UK Chemicals industry



USING POLICY SUPPORT FOR A 'JUST TRANSITION'

KEY FINDING 05

The timeframes where public support is provided can be used to deliver CCS in ways that better align with 'just transition' and regional 'levelling up' agendas

The best way of improving 'just transition' and regional distributional outcomes for CCS deployment in any nation is to use the timeframes where policy support is provided to de-risk the investment and operation any new industry activity (such as the new T&S industry considered here for the UK) and to reduce the acute competitiveness challenges of carbon capture. There may be

external drivers, as competing firms in other nations follow in reflecting CCS costs in particularly commodity output prices – and/or otherwise more fully reflecting carbon costs in prices – but there is also potential to explore, develop and exploit sources of first mover competitive advantage.

Referring again to the example of carbon capture in the UK 'Chemicals' industry, **better outcomes**



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begin to emerge over the mid-term timeframe where industry is likely to be expected to pay where international competitors similarly adopt carbon capture and face the associated (capital efficiency driven) costs.

This allows competitiveness driven losses to be almost eradicated with no job losses in the UK capture industry. There are still some slight negative impacts on the industry and wider economy. This is due to the fact that, with carbon costs more fully reflected in global chemicals prices, there will be lasting pressure on the UK CPI (estimated at +0.14%) and, as a result, a sustained marginal loss in per annum GDP by 2040 (-0.1%). This does come with a lasting negative impact on jobs (sustained losses of around 13,000 across all sectors), but no longer with the same regional concentration around the industry clusters where the 'Chemicals' industry is located.

The key to improving the mid-term situation is where some competitive advantage can be

developed by the early mover, either through 'learning-by-doing' and/or further technical progress. For example, in our scenario simulations for UK 'Chemicals', we considered what may happen if the capital efficiency loss associated with capture activity in the UK chemical industry could be halved by 2040 (relative to what firms in following nations may encounter) as a result of moving early in the 2020s with the aim of full capture uptake by 2030.

Here we found that UK 'Chemicals' could actually enjoy growth in its activity, employment and contribution to value-added. In particular, our results suggest that the industry would take on rather than lay off workers by 2040, and that the offshoring process would effectively be reversed, with UK 'Chemicals' industry exports rising by 5% (£667million) while imports of chemicals to the UK fall by 4.5% (£296million). That is, reliance on now-decarbonised UK chemicals at home and abroad would increase, supporting consumption of a multitude of every-day products and essential services, and real income gains associated with growing employment would boost local service sectors.

The economy-wide picture would still remain slightly negative, for the same reason as outlined above: now that carbon prices are more fully reflected (again, here through carbon capture) in a commodity, chemicals, that ultimately features in multiple supply chains across the UK economy, costs of production and prices of consumption will rise.

However, with increased efficiency and early mover competitive advantage in operating carbon capture in 'Chemicals' industry production would partly mitigate this: in our scenario results the CPI increase by 2040 is reduced to 0.113% and the GDP contraction is reduced to 0.028%. This is associated with a slight reduction in total UK employment, but our results suggest that gains in higher wage jobs in the Chemicals industry/supply chain might enable a slight increase in real UK household spending that would help offset wider price driven losses in other UK sectors.

Thus policy support for CCS-related activities should be justified not only by sustaining economic activity through the net zero transition, but by using timeframes of support wisely to generate new future sources of value and jobs, with a focus on enabling a 'just transition' for people in all regions.



FUNDAMENTAL LESSONS FOR NET ZERO TRANSITIONS



While further scenario analyses are required to consider how the deployment of CCS in any given nation may impact in practice, and, crucially, in the context of other key net zero policy actions, and changing economic circumstances, three key messages emerge from our analysis of the economy-wide impacts of CCS as an industrial decarbonisation solution. Moreover, given the characteristics and drivers identified in our CCS analyses, these are essentially generic lessons that will apply across the net zero domain.

LESSON 01

- Reducing carbon emissions to meet net zero targets will involve increased costs (here the costs of CCS assuming no changes in other carbon prices or other decarbonisation costs). These will feed through to consumer prices and risk losses in GDP.**

Where one nation moves first in incurring these costs (and/or not acting to cushion them somehow via policy interventions), it will lose competitive advantage in international markets in the near term, but could potentially win this back through technological progress/efficiency gains over time. Nonetheless, some lasting impacts on consumer prices are inevitable, unless, of course, these can be offset by wider efficiency gains (see our second key message).

This is important, particularly in the context of decarbonising the types of outputs produced by the Chemicals industries that we

focus the latter part of our analyses on. The population doesn't tend to consume these outputs directly but they appear in the supply chains of a multitude of every day essential goods and services (e.g. the toiletries we use, the medical supplies/equipment we need the NHS to use, the cars we drive, the wind turbines that generate our renewable electricity). This is what drives the CPI increases we find in all scenarios, and which indicate a need for discussions around socio-economic and 'just transition' concerns. Here attention usually focusses on 'energy poverty' – where policy attention is often focussed on a single/small group of prices, i.e. energy bills – but, given the scale and multitude of actions that will be required to deliver the net zero transition, a shift is needed to consider a more fundamental concern around potential 'carbon poverty', where the challenge becomes much more complex.

LESSON 02

- **'Green growth' opportunities (such as introducing a new CO₂ transport and storage industry to the economy) could help offset cost-driven employment and other economic losses associated with decarbonisation costs. However, like any form of economic expansion in the presence of labour supply and/or other constraints, 'green growth' should be expected to introduce additional pressures on consumer prices.**

That is, 'green growth' is like any form of economic growth in that the presence of supply constraints such as those currently apparent in UK labour markets will bring another form of price pressures. Thus, an expanding 'green' economy can 'overheat' like any other, but where associated CPI increases could contribute – even if just at the margin in the context of individual and relatively small (macroeconomic) scale actions such as a UK T&S industry – raise challenges around 'carbon poverty' and ultimately affect the delivery of a 'just transition'. The fundamental policy response must focus on enabling increased productivity across the economy, to limit absolute price rises flowing through from the supply side of the constrained economy, alongside supporting efficiency gains in the use of new technologies to reduce the impact of nominal price changes on their real production and consumption needs.

Crucially, these lessons are not only important in terms of ensuring wider climate justice at home. Offshoring of regional activities may not in fact result in a reduction in global emissions (not least given the climate impacts of international transportation systems), rendering the 'net zero transition' nothing more than a somewhat a null and void national concept, and certainly not equating to a 'just transition' for populations and workforces.

Next steps

The research presented in this report provides important insight into emerging challenges and opportunities associated with introducing CCS into the UK economy, crucially based on the development and application of rigorous and theory consistent social science methods. Further

LESSON 03

- **Potential tensions exist between decarbonisation, 'green growth' and 'levelling up' agendas. For example, the costs of introducing CCS to decarbonise UK industry may be borne disproportionately by firms, workers and households in cluster regions.**

Particularly where decarbonisation actions involve new large scale infrastructure development to operate in and/or service new/existing activity in regional locations, much policy and public discourse focusses on the potential near-term benefits for those regions linked to construction projects and long-term benefits where industries become sustainable in a net zero world. However, where the transition process involves additional costs being borne by the industries and people currently operating/working in those regions directly or indirectly bearing costs, particularly where these costs cause a loss in international competitiveness of regional economic activity, jobs and investment could be lost/offshored in ways that are difficult to reverse.

Improving productivity and efficiency is key to preventing such negative outcomes. Periods of policy support must focus on embedding productivity and efficiency gains in transitioning sectors. Crucially, this allows early movers to focus on developing sources of competitive advantage in a net zero world, rather than waiting for external markets to catch up in fully incorporating carbon prices. A strong economy provides a basis to redistribute costs and benefits to ensure that wider 'just transition' agendas can be fulfilled.

research is urgently needed to understand how other factors, such as the further emergence of significant carbon prices in the UK and beyond, might impact how and the extent to which decarbonisation costs falling on firms, households and/or the public purse, will in turn affect the type of outcomes and consequences considered here. Further research is also needed to understand how emerging opportunities such as exporting CCS technology and services (e.g. shipping CO₂ from other nations to UK stores) and the development of markets for green products might ultimately affect outcomes.

MODELLING APPROACH AND SCENARIO SET UP

We adopt a computable general equilibrium (CGE) modelling approach in our scenario simulation analysis. A CGE model was used by Turner et al. (2021)¹⁰ to explore the economy-wide impacts to the Scottish economy due to the introduction of carbon capture on the Scottish Chemicals industries. CGE models are used by organisations at different policy levels, including the European Commission, the Scottish Government and HM Treasury. The model we use here is calibrated on a social accounting matrix incorporating 2016 input-output (IO) data published by the Office for National Statistics.

Fuller detail on the CGE model used for the level analysis here (and on the scenario simulation results) is available on request (we have a number of papers in the process of peer review with scientific journals that we can share on an embargoed basis).¹¹ Here, we provide an overview of key features of the model and scenario simulation approach for the analyses reported in this report.

The model includes all the different production sectors in the UK economy, aggregated into 34 groupings, with focus on distinguishing key capture industries alongside energy supply sectors (coal extraction, oil and gas extraction, refined petroleum, electricity and gas), as well as the newly introduced (T&S) sector. All production sectors in our model use labour, capital and intermediate (both energy and non-energy) goods and services to produce their output and we can track how the use and cost of each of these elements changes for every UK sector, and the subsequent impacts on level and prices of output.

We set the introduction of carbon capture in an existing industry setting (here for the example of the wider Chemicals industry) and consider CO₂ T&S in the context of the introduction of a new industry (potentially servicing all cluster industries). In either case, these are modelled as shocks to the UK economy, with the scenario simulation analyses focussing on explaining the impacts on key indicators of policy interest, such as GDP, employment, the consumer price index (CPI), household spending and impacts across different sectors on a dynamic

year-by-year basis. Crucially, through systematic sensitivity analyses, we are able to investigate the extent to which all outcomes are sensitive to different assumptions about the labour market, or international market responses to changes in prices of UK goods.

Scenario set-up for introducing the CO₂ T&S industry

Our analyses in Section 2.1–2.3 focus on the UK Government's goal to introduce CCS to a number of industrial clusters, with a view to achieve two net zero clusters by mid-2020s and a total of four by 2030. Based on this we analyse the economy-wide impacts of the development and operation of a sufficiently large T&S sector to service four different types of regional industrial clusters.

1 The new T&S sector shares the same structure as the existing O&G industry, but services a new market. In fact, the T&S sector is derived by the existing O&G industry and starts as a 0.2% share of it.

2 The investment to expand the T&S sector takes place in two phases; first to service two industrial clusters by 2025 (year 5) and then to service all four clusters by 2030 (year 10). Crucially, the sector is initially oversized, meaning that the magnitude of the investment and the new infrastructure is considerably larger than the initial demand for T&S services.

3 The CAPEX to develop the necessary infrastructure is £2,344million, but the total investment required

is £3,776million as it needs to cover the depreciation of the existing capital over time. CAPEX includes the costs of onshore transportation equipment and the cost of developing offshore storage facilities. We draw information from the work of Calvillo et al. (2021)¹² in determining the levels and timing of up-front investment.

4 The economy starts from an unchanging base, informed by the available data. We assume that, apart from the expansion of the T&S sector, the economy remains unchanged. This implies that for example the production technologies will not change over time. This allows us to isolate the impacts of the T&S sector.

5 We assume that UK is ahead of international competitors (e.g. industry bearing costs ahead of competitors and without the impacts of a carbon price) in applying CCS.

6 We also consider different broad 'who pays' approaches, initially simulating a case where government covers costs by running a deficit with the model configured to have no constraint on the public budget. In subsequent scenarios we still allow the public budget to adjust (i.e. no central constraint) but assume the UK Government to recover the costs of guaranteeing demand for T&S output on an annual basis by adjusting indirect business taxes in those regional cluster industries where emissions can be captured with a direct link to the physical tonnage of emissions generated, or by imposing a lump sum tax on households, which must be paid before any consumption demands are met.

Scenario set-up for introducing carbon capture in the UK 'Chemicals' sector

In Section 2.4 we shift our attention to the introduction of carbon capture in the UK 'Chemicals' sector. We focus on the collective UK 'Chemicals' industry as a dominating presence in several regional industrial clusters that the UK Government aims to decarbonise (Grangemouth in Scotland; Merseyside, Teesside and Humberside in North England). The scope is that 'Chemicals' have the full capture capacity in place by 2030, the year in which the T&S sector for all four clusters should be operational to transport and store the captured CO₂.

1 We assume that the carbon capture activity requires increased capital inputs to produce a given level of output. Building on Turner et al.'s (2021)¹³ Scottish CGE work, and informed by engagement with UK chemical industry actors, we impose a 30% reduction in the efficiency of capital in the 'Chemicals' sector.

2 We do not explore the combined effects of carbon capture and T&S services as they lead to fundamentally different impacts on the sectors involved and because there will be value to readers in different contexts in understanding the impacts of different elements of CCS. T&S costs are an additional cost to industry, while carbon capture changes the structure and the production technology of the sector. Hence, the drivers behind the impacts are different, motivating our approach if initially studying these separately.

3 To combat the reduction in efficiency and to restore the returns to capital in the case of carbon capture, a key criterion for industries on where their activities should be located, the industry must make additional investments and, therefore, increase the price of its output, which when operating in international markets, will impact on their overall output and economic contribution.

4 Initially we assume that the international competitors of the UK 'Chemicals' industry do not have to bear the carbon capture costs or at least their government somehow offsets said costs. However, we explore the impacts of different conditions in international markets. Namely, greater or reduced responsiveness to relative price changes, international industries facing the same costs or the introduction of domestic instruments such as a border tax adjustment.

5 We also explore how the potential outcomes are affected if the UK 'Chemicals' gain a first mover advantage compared to its international competitors and, instead of 30% capital efficiency reduction, it faces a 15% capital efficiency reduction.

6 We also run a scenario where the UK Government subsidises capture firms at a rate sufficient to offset the long-run price impacts/competitiveness loss of the capital efficiency loss associated with adopting carbon capture. The costs of doing so are recovered from UK households via an annual lump sum transfer.

¹² Available to download at <https://strathprints.strath.ac.uk/77310/>

¹³ Available to download at <https://strathprints.strath.ac.uk/75489/>

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