Reframing the Value Case for CCUS: Evidence on the Economic Value Case for CCUS in Scotland and the UK (Technical Report)

By Karen Turner, Oluwafisayo Alabi, Ragne Low and Julia Race, Centre for Energy Policy, University of Strathclyde, Scotland

Summary (see also project Policy Brief at https://doi.org/10.17868/67392)

The key message emerging from our research is that **CCS could play a key role in sustaining over 26,000 direct jobs in the on-shore support industry** that have traditionally associated with oil and gas, and around **another 18,000 supply jobs associated with this industry and the emerging offshore renewables sectors**. This would be through **delivery of infrastructure and capacity for CO2 transport and storage around Scotland associated with off-shore geological sites**. The research also highlights how having access to CCUS services could **help our process industries decarbonise**, thus helping sustain jobs in those industries and **offering opportunities to attract inward investment in low or decarbonised industrial clusters**. In this context the **Scottish Petroleum and Petrochemicals industry already supports over 6,650 direct and supply chain jobs**. CCUS, and in particular CO2 transport and offshore geological storage, could therefore could be **crucial to Scotland in the context of the 'just transition' from fossil-based economies to a 'clean' energy and industrial future**.

The research has been conducted with reference to, but aims to add to, the evidence base on **potential political economy value** generation that may be associated with **CCUS in Scotland and the UK**. We highlight the '**just transition**' focus that underpins the Paris 2015 agreement and is of immediate concern in a Scottish context, where the Scottish Just Transition Commission has been established in December 2019. We review a range of studies on the economic impacts of CCUS and conduct a **new preliminary analysis of the potential jobs multiplier impacts associated with CCUS for Scotland**. We conclude that 'techno-economic' measurement of CCUS project metrics are important but insufficient, and not the first consideration in considering the broader political economy **value statement and narratives around the role of CCUS**. In meeting long term climate ambitions at regional and national levels, there is a need to **retain and ultimately grow jobs and production activity** therein. Thus, a fuller political economy perspective becomes necessary.

We demonstrate that **economic multiplier** methods enable a transparent and rigorous initial assessment of how many direct and indirect supply chain jobs and GDP may be sustained and/or created where a solution like CCUS is introduced to **allow industries to decarbonise and continue to grow in key regional locations**. We report multiplier evidence for Scotland. For example, in 2014, the Scottish Petroleum and Petrochemicals industry had full-time equivalent, FTE, employment of just over 1,900. But, through indirect and induced supply chain linkages, the total number of Scottish FTE jobs supported by the industry's activity was over 6,650. In the on-shore 'Mining Support' industry, which services the off-shore oil and gas industry, just over 26 thousand direct jobs equates to more than 44 thousand Scottish FTE jobs are supported by demand for the on-shore industry's services.

We consider how multiplier results can be set against the spending requirement to compute the **'cost per job' (CPJ)** metrics for the CCUS scenario in question, enabling comparison with CPJ outcomes can then be compared for alternative CCUS projects and/or a range of other options where government support and investment may be directed. With its high 'employment multiplier', the on-shore 'Mining Support' industry delivers the most jobs relative to its current expenditure levels, and thus has the lowest final expenditure requirement per job of the CCUS relevant industries considered (just over £86k). We note that the economic multiplier impacts would be larger if fuller links to the off-shore oil and gas extraction sector, currently accounted within the UK Continental Shelf, were included.

Cite this document: Turner, K., Alabi, O., Low, R., & Race, J. (2019). *Reframing the Value Case for CCUS: Evidence on the Economic Value Case for CCUS in Scotland and the UK (Technical Report)*. Glasgow: University of Strathclyde. https://doi.org/10.17868/67391

Acknowledgements

The research reported here is funded by Crown Estate Scotland. It builds on an EPSRC 'Impact Accelerator' project linking to EPSRC Grant refs: EP/M00760X/1 and EP/JO16454/1. The authors acknowledge engagement with numerous groups, agencies and government departments in developing narratives around the economic value case through the EPSRC Impact Accelerator project. These include: the UK Department of Business, Energy and Industrial Strategy; HM Treasury; the Committee on Climate Change; Carbon Capture and Storage Association; National Infrastructure Commission; Scottish Government; Caledonian Clean Energy Project; the European Zero Emission Platform (ZEP); and the International Energy Agency. Valuable input and feedback at various stages of our project was also provided by the University of Strathclyde's Centre for Energy Policy Advisory Group, colleagues at the Scottish Carbon Capture and Storage research group and Imperial College London (via the EU ACT Elegancy project and including project stakeholders at INEOS), along with the CCUS Cost Reduction Taskforce Work Stream 1 group. The authors retain responsibility for the content of this report.

Contents

1. Introduction

This study extends the evidence base on the economic value case for CCUS[1] linking both to industrial decarbonisation and the role of the oil and gas industry (and its supply chain) in enabling the transport and geological storage of carbon. It does so in two ways.

First, it reviews recent high profile works that have attempted to consider potential societal/macroeconomic value that may be delivered via support for CCUS programmes. In reviewing these works, this new study considers the potential for new ways of measuring value, building up from what are largely techno-economic project-level studies, set in a domain where metrics such as the Levelised Cost of Energy (LCOE) have traditionally dominated the comparison of energy options. Where concern is with whether or not there is a wider social and/or (macro)economic value case for supporting CCUS, there is increasing attention to more economy-wide focussed studies and a need to consider new metrics.

Here, we argue that traditional 'energy system' measures such as LCOE , while still useful, are insufficient in the realm of wider societal value measurement, particularly where large new infrastructure developments may require some form of public resource. If this is the case, attention must be a wider range of outcomes, such as employment, incomes and tax revenues. As the scope of studies reviewed extends to more of an economy-wide perspective, the type of multiplier mechanism widely used in economic policy evaluation work emerge as a foundation for developing new metrics. For example, employment multipliers report the **total number of jobs generated throughout the economy for a given level of spending in a particular sector and/or reset in terms of total jobs across the economy per direct job**. These can be linked to cost effectiveness 'cost per valued outcome' metrics, with a common example being 'cost per job' (CPJ). The approach of comparing the costs of alternative ways of producing the same (or similar) outcomes valued by society is one used in the **Cost Effectiveness Analysis (CEA)** outlined for public sector appraisal in the HM Treasury 'Green Book' as a simpler version of full **Social Cost Benefit Analysis (SCBA)**. This context becomes increasingly important (particularly in the context of the CCUS Delivery and Investment Frameworks to be addressed in 2019 via the BEIS 2018 CCUS Action Plan) given that HM Treasury's Spending Review in 2019 will consider all public investments in terms of contributions to prosperity in general, and value delivered per £ of public resource required.

This provides the basis for the second way in which this study extends the existing evidence base. It develops the existing primary multiplier research with UK national and international focus presented in Turner *et al.* (2018b,c) to a Scottish level. This is both in terms of how multiplier analyses may provide a basis for formulating economic narratives around CCUS, and considering the translation to 'cost per valued outcome' (e.g. CPJ) metrics that may be more directly useful in informing the inevitable government intervention that would be required to facilitate CCUS deployment.

This report is written for a relatively informed technical audience including government analysts and private sector experts.

2. Taking a wider political economy perspective

[1] The term 'CCUS' is widely used to cover carbon capture, transport, utilisation and storage in a general sense. However, possibly with limited identification of utilisation potential, not all of the studies we have reviewed explicitly address utilisation and the narratives we consider focus more on the capture, transport and storage elements of CCUS. In this context, we generally refer to CCUS at this stage.

It is this economy-wide and societal value focus that provides the context for the current study and the motivation for Crown Estates Scotland to work with the Centre for Energy Policy (CEP) at Strathclyde in this regard. Previous applied research at CEP (Turner *et al*., 2018a) consider how policy narratives around carbon capture, use and storage (CCUS) may develop specifically in a political economy context. [2] To date, our research has focused on how quantitative evidence on economy-wide 'multiplier' effects at UK level may inform development of a 'sustained contribution' narrative around industries that already exist and deliver value in the economy and may continue to do so through the low carbon transition. This narrative is reflected in the BEIS (2018) **UK Government 'Action Plan' on CCUS**, which cites the Turner et al. 2018a work within the following text:

> *"At a local and regional level, direct high value jobs in capital intensive industries, such as oil and gas, chemicals, and other energy intensive industries have been shown to support up to four jobs in indirect employment. Decarbonising these industries, potentially through deployment of CCUS, allows their **sustained contribution to economic growth** both nationally and in the regions in which the industry is concentrated. This is a key reason why CCUS is being progressed in other European industrial centres such as the Port of Rotterdam. Furthermore, skills and supply chains from the oil and gas and chemicals industries could transition to service a growing CCUS industry, allowing the **retention and creation of further high value jobs**."* (BEIS, 2018, p.29)

This type of **political economy narrative** development builds on previous work by CEP in the context of hydrogen. For example, our previous Smith *et al*. (2017) and Turner *et al.* (2018b) studies consider the continued role of the existing UK gas and electricity supply industries in a hydrogen economy (with particular focus on private transport solutions). There we focus on how a key source of wider economic benefits may be domestic supply chain activity to support fuelling, and propose framing of policy actions in this regard. Extending focus to CCUS, the Turner *et al.* (2018a) work considers the potential **role for carbon capture, transport and storage sectors and supply chains in helping retain and potentially create new high value jobs and GDP in key CCUS-relevant sectors** (both capture and supply of transport and storage 'services'), and ultimately to enable further economic expansion as CCUS roll out is delivered.

In building on these foundations, the research presented here has been carried out in parallel with and builds on the work of the University of Strathclyde's Centre for Energy Policy in two other domains that Professor Karen Turner (the principal author of this report) was involved. First, Turner was involved in a work stream informing the **UK CCUS Cost Challenge Taskforce** set up by the Minister of State for Energy and Clean Growth, Claire Perry, which reported in July 2018 (CCUS Taskforce 2018). This included submission of the Turner *et al.* (2018a) paper on behalf of the CEP team, which ultimately helped underpin the Taskforce **recommendation to "more fully assess [the] value of CCUS to the wider UK economy"** (CCUS Taskforce 2018 p.24). In turn, it is likely that this Taskforce recommendation provides the basis for the tailoring of the narrative presented in the BEIS (2018) Action Plan cited above. Second, Turner and Alabi were co-authors of the July 2018 **Zero Emissions Platform report entitled "The Role of CCUS in a Below 2 Degrees Scenario"**. The research presented in the current report has been conducted with reference to, but extending on those two other strands of work specifically in a Scottish and UK context.

---

[2] This research builds on an evidence base that explores societal value in the form of wider economic impacts, including building on a study on economy-wide impact of hydrogen solutions in the form of peer reviewed EPSRC-funded work published in the journal Energy Policy by Turner *et al*., 2018b, in turn extending work reported in a White Paper published by the EPSRC Supergen H2FC Hub, (Smith *et al*. 2017).

The key conclusion emerging from the current study is that an important, transparent and easily communicated way of measuring the societal value of CCUS in wider economy or macroeconomic terms is to conduct **economy-wide multiplier analysis for a socially valued outcome, such as jobs or GDP**. Economic multiplier methods can be used to compute the potential impacts of CCUS deployment in these terms and/or the **public and/or private expenditure required** to achieve them. Moreover, where economy-wide multiplier analyses can be set in the context of scenarios for both deployment of CCUS (and/or other low carbon options such as hydrogen) and projected government support requirements, the latter type of metric is consistent with input to the type of **Social Cost-Effectiveness Analysis (CEA)** recommended by HM Treasury as a simple variant of fuller Social Cost Benefit Analysis (SCBA).

3. Background to the challenge of CCUS in the political economy context

3.1 Developing broader economic narratives on the value of CCUS

The **UK Industrial Strategy** sets out an objective for business to create high quality, well paid jobs right across the country; and to create a partnership between government and industry to nurture industries that are of strategic value to our economy (BEIS, 2017a, p.4-5). It gives particular focus to working with the existing oil and gas sector to explore the contribution that industry could make to clean growth through **enabling both CCUS and 'the hydrogen economy'**. The Clean Growth Strategy states that CCUS is a potentially large global economic opportunity for the UK and suggests that CCUS could add £5bn - £9bn of gross value added (GVA) per year by 2030 (BEIS, 2017b, p.69)[3]. More recently, the UK Government CCUS Action Plan sets out pathways that map to the UK Industrial Strategy. It places emphasis on the types of **CCUS-relevant industries that are key in delivery of a sustained and growing contribution to economic growth at national and regional level** (BEIS, 2018, p.29.)

The clear framing emerging from these key UK Government documents is for CCS/CCUS to be seen as **part of an industrial policy, not (just) a climate policy**. This framing is already developing at EU level, with the recent European Zero Emissions Platform (ZEP) 'Below 2 Degrees' report explicitly arguing that an economic narrative needs to be built around CCUS that demonstrates its **role in protecting jobs and creating new economic prosperity**. This reinforces the just transition element of the **2015 Paris Agreement**, which takes into account 'a **just transition of the workforce and the creation of decent work and quality of jobs**' (UNFCCC, 2015, p4).

ZEP (2018) argue that the 'just transition' focus is necessary to develop consensus around a low carbon transition that is both perceived as just within European nations, and avoids the destruction of key industries 'at home' in tandem with counter-productive carbon leakage in meeting European climate policy goals (Turner *et al.* 2018c, ZEP, 2018). The ZEP report emphasises the type of multiplier narratives developed in the Turner *et al.* (2018a) work, but also considers a wider range of studies, such as that of Pöyry (2018), citing the result that "a portfolio of solutions which includes CCUS, biomethane and hydrogen as part of a balanced energy mix, delivers a saving of over €1,150bn compared to a pathway without CCUS" (ZEP, 2018, p.4).

[3] Note that BEIS has taken this GVA range from a report by CCUSA & TUC published in February 2014: 'The economic benefits of carbon capture and storage in the UK', http://www.CCUSassociation.org/press-centre/reports-and-publications/ .The data in the CCUSA & TUC (2014) report were themselves based upon analysis dating from 2012 and 2010, and what may be regarded as optimistic assumptions about UK content and labour input.

In the UK there is growing recognition that this type of wider-economy narrative is required, where the multiplier focus maps to potential gains through the type of competitive domestic supply chain activity prioritised in the UK Industrial Strategy. This is specifically reflected in the Taskforce's Recommendation 9 (CCUS Taskforce 2018, p.10, p.24.) and the recent UK government CCUS Action Plan on (BEIS, 2018, p.29.). On the other hand, much attention within the UK remains largely focussed on marginal cost reduction at project level.

In this regard, it may be argued that, at least until recently (with the publication of the UK Government's Action Plan), focus on articulating societal value in a broader sense has been more developed at European level than has been the case in the UK. As the ZEP report attests, increasing attention is being paid in other European countries to the potential role of CCUS in **enabling continuation of high value economic activity both in industries that currently supply fossil fuels and in those that use fossil fuels for industrial processes and produce CO_2**. In particular, the ZEP report argues that there is a substantial risk of investment, employment, GDP and more generally economic value leakage overseas from climate policy actions aimed at tackling emissions at their current point of generation.

Our work in Turner *et al.* (2018 c, d) further explores this **leakages/offshoring** issue using multiplier methods. At the same time, this builds to a positive forward looking view in terms of considering opportunities for new industrial activity to emerge from developing a mature CCUS supply chain, and one of the contexts highlighted is the role of CCUS in developing future solutions around hydrogen as both a low carbon fuel and economic opportunity.

For example, a recent study on the **economic opportunities from CCUS for Norway** concludes that realising CO_2 management could contribute to the retention of 30,000 existing jobs and support the creation of over 25,000 new jobs by 2050 (SINTEF, 2018). The SINTEF Norwegian analysis includes focus on the **link between CCUS infrastructure and the production of hydrogen as a low carbon fuel**, a key potential new source of economic value and jobs generation, possibly ultimately supporting as many jobs as already exist in Norwegian processing industries.

Bringing consideration of hydrogen into assessment of the societal value that may ultimately be delivered by CCUS is likely to be important for Scotland (and the wider UK) as a fellow oil and gas producing nation. A key point to note is that the SINTEF (2018) study links the CCUS narrative to Norway's key **existing economic strengths in the extraction of natural gas** where there is potential for existing industry players to participate in an evolutionary process towards the production and distribution of hydrogen as a source of sustained economic value in the low carbon transition. A second key point to note is in terms of the **timing of such opportunities**: in both Norway and the **Netherlands**, projects (at different stages on the feasibility to operational range) are being taken forward now to ensure that these regions are ready to take advantage of the commercial and economic opportunities from what is likely to become a **Europe-wide economic sector** (SINTEF, 2018; Port of Rotterdam Authority, 2018).

As noted in the previous section, the UK Industrial Strategy already recognises the potential for CCUS infrastructure to link with hydrogen production as a new source of value generation. It states that the UK Government will explore the potential for the oil and gas sector to contribute to clean growth through CCUS and hydrogen (BEIS 2017a, p.149). The **UK Clean Growth Strategy** echoes this, noting the need for CCUS to underpin potential under a 'Hydrogen pathway' to 2050[4] for a large new industry

[4] The 'Hydrogen pathway' is one potential route to achieving the deep emissions cuts required by 2050, modelled by analysts in BEIS.

to develop, supporting hydrogen production from natural gas with CCUS (BEIS 2017b, p.56). At Scottish level, the Scottish Energy Strategy also sets out an indicative Hydrogen scenario, which again requires CCUS to enable large-scale production of hydrogen from methane (Scottish Government, 2017). There is clear recognition across these policy statements of the **value of CCUS in underpinning deployment at scale of a wider set of decarbonisation options** such as hydrogen and biomass.

Importantly, the ZEP and SINTEF reports – representing perhaps the key current works outside of the UK informing discussion around framing the value of CCUS – **do not focus on traditional cost comparison metrics such as levelised cost of energy (LCOE)**. Rather, the ZEP and SINTEF works more or less ignore these, giving attention instead to how metrics used in wider economy analyses may demonstrate the potential value of CCUS at the scale of the whole system. This is most likely because traditional energy system cost metrics cannot easily capture wider societal value, and because they are less suited in physical and market terms for assessing the value of infrastructure and supply chains that do not yet exist (as in the case of CCUS).

We argue here that taking traditional cost-metrics approach (such as levelised cost) has two significant disadvantages where attention initially needs to be on **building a wider consensus around the societal need** for new low carbon system developments such as CCUS.

Firstly, the narrow focus of such metrics naturally means that they fail to value the full suite of benefits of any technology/service (particularly where these are not currently reflected or valued in the market system). This is crucial for a low carbon solution like CCUS where costs must be set in the context of a wide range of potential benefits, including those economic benefits not limited to ancillary ones, but extending to what industries enabled in the low carbon transition can continue to deliver. That is, **sustaining jobs and sectors we have already established and invested in and which can continue to provide opportunities for new sector growth and export**. Metrics such as 'cost per valued outcome', with the common example of 'cost per job' (CPJ), used to inform cost effectiveness analysis (CEA) of different options in public sector appraisal may provide more appropriate metrics in this context. Secondly, even where a specific focus on energy system options is required, narrowly focussed technology cost metrics are likely to provide a distorted picture for technologies and energy services that are not currently deployed (and infrastructure and/or markets that does not yet exist).

While the specific focus of the research reported here is CCUS, it more generally provides an exemplar for a **'new' way of looking at value associated with different low carbon investments**. We qualify the use of the word 'new' as it may not be so different to the fundamental perspective historically adopted in in considering developments required to enable public water and transport systems, as argued in the ZEP, 2018, report). This is a crucial point: without a 'public resource', way of understanding value, CCUS and other large scale low carbon solutions may be permanently disadvantaged by a non-level playing field, where the rules of the game are such that 'wrong' metrics may be applied to a 'right' technology.

Arguably, the ZEP and SINTEF studies may also have recognised that traditional energy cost metrics are also not appropriate where costs will be directly impacted by the very public support decisions that the metrics are seeking to inform. That is, public policy decisions regarding how an industry is supported are likely to have a direct effect on project and system costs, in particular through the way that risk is priced. This **feedback loop between public policy decisions and actual costs** means that cost metrics produced through a traditional cost-benefit assessment might influence - potentially perversely - the actual levelised costs of the technology that is seeking public support.

3.2 Approach adopted in the review element of this study

A core element of this study is to review the evidence to date from five key studies on the costs and benefits of CCUS in the UK in order to propose a set of relevant and publicly understood value metrics. We consider how these may be used to best **articulate the potential societal 'value' of CCUS technology and infrastructure**. It also offers some expansion in context and directions for future research through initial consideration of two key non-UK reports: The Zero Emissions Platform report 'Role of CCUS in a below 2 degrees scenario' (ZEP, 2018); and, the SINTEF report 'Industrial opportunities and employment prospects in large-scale CO_2 management in Norway' (SINTEF, 2018).

We have identified three types of study for review, which we distinguish by the analytical approach taken to assess economic impacts. As noted above, we approach this study from the perspective of the potential for economy-wide 'multiplier' effects at UK level to inform a 'sustained contribution' narrative around the societal value of CCUS. Thus, our review builds towards this focus and we have termed the three study types respectively 'techno-economic studies', 'extension studies' and 'economy-wide studies', as follows:

(a) ***Techno-economic studies.*** These are studies that use economic methods other than economy-wide multiplier analysis to evaluate and assess the cost and value of CCUS in the UK. Here attention is usually set in the context of a **project-by-project financial case** and assumptions about the CAPEX and OPEX costs of technologies, the cost of finance, discount rates, levels of public support/subsidy and costs avoided (most often the cost of carbon). The studies in this category tend to have been **carried out earlier** than those in the other two categories, generally between 2013 and 2016, with analysis conducted based upon the assumption that the second competition for government support for CCUS (hereafter '**the CCUS competition**') would proceed and result in operational CCUS deployment in at least one or perhaps two sites. However, the competition was cancelled in November 2015 after £1bn of funding for the competition was withdrawn by HM Treasury, which may have shifted attention to the conduct of studies with a broader focus.

(b) ***Extension studies.*** These extend the analysis beyond that in the techno-economic studies, to consider **whether a broader societal value case can be articulated for CCUS/CCUS**. The studies in this category, draw on multiplier evidence along with outcomes of other analyses. That is, this second approach tends not to involve directly conducted multiplier analyses, and does not go so far as to explicitly consider a fuller set of interactive effects between economic sectors. However, the extension approach does go some way to addressing the wider set of issues that may have been of concern to HM Treasury in its assessment of the value of the CCUS competition (Turner and Race, 2016).

(c) ***Economy-wide studies.*** The focus of the third type of study is to begin to explore a wider set of economic interactions through adopting an economy-wide multiplier approach and settling results in an explicitly **political economy** context. That is, to consider how **supply chain interdependences** in particular give rise to economic multiplier impacts that ripple through a wider set of sectors, thereby generating a range of output, employment and GDP effects that are **valued by a wider societal stakeholder community**. These are all outcomes that would command value in a full Social Cost Benefit Analysis (SCBA) and more limited Cost Effectiveness Analysis (CEA). Thus, identification and quantification of basic multiplier metrics in turn provides a basis for reporting metrics, such as cost per job (CPJ) that would be used in the context of such public policy appraisal techniques. Thus, they provide a basis to begin assessing the overall societal value of the economic activity associated with CCUS in a manner familiar to a wider policy stakeholder audience. The economy-wide studies reviewed here explicitly apply, or draw on results from the application of, economy-wide modelling tools built on **input-output (IO) national accounting data**. In this regard, they generally draw on multi-sector IO tables that are published as part of national statistics by governments – here, the Office of National Statistics for the UK, or the Scottish Government IO team for Scotland.

The **timing of the studies** is important as the context around the CCUS debate has evolved significantly since the earlier techno-economic studies were conducted. As alluded to above, the **cancellation of the CCUS competition** had a profound effect on the type of analysis conducted within the UK. However, a broader international trend is also observed, with a greater emphasis in studies conducted after 2015 in attempting to align analytical frameworks to those used by governments to evaluate the social costs and benefits of potential public investments.

A further contextual change over the time period of the studies we review is the **change in emphasis in terms of where in the economy CCUS should be deployed**. Here, a confluence of two things seems to have influenced the approaches of more recent studies that have more explicitly looked at the value of CCUS to (i) established industrial sectors with high process emissions; (ii) potential new/shifting existing sectors, such as, and perhaps particularly, the production and distribution of hydrogen.

In this context, similar to the narrow focus of LCOE metrics, one issue is that early studies regarded **Cost for Difference (CfD) feed-in tariffs** as the main policy intervention through which financial case for investment could be made. This was based on the assumption that CfDs would provide the stable revenue stream for CCUS operators. The potential value of CCUS in the thermal power sector has changed dramatically in recent years as the make-up of the electricity mix has changed and the CfDs regime with it. It seems that the assumptions made in earlier studies about the potential level and availability of CfDs into the future may have been somewhat optimistic. Again, the cancellation of the CCUS competition in late 2015 seems to have led to a **shift in focus and greater emphasis on understanding societal costs and benefits in the broader context within which Government must make budgetary and strategic decisions**. In this context, it became more natural for studies to extend focus beyond consideration of costs and price determination in decarbonising thermal power generation, and to give attention to other sectors where key elements of economic value might be derived from CCUS.

4. Evidence Review

The studies reviewed here span a time period across the 5 or 6 years between 2013 and 2018. As noted above, the context of the public debate around CCUS in that period has evolved significantly, both in the UK and beyond. In the UK context, the cancellation of the CCUS competition in November 2015 seems to have triggered a growing recognition amongst CCUS stakeholders of the need to set out a fuller societal value case. The motivation for this is likely to be attempting to inform decision-makers who are used to assessing cases for public investment on the basis of an analysis of a broader set of *social* costs and benefits. The formal way that social cost-benefit analyses are conducted by government(s) in the UK is set out in the **HM Treasury 'Green Book'** (HM Treasury, 2018), which also includes advice regarding **simpler cost effectiveness approaches**. With this reference point, commissioned studies sought increasingly to provide the sort of information that could be fed into this type of evaluation exercise. There are two elements to this. First, the provision of **trusted, robust and specific data** to allow the quantification of a broader set of costs and benefits accruing at a wider public or societal level. Second, the **communication of those data in a transparent way**, demonstrating how they were arrived at and what assumptions have been made. Studies that fall into our second and third categories (extension studies and economy-wide studies) have begun to address these needs.

On the other hand, in the early techno-economic studies, this motivation was not really present. Thus, results were simply not provided or communicated in a manner that would allow decision-makers in government to actually incorporate those data into their own social cost-benefit modelling frameworks (Turner and Race, 2016).

A further important issue in relation to decision making about levels of public support for any given infrastructure programme (by whatever means, including dedication of resources within public sector activity as well as grants, loans, tax incentives etc.) is the **balance of private versus social costs and benefits**. The Green Book methodology allows this to be explicitly explored, but with the requirement of a specific analytical approach and transparent datasets to enable this. Again, it is not clear that the earliest studies were able to address the issue of private and social costs/benefits in a structured way that would **align with those methods employed by decision makers in making public budget decisions**.

As well as reviewing the existing body of studies that have considered the economics of CCUS using these three types of approach. Our current research here extends that body of work to provide a fuller analysis for Scotland, based on the third approach (economy-wide, multiplier analysis).

We then consider how all these types of evidence could ultimately be integrated to allow a more **comprehensive consideration of the societal value of CCUS** and the implications for industrial policy. The study we refer to as the 'CO_2-EOR report' (Turner, 2015) takes the first step in setting out this research agenda. It **draws on evidence from 'bottom up' techno-economic analyses of the economic impacts of projects to begin to integrate that into whole-economy modelling**. Important steps are also taken in the East Coast study (Summit Power, 2017) where several modelled scenarios start to get at the crux of the wider societal value case but still draw on 'bottom up' information on projects. The conclusions section of this report extends these insights and sets out the research agenda in more detail. At this stage, we now review the key studies in each category, beginning with techno-economic studies.

4.1 Techno-economic studies

We were only able to review two studies here, both due to the time constraints on the research and confidentiality constraints on what are generally industry generated and/or focussed studies. The first is a report produced by the Energy Technologies Institute (ETI) in 2015 assessing scenarios and actions for development of a CCUS sector and is in fact an amalgamation of more than one study. The 2015 report synthesises previous ETI work on the overall costs of CCUS for power generation in the UK under various technical scenarios, and builds this out to consider wider application of CCUS. The second is research carried out by Atkins for Scottish Enterprise to work up an initial 'Industrial Carbon Capture and Storage Roadmap for Scotland', completed in August 2016. The study report is unpublished for reasons of commercial confidentiality, and was made available on a non-disclosure basis to the authors of this report. It is reviewed here (respecting non-disclosure constraints) because it fits within a suite of studies that consider (aspects of) potential CCUS project costs.

A more detailed consideration of each of the two techno-economic studies can be found in Appendix 1. The text below focusses on the main issues arising from the societal/political economy perspective of the current study. In this regard, **the crucial point to recognise is that the techno-economic studies considered simply do not seek to draw specific conclusions about the overall economy-wide impacts and 'societal value' of CCUS technology and infrastructure deployment**. Rather the economic analyses included in these **focus on assessing the direct costs and benefits of investment in the CCUS projects** modelled in the studies. In other words, they are primarily technically-driven, or techno-economic, studies, with the **economic analysis an adjunct to primary technology and engineering analyses**. Thus the economic analysis tends not to go beyond the projects' boundaries.

Nonetheless, these studies do seek to draw conclusions on whether projects are viable from both private and public perspectives. That is they seek to consider whether public investment can be justified, on the basis of demonstrating whether benefits outweigh costs with the assumption of some level of (initial and/or ongoing) public support. In the UK context, this approach was very much the norm for assessments done before the cancellation of the CCUS competition. Viability tended to be demonstrated by analysis of the revenues potentially accruing through CfDs and by comparing the costs per tonne of CO_2 stored with an escalating carbon price metric. Thus, some **public sector costs are implied**. But these are only the **direct public costs of providing subsidy or grant funding for capital investment**. That there may also be more indirect public costs, as well as indirect public benefits is not considered by the techno-economic studies considered here. Insofar as wider societal costs were considered, this was **framed in the language of 'avoided emissions' and/or in relation to investing now to avoid higher costs in the future.**

Overall, the data used in these avoided costs and 'spend to save' analyses, as well as the precise ways in which they were used, are often rather opaque. The key implication is that **it may not be obvious to other potential users of the information just how (or if) study results could be applied in their own decision analyses**. This includes but is not limited to government/public sector decision makers.

So what *do* these techno-economic studies do? The two reviewed here appear to adopt a reasonably similar approach to assessing project costs. The Atkins study explicitly quantifies the costs of various capture technologies on a £/tCO_2-captured basis, as well as the potential carbon price avoided (Atkins, unpublished). In analysing three scenarios of CCUS deployment out to 2030, the ETI study considers the capital costs of CCUS technology deployment and the required strike price for CfDs (as the main revenue stream for CCUS-with-power) and the £/tCO_2 price to EOR (for CCUS with EOR).

The aim of the Atkins study is to provide a route map to phased investment and as such the detailed analysis is focused on assessing a set of potential 'first project' sites based on projected costs. On the other hand, not all of these are actually quantified – many are simply scored on a scale of 1 to 5, relative to one another. The study is based upon the premise that a clustering approach to CCUS deployment brings down costs overall, in particular through de-risking future investments.

The collective ETI studies (ETI, 2015; ETI, 2016) do discuss risk more explicitly, based on the same premise that clustering and phased deployment brings down costs overall. ETI (2016) goes beyond capital costs and calculates LCOE, demonstrating, and going some way to quantifying, how reducing project risk influences investability and therefore total project costs. It concludes that levelised costs can be significantly reduced through risk reduction due to staggered investments and clustering (ETI, 2016). However, **LCOE by definition does not give attention to a full range of societal outcomes** delivered by different options. It is a comparator that is focussed on energy system costs (and limits attention to those already fully valued in markets) and are therefore not readily applicable to the realm of wider societal value measurement.

Generally, the techno-economic studies reviewed here set out to assess deployment costs and the cost reduction potential of CCUS. In that sense they – and more widely, the sort of analysis involved – are indeed **critical in building up a credible evidence base for considering the investment case for CCUS from a wider societal perspective**. This type of analysis is needed in particular to inform decision making on **the extent of public support that might be needed to bridge the investment gap**. These studies do attempt to quantify that level of public support.

On the other hand, they **do not attempt to consider whether and how a wider set of economic impacts will arise if any CCUS deployment scenario is implemented**. Even where project costs are the key concern, what is missing is the potential for feedback loops (for example around how risk is priced) between the techno-economic estimates of project costs and the extent to which these **costs may**

ultimately be affected as a result of policy responses to a wider set of economic ripple effects arising. Crucially, this sets the context for considering how the case for public support is likely to depend upon more than evidence of deployment costs – the higher-level economic ripple effects of investment are of significant interest to public investment decision-makers.

Another key point is that these techno-economic studies **focus attention very much on the present (at the time of study) costs and values** associated with CCUS deployment. That is, they do not extend to consider key issues now associated with CCUS, such as links to hydrogen scenarios. This is because hydrogen was not an immediately relevant issue at the time. However, this is generally a limitation where **solutions are likely to require significant payback across a rank of outcomes over a number of decades**.

4.2 Extension studies

The type of analyses covered under the 'extension studies' category includes those that add in and/or implicitly draw upon economy-wide multiplier evidence along with other types of analysis (including the type of techno-economic work reviewed above) but do not conduct new economy-wide multiplier analysis themselves. They build out from the techno-economic analysis of the first type of study, usually updating the project-specific cost data and providing more detail in this regard. The key study here is the **East Coast study: 'Clean Air - Clean Industry - Clean Growth: How carbon capture will boost the UK economy'**. This focuses on activity covered by the East Coast UK Carbon Capture and Storage network and was conducted by Summit Power, with publication in October 2017 (Summit Power, 2017). In addition, we have considered the Caledonia Clean Energy Project (CCEP) Phase 2 feasibility study report (Summit Power Caledonia UK Ltd., 2018).

Also relevant is the **Norwegian study 'Industrial opportunities and employment prospects in large-scale CO_2 management in Norway'** published in May 2018 (SINTEF, 2018). We have grouped this study here as an extension-type study, as it has used relatively straightforward multipliers to consider the indirect effects on sectors that buy and sell goods and services to those sectors directly impacted by CCUS. We also highlight the US EOR study titled 'Making Carbon Commodity published in late July 2018 (CURC, 2018). We group this under the extension study category as its primary focus is to examine the potential for market-driven deployment of carbon capture projects for enhanced oil recovery, but with industry multipliers applied to consider wider macroeconomic benefits of the required RD&D in making the argument for public-private partnership.

While only the East Coast Study is conducted in a UK context, we note that all of this work has taken place in the broad timeframe that encompasses the period following the cancellation of the UK CCUS competition in November 2015. As highlighted above, the emphasis of UK-focussed studies shifted following this decision by Government. The shift as reflected in the East Coast Study was in terms of being **more attentive to quantifying wider societal benefits and costs, and considering the 'social discount rates' used in formal social cost-benefit calculations**. However, studies in other country contexts have similarly broadened their focus. Broadly this reflects a general tendency where the landscape within studies have either been commissioned and/or have set their terms of reference to change as stakeholders became increasingly aware of the need to provide robust social cost-benefit data. Again, the need is becoming more broadly recognised to generate information of a type that political decision makers can make use of to **consider and justify spending decisions to wider publics**. Moreover, there seems to be an increased awareness of the need to communicate those data in a **transparent** way to ensure it was trusted by those who may ultimately assess CCUS from a public policy evaluation perspective.

A detailed review of each extension study can be found in Appendix 2. Here, the key conclusion drawn is that what we class as 'the extension studies' take the analysis beyond that in the techno-economic studies. This is through their assessment not only the direct costs of CCUS deployment and the value of avoided CO_2 but **extending to consider broader elements of value to the wider economy that may be directly linked to CCUS investments**. The overall approach remains one of ultimately informing cost-benefit analysis, but with the scope of costs and benefits extending from the project focus of techno-economic studies to the 'social' focus of public policy evaluation. The CCEP study, for example, seeks to quantify 'other socio-economic benefits' in terms of GVA and jobs, in addition to the energy system benefits of supporting integration of intermittent renewables into the power grid.

In this regard, and taking an **international industry development focus** (reflecting the operation and proposed future development of the Norwegian oil and gas industry), the SINTEF study adopts a similar approach to the East Coast study. This is in so much as it applies an **existing economy-wide multiplier** – in this case for the oil and gas industry – as a proxy for what the indirect effects will be from CCUS roll-out on those industries that will buy and sell goods and services to the CCUS sector. In so doing it arrives at an estimate of the number of indirect jobs potentially created in what the East Coast study terms **'linked economies'**. Similarly, the US EOR study explicitly notes the history in a broader literature, including industry studies, of the type of economic multiplier application they use in estimating a broader set of macroeconomic benefits that may **help motivate public-private partnership in the full cycle of RD&D** required to enable EOR via a CCUS system.

As the East Coast study report notes, the economic benefits estimated

> *"are not exhaustive and further detailed study would be required to get a fuller and more accurate assessment. In particular, the assessment has not included all of the potentially linked economies including for example the potential for enhanced oil recovery (EOR) in the UKCS"* (Summit Power, 2017, p. 29).

The analysis considered impacts on a number of directly 'linked economies' but **not the ripple effects of CCUS deployment activities across the economy as a whole**, including, importantly, what those ripple effects might be in the services and oil and gas sectors overall. To consider these impacts requires fuller economy-wide modelling. Studies that begin to do this are considered in the next section.

4.3 Economy-wide studies

Economy-wide studies permit an understanding of the **knock-on effects across the whole economy of a boost (or decline) in economic activity in one area/sector**. They do this in one of two ways. The first (and most common) of these is to provide a set of **headline multipliers** that describe the **overall, or high-level, effect mostly commonly on GDP and jobs across the whole economy**. The second is to enhance the headline multipliers by providing a **breakdown (or 'decomposition')** outlining **where in the economy the impacts (jobs and GDP) are likely to be located**. That is, in which individual sectors these impacts are located. For this second type of analysis, it is essential to have the underlying IO data in appropriate analytical form that sit below the high-level headline multipliers data often published by governments alongside the IO reporting required under systems such as Eurostat and the UN System of National Accounts.

The Turner (2015) CO_2-EOR study discussed below used experimental (i.e. estimated) data, derived from UK national IO accounts presented in another format to conduct a decomposition analysis of this second type. Similarly, the Smith et al. (2017) and subsequent Turner *et al.* (2018b) hydrogen study use these experimental data but with focus on hydrogen and other electric vehicle 'power trains' in private transportation. In the current research we can go further for Scotland. This is because the Scottish Government publish on an annual basis the underlying data in the appropriate IO format for multiplier analysis, something that the Office for National Statistics do not do sufficiently regularly for the UK as a whole.

The quality of IO accounting and reporting for Scotland enables the new applied research conducted for this project to be presented below in Section 4. In focussing this new work, we build on the example of the Smith *et al*. (2017) and Turner *et al*. (2018b) hydrogen work, where multiplier analysis and decomposition of headline results are conducted to consider where in the economy output, GDP and employment impacts are located. These were carried out using existing electricity and gas industries as proxies for hydrogen production. There we found **important impacts located particularly in service sectors and in oil and gas alongside those in the manufacturing, construction and utility industries more traditionally associated with development and roll out of new technologies**. The key point emerging from these two studies (and illustrated for hydrogen and/or electric vehicles) is that **sectors not commonly associated with low carbon transition discussions may be critically important** in terms of both delivery of low carbon outcomes and the strength of a broader set of potential economic gains. Thus, taking a multiplier approach that focuses on 'identifying where in the economy' impacts are realised maps well to addressing priorities set out in the UK Industrial Strategy. In more recent work Turner *et al*. (2018c,d) extends the decomposed multiplier approach to other European and international economy contexts.

An interesting feature in moving from the extension studies in Section 3.2 to the full economy-wide ones here is in terms of '**scale vs. intensity**' in reporting of multiplier results. The extension studies discussed all identify and consider specific scenarios. In reporting they tend to focus on the overall scale of multiplier impacts emerging. That is, the underlying multiplier applied to (multiplied by) the scale of activity emerging for the given scenario. The economy-wide studies reviewed here tend to focus on the underlying multiplier itself, with **more focus on what the marginal or incremental impacts of increased activity under any given scenario may be**. The full Smith *et al*. (2017) EPSRC Supergen H2FC hub White paper that Turner *et al*. (2018b) is based on does both (with scenarios for a switch to hydrogen fuelled vehicles simulated via the UK TIMES energy system model). However, it is the headline multiplier results (or average 'intensity' of economy-wide impact in terms of GDP, jobs, wage, income) and their 'source sector' breakdown that is the focus of the later Turner *et al*. (2018b) publication, with potential scenario analysis identified for a wider range of electric vehicle 'power train' applications.

The key point developed in the new research reported here is that it is the underlying multipliers themselves that provide a **basis for reporting metrics** – such as **cost per job (CPJ)** – that become relevant in **cost effective analysis (CEA) appraisal of government spending options**. It is also possible, as in the Turner (2015) CO_2-EOR study, to back track underlying scenario-specific multipliers out of calculations that report both direct activity levels and/or government spending simulated and the total multiplier impacts estimated. These will be entirely consistent with multiplier metrics used as tools to generate results, but set these in the context of the given level of, for example, public or RD&D activity considered in the scenario simulated.

Two reports are fully reviewed in Appendix 3. The first is the 'Preliminary Study on Developing Economic Multipliers for CO_2-EOR Activity' by Karen Turner (the CO_2-EOR study, Turner, 2015). The second is the CEP brief entitled 'Making the macroeconomic case for near term action on CCUS in the UK'. As with the current study, both are authored by CEP team members, which reflects the lack of attention to date to wider set of societal costs and benefits in the CCUS discussion. **What are the key conclusions that can be drawn in terms of where we need to go next?**

Importantly for our purposes here, a crucial point is that the type of analysis conducted in the CO_2-EOR study was the **first real attempt to produce economy-wide metrics that can be used to frame policy (and government support) arguments around CCUS**. As noted above, it also lays foundations for developing multiplier metrics with a view to informing public sector evaluation processes such as CEA, which come into play if any form of government support is likely to be required. Moreover, it demonstrates the richness of detail that can be generated from a comprehensive multiplier analysis, through explanation of economy-wide effects in terms of the breakdown of economic impacts across and within sectors. The work presented in the Turner *et al*., (2018a) brief takes this forward in narrative terms, concluding that the **'sustained contribution' of existing high value sectors, in which we have already invested and from which we need to realise growing value**, driven directly or indirectly by roll out of CCUS and/or linked activities such as hydrogen, is likely to be the **most compelling economic narrative** in the current UK context.

In terms of **metrics**, one key point already noted above is that the CO_2-EOR study sets multiplier metrics up in terms of the **value of government support associated with CCUS.** This is distinct from the focus on activity levels associated with expenditure levels more generally in the standard multiplier metrics used in the Turner *et al*. (2018a) work. This provides a basis for considering how multiplier metrics could be restated in terms of the type of 'cost per job', or other **outcome(s) commanding societal value**, metrics that are used in the context of UK public policy appraisal linked **social Cost-Effectiveness Analysis (CEA)**. [5] Multiplier results could be focussed in this way where the concern is in terms of spending having to be made, rather than (or as well as) the type of broader narrative development that the Turner *et al*. (2018a) brief focusses on. Moreover, this may be a useful approach in a broader range of low carbon settings (e.g. hydrogen) and for a wider range of outcomes valued by society (i.e. not just absolute number of full-time equivalent jobs).

We consider this proposition further in the context of the new Scottish analysis presented below (Section 5). However, a key feature of the CO_2-EOR multiplier study not developed further at this stage is how the nature of the stimulus will depend on the scenario in question. That is, in the EOR context, the multiplier impacts triggered by government spending to support CCUS (with capture in the power sector) are enhanced by an additional market stimulus through demand for oil recovered via EOR processes. The study considers how this additional stimulus can be attributed back to initial £ of government spending. For example, the study finds total economy-wide impacts of £7.15 in additional output and £3.94 in additional GDP per £1 of government support for CCUS deployment in the (coal) powered electricity generation sector.

Another crucial feature of the CO_2-EOR study, as well as in the economy-wide Hydrogen study (Smith *et al*.; 2017; Turner *et al*., 2018b), is that (albeit experimental[6]) full IO modelling is used to more comprehensively understand the sectoral location of multiplier impacts. UK IO data are used to compute and also decompose multiplier effects to consider sectoral sources of supply chain benefits. This is in contrast to Turner *et al*. (2018a), where the authors opt to use headline multiplier data generated by ONS for BEIS. In the absence of the underlying, more granular published IO data in the appropriate form for multiplier analysis being available at the time. The benefit of accessing data produced by the national statistical agency is thus set against the cost of only being able to scrutinise

[5] CEA compares the costs of alternative ways of producing the same or similar outputs and is identified in the HM Treasury 'Green Book' (on public sector spending/project appraisal and evaluation) as an (imperfect) variant of full Social Cost-Benefit Analysis (SCBA).

[6] Experimental here means that the IO matrices used to compute and decompose multiplier using data in the required analytical (basic price industry-by-industry) form were estimated based on a conversion of matrices publicly reported in market price supply-use format published by ONS. This is necessary to provide the level of granularity required for analysis breaking out sectoral/industry sources of multiplier effects.

high-level multiplier effects that could be generated. With access to the underlying data, it would be possible to break down full multiplier effects, as was done in the CO_2-EOR study.

On the other hand, the **Scottish Government publishes a full set of IO accounting data**, including the full analytical matrices in industry-by-industry basic (producer) price format required to conduct more detailed multiplier analysis. Therefore, here, we at CEP have been able to use these data to model the full breakdown of economy-wide multiplier impacts for Scotland for activity levels in CCUS (and hydrogen) relevant sectors. This type of research allows a **fuller picture** to be painted of **overall societal value**, including breaking down the economic effects for different sectors and to provide the basis for generating metrics relevant to public sector spending appraisal. We present research that begins to do this for Scotland in the next section.

5. Building understanding of the potential wider societal impact of CCUS for Scotland

5.1 Context for the new Scottish work

The work presented in the CEP brief (Turner *et al*., 2018a) used ONS-BEIS headline multiplier metrics data rather than full IO data required for fuller analysis of the breakdown of multiplier effects across sectors of the economy. Nonetheless, it set out the next stage in the development of a robust analytical approach to understanding the wider societal value of CCUS and potential linked activities, such as hydrogen deployment. This section of our report presents research that applies that next stage analytical approach. The focus and contribution is two-fold.

First, to retain the full economy-wide multiplier study approach of decomposing in a manner in line with both the C02-EOR study and the economy-wide Turner *et al*., (2018b) Hydrogen study, but here with a focus on Scotland. Given the availability of the full Scottish analytical IO dataset, we have been able to conduct the multiplier analysis in a way consistent with that in the economy-wide Hydrogen study (Turner *et al*., 2018b, where the analysis was focused on Low Emissions Vehicles). That is, the analysis gets at the **direct and indirect implications for existing industries were new low carbon solutions to be deployed** (thereby providing a framework that may be developed and employed in a wider range of low carbon economic development settings, not limited to CCUS).

Second, to adapt presentation of headline multiplier results – here for employment, but referring also to GDP results from the Turner (2015) CO_2-EOR study – to provide an initial demonstration of what would be involved in derivation of **'cost per valued outcome'** metrics to inform the simpler social cost effectiveness analysis (CEA) used in **public sector appraisal**.

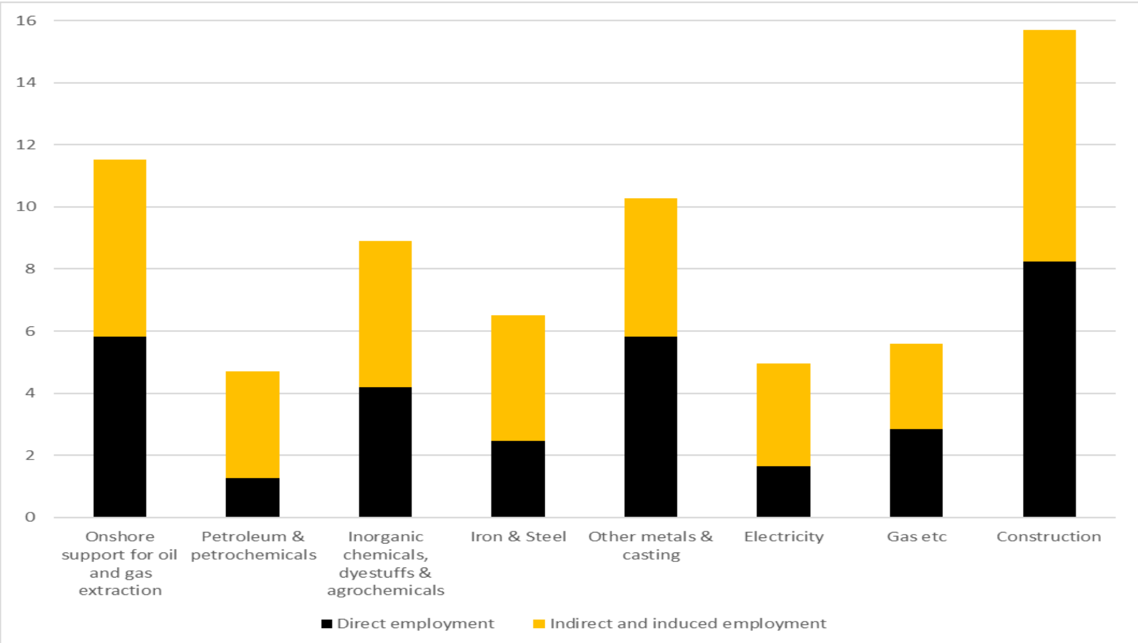
More generally, we extend the existing primary research base for economy-wide impacts from a national (UK) to a regional (Scottish) level context. Scotland is a particularly interesting case to show the additional and extended analysis that can be done if the underlying data permit consideration of the current economic structure, including clustering of potential capture industries, and opportunities presented by existing oil and gas extraction and distribution infrastructure capacity. In particular, focus on potential '**carbon capture clusters**' requires a greater degree of regional focus, potentially even lower than the devolved regional level of our new analysis here. This is because CCUS is likely to involve rollout via clusters of industrial activity in particular locations within the UK. This, in turn, may indicate a need to move from, or at least combine, CEA-type metric development with the fuller insight of SCBA, where different weight attached to, or means of **valuing different outcomes in different areas** may be required.

However, construction of IO data at regional and/or devolved level within the UK is limited, with Scotland being the only sub-national case where official region-specific IO data are routinely published[7]. Thus, it is outwith the scope of the current study to consider more spatially detailed analysis and the potential implications in terms of metrics to inform public sector appraisal methods. However, this should be a focus of future national accounting and research.

5.2 Scottish multiplier analysis to inform the 'sustained contribution' narrative development

In Figures 1 and 2 we report multiplier metrics that incorporate direct, indirect (inter-industry) and induced (wage income-expenditure) employment effects for key CCUS relevant industries, including gas production and distribution in the context of potential future hydrogen deployment.[8] Note that Figure 1 in particular should not be directly compared with the equivalent UK in shown in the CEP brief (Turner *et al*., 2018a) because (a) the IO data are reported for different years; (b) there is some variation in industry groupings reported and (c) includes induced (consumption and income) multiplier elements.[9]

Figure 1. Output-employment multipliers for selected Scottish industries: FTE jobs across the Scottish economy per £1million industry output produced to meet final demand



Source: Authors' calculations using [Scottish input-output tables]() for accounting year 2014.

In terms of this second point (b), there are two key cases where industry classifications in the Scottish results reported below differ from their UK counterparts. First, due in particular to the ownership of

[7] We also note that even so, due to the complexity of the data involved, IO tables are reported with some time lag: the most recent year for which Scottish IO data that were available at the time of conducting the applied work for this study, 2014.

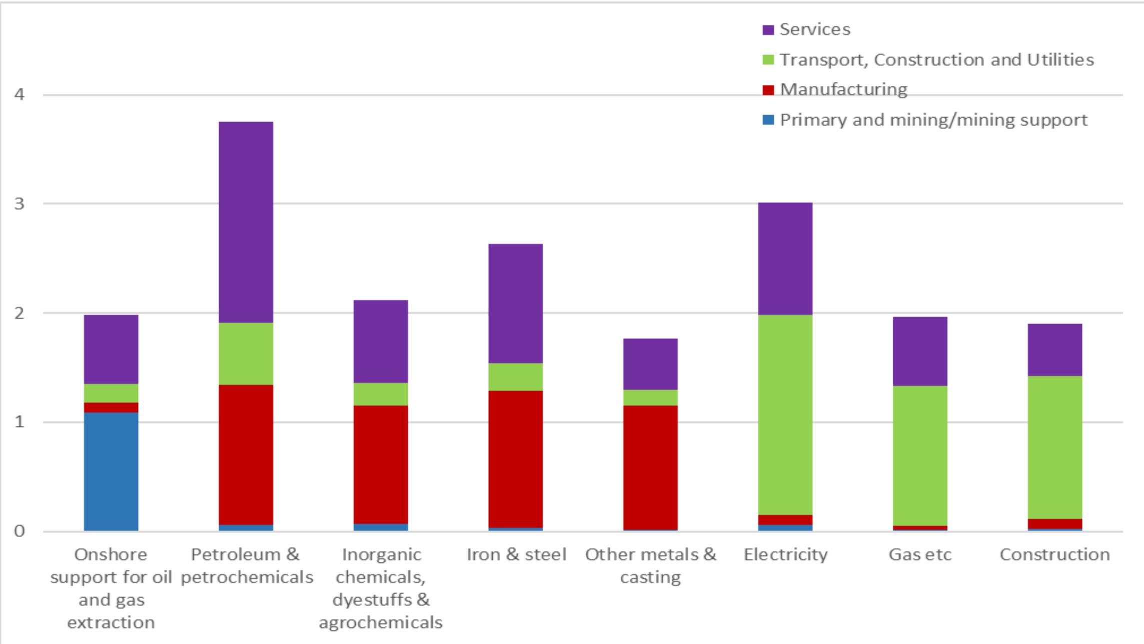
[8] Our calculations are based on the 2017 issue of the Scottish Government IO tables for 2014. Since the time of conducting analysis a subsequent (2018) issue has been published. Due to accounting updates, the specific multiplier values reported here are likely to differ slightly from those calculated using the more recent data issue.

[9] This is the 'Type II' form of multiplier analysis, which incorporates consideration of additional induced effects that result from the fact that wage income from employment is spent by Scottish households, thus triggering a further round of multiplier effects

various activities at the Grangemouth complex in the Eastern Central Belt of Scotland, non-disclosure issues mean that the reporting definition for the industry grouping including petrochemicals is different to that of the UK. Second, note that we have not included an Oil and Gas Extraction Industry. This is because only a small on-shore mineral extraction industry is reported within the Scottish IO accounts. The off-shore industry is formally located in an extra UK 'production only' region, the Continental Shelf. The Scottish Government is in the process of developing IO accounts that link the Scottish IO framework to Scottish and other UK off-shore activity. However, these accounts are not yet publicly available or in sufficient state of development for the purposes of the type of research reported here. We return to the question of how the contribution of the off-shore oil and gas industry to the Scottish economy can be considered using existing data below.

In considering comparable multiplier metrics for any sub-national region or devolved nation, the first thing to note is that values will be smaller than those observed at the wider national level. This is simply because the geographical space and economy will be smaller and rely to some extent on imports from the wider economy. That is, 'leakage' from the domestic multiplier will be greater. In Figure 1, for example, if the wider UK supply chain could be captured, this would result in a larger 'indirect and induced' bar for each industry. Ultimately, where data permit, it could be possible to capture full global supply chain multiplier effects (see Turner *et al*. 2018c,d).

Figure 2. Employment-employment multipliers for selected UK industries: FTE, indirect and induced (supply chain) jobs grouped into broad industry areas across the Scottish economy per direct industry FTE job[10]



Source: Authors' calculations using [Scottish input-output tables](#) for accounting year 2014.

Figure 2 reports the employment multiplier in terms of total direct, indirect and induced jobs supported across the Scottish economy (the full bar for each sector in Figure 1) per direct industry job (the black portion for each sector in Figure 1). In absolute terms, a key point to note from Figure 2 is the examples of key potential capture industries, for example, the sector including petrochemicals

[10] Note that 'Gas etc.' is the label used in the Scottish Government IO tables for the 'Manufacture of gas; distribution of gaseous fuels through mains; steam and aircon supply'

(where carbon capture is relevant *now*) and gas (relevant in a hydrogen future), showed relatively small multipliers in Figure 1 where focus is on jobs per unit of output. This is in large part due to the **capital intensity** of production in these sectors. In Figure 2, where data are presented in an alternative way to focus attention on a ratio of total to direct jobs the multiplier impact is relatively large in the case of more capital intensive activities. In this regard, Figure 2 reflects the fact (discussed for the UK in the CEP brief, Turner *et al*., 2018a) that **for every one direct job gained, sustained or lost, a significant level of different types of jobs in a range of other industries across the wider economy may be impacted**.

For example, according to the 2014 IO data used here, there are **1,926 direct FTE jobs in the 'Petroleum and petrochemicals' industry**. If 10% of these, or 193 jobs were lost/relocated outside of Scotland, the employment-employment **multiplier of 3.75** (the full bar in Figure 2) suggests that 724 **additional jobs would be impacted across the Scottish supply chain**. The purple component of the bar shows that just over half of these would be in Scottish service sectors.

Identification of this latter result, reflects the fact that, for the Scottish analysis, we have access to the underlying IO data and this enables fuller inspection of the industry composition/location of supported multiplier jobs. Thus, the results provide fuller information on the nature of Scottish economic activity and jobs that may be sustained where CCUS enables the continued performance of industries such as those represented in Figure 2. For simplicity we have focussed on four broad sectoral groupings where jobs across the Scottish economy are supported by activity in the eight sample 'CCUS-relevant' industries; however, results are available to report the distribution of indirect impacts across all 98 sectors reported in the Scottish IO.

The main pattern to note is the dominance of the broad Scottish 'Services' sector as the location of supported supply chain jobs across most of the industries we focus on in Figure 2. This reflects arguments put forward in the Hydrogen study by Turner *et al*., (2018b) regarding the importance of considering a fuller range of supply chain activities. That is, beyond the technical requirements most commonly considered in the context of potential CCUS deployment.

In providing a final example of how employment multipliers of the type reported in Figure 2 may be used, we return to the issue of the **off-shore oil and gas industry in Scotland**. As explained above, there is a problem in that this industry is not reported as part of the Scottish economy in national accounting frameworks such as the IO tables. Instead, Scottish industries export to the off-shore industry. The off-shore oil and gas extraction industry (which is fully incorporated in the UK level IO data used in the CO_2-EOR and CEP studies (Turner, 2015; Turner *et al*., 2018a) will purchase inputs from a wide range of Scottish industries (and these will show as 'exports to the rest of the UK' in the Scottish IO tables).

Informal initial access to the off-shore accounts currently in development[11] and inspection of the UK IO sector, suggests that around half of Scottish industries will be directly impacted (via direct 'export demand' from the off-shore sector) to some extent. However, sectors like the Mining Support and Construction sectors above, along with manufacturing sectors such as Fabricated Metals and service sectors such as Financial Services and Legal activities, are the main direct beneficiaries. Thus, it would be possible to assess the impacts of changes in activity in the off-shore oil and gas industry – for example if CCUS enabled an adjusted timeframe for decommissioning enabling current activity levels to be sustained – using one or both of the types of multipliers above for these Scottish industries.

[11] We acknowledge the kind cooperation of the Scottish Government Input-Output Team in this regard.

For example, the clearest direct beneficiary of 'export demand' from the off-shore sector is the **on-shore Mining Support industry**, which could be expected to pay a key role in delivery of carbon transport and storage services, just as it does with oil and gas extraction and distribution. With only limited on-shore extraction activity back in 2014 (before shale gas extraction began proper in England), and the majority of Continental Shelf extraction activity being in the Scottish North Sea, we can assume that the off-shore extraction industry is the main demand driver of most of the Mining Support sector's exports to the rest of the UK in that year. The 2014 IO figure for this item is £3,175million. If we apply the onshore support for oil and gas output-employment multiplier from Figure 1, which is 11.53 this tells us that a total of around 36,612 Scottish jobs were supported by this particular source of demand. In total (with non-household final demand, including non-UK export demand, of £3,840) **44,284 Scottish jobs** are supported by demand for the Mining Support industry. In either case, just over a half of these (51%) are direct (black bar from Figure 1), so that the remaining 49% are indirect and induced supply chain jobs. Reference to Figure 2 tells us that 32% of the total are service sector jobs.

Nonetheless, it is important to note that, given the lack of fuller information to conduct a more extensive multiplier analysis of how the off-shore oil and gas industry supports activity in the Scottish economy via direct 'export' demand for the output of a range of industries, our analysis here is rendered incomplete.

Extensions to the multiplier analysis above could, however, be carried out for the sectors and activities that we can identify in the currently reported Scottish IO accounts. For example, a fuller multiplier analysis of wage income, to reflect '**quality of jobs**' or '**wage premium**', and total value-added (GDP) variants of Figure 2 (e.g. see Turner *et al.,* 2018b) would provide a richer set of information for a fuller range of case examples relevant to CCUS. Ultimately, however, given that the roll-out of CCUS would have a **range of market and fiscal impacts**, it is advisable to incorporate the richness of the IO database used here in a more flexible economy-wide model. To this end, the Scottish Government and research community already make use of the computable general equilibrium (CGE) model developed at the University of Strathclyde's Fraser of Allander Institute. The team at the Centre for Energy Policy have played a key role in developing this for energy and climate policy analysis and are currently engaged in considering how it may be further adapted to consider issues around CCUS and hydrogen deployment (e.g. see Turner and Race, 2016).

5.3. Initial consideration of converting multiplier results to public sector CEA-relevant metrics (example of employment multipliers and CPJ)

One thing that none of the extension of economy-wide studies reviewed attempt to do is directly set multiplier results in the language or metrics directly relevant to public sector appraisal techniques such as social cost benefit analysis or social cost effectiveness analysis. As discussed above, the Turner (2015) CO_2-EOR study comes closest, by expressing multipliers in terms of "the implied government intervention" (Turner, 2015, p.5). That is, rather than focussing on the broader per unit of total final expenditure or direct jobs/GDP that IO multipliers reported with national accounts are generally stated in terms of, the report considers scenarios for the scale of total socially valued 'outcome' activity (e.g. GDP) that can be generated *as a result of government intervention* (via CfD).

The key point is that while these may map directly (given that government expenditure is an element of final expenditure in IO report), this will depend on the scenario being considered. In the CO_2-EOR study the key focus is on a scenario involving EOR, and a second 'trigger' of market demand for oil recovered. This involves considering a combination of activities that multipliers are reported for and both public and private spending, then relating that combination back to the pound amount of required government spending to support just one of the activities (carbon capture in the electricity generation sector).

The result is referred to as the **implied government intervention multiplier** – GDP generated per £1 of government spending. What is missing is the translation to the 'cost per valued outcome' that we propose here. But this is simple to derive. In Table 1 we adapt the GDP results reported in the summary table on p.5 of the Turner (2015) report to express in terms of 'cost per £1 of GDP' (the GDP equivalent of cost per job). That is, in the first numerical column we repeat the headline result of GDP per £1 of government spending reported in the CO_2-EOR. In the second we simply invert this (£1 divided by the multiplier value) to report in terms of the cost of realising the valued outcome (each monetary unit of GDP).

Table 1. CO_2-EOR study 'Implied government intervention GDP multipliers' expressed in CEA 'cost of valued outcome' metrics

Scenarios	Implied government intervention multiplier - GDP (£ per £)	Implied public cost per £ of GDP
1. Off-shore wind	1.52	£0.66
2. Coal-CCS	1.16	£0.86
3. Coal-CCS with CO2-EOR	3.94	£0.25

Can we do this for the new Scottish multiplier work reported in Section 5.2? The answer is strictly 'no', given that we do not analyse a specific scenario around a particular CCUS activity/project or level/nature of government spending involved. However, it is possible to demonstrate the same type of adjustment that may be performed if the employment-output multipliers reported in Figure 1 (which express total jobs generated per £1million of final demand expenditure) did in fact relate to some element of government expenditure in those sectors to support deployment of a CCUS outcome.

Table 2. Expenditure per job implied by Scottish industry output-employment multipliers

CCUS-relevant sector	Employment-output multiplier (Jobs per £1million of final demand)	Implied expenditure per job
Onshore support for oil and gas extraction	11.53	£86,720
Petroleum & petrochemicals	4.71	£212,246
Iron and steel	6.51	£153,647
Inorganic chemicals, dyestuffs & agrochemicals	8.90	£112,312
Other metals & casting	10.28	£97,260
Electricity	4.96	£201,605
Gas etc	5.58	£179,143
Construction	15.69	£63,731

That is, suppose government support for carbon capture and/or transport/storage related activity – or, for example, a switch to hydrogen production in the case of the 'Gas etc' sector - in one of these sectors enabled continued production in that sector (linking to the 'sustained contribution' narrative). Under these circumstances, it may be appropriate to translate the Scottish 'output-employment' multipliers from Figure 1 in CPJ terms. On the other hand, it may be more appropriate to contemplate the illustrative conversion in Table 2 in 'expenditure per job' terms, reserving consideration of the extent to which expenditure relates to a government spending/intervention cost. On this basis, and more generally for purposes of demonstrating the data manipulation involved, the first numerical column in Table 2, records the total employment multiplier values in figures mapping to what is reported in Figure 1, while the second inverts to report in 'expenditure per job'.

The standard approach in cost effectiveness analysis is to compare options across CPJ, or cost of delivery of other valued outcomes. While this may be straightforward in the case of Table 1, where the multipliers converted to 'cost per valued outcome' metrics are based on specific scenario analyses, the metrics reported in Table 2 should not be interpreted so directly. That is, any given CCUS deployment option is likely to involve different types of activity over different types of sectors, and a mix of both public and private spending via different instrument(s) and market. Thus, it is not simply a case of deciding which sector to direct support at to create the most jobs throughout the economy and back a CPJ measure out of to inform CEA.

Rather the multipliers in Figure 1/Table 2 (and/or Figure 2, where, for example, scenario input data may focus on direct jobs being created rather than/as well as different expenditures involved) would first be applied in the type of scenario analysis that would generate the type of outcomes reported in the CO_2-EOR study (and replicated in the first column of Table 1). Nonetheless, Table 2 both demonstrates the relationship between multiplier and 'cost per' metrics. It also gives a more general idea of where wider job creation may be most cost effectively supported: in short, this will be in sectors with stronger domestic supply chain linkages where larger multipliers will by definition require the lowest expenditure to achieve a given domestic outcome.

6. Conclusions and recommendations

This report has reviewed a number of key studies on the economic value generated by CCUS and conducted new research on the wider economic value of CCUS in Scotland. The key conclusion is that the need for a **transparent and easily communicated way of measuring the societal value of CCUS** in economy-wide or macroeconomic terms can be met through identification of an outcome that is valued by society (e.g. jobs, GDP) and the use of multiplier metrics to compute the impacts of CCUS deployment in these terms and/or the expenditure (private and/or public) required to achieve them. More specifically where economy-wide multiplier analyses can be set in the context of scenarios for both deployment of CCUS (and other low carbon options such as hydrogen) and projected government support requirements, the latter type of metric is consistent with input to a Social Cost-Effectiveness Analysis (CEA). CEA is a simpler variant of Social Cost Benefit Analysis (SCBA) recommended in the HM Treasury 'Green Book' that compares the costs of alternative ways of producing the same or similar outcomes. The 'cost per job' metric is perhaps the best known among those used in this sense to inform government intervention decisions. Computation of multiplier metrics in the first instance in terms of required expenditure per unit of the socially valued outcome, then moving (through scenario development and analyses) to focus on government intervention costs, would help support communication of the potential of CCUS to sustain existing industries. Taking a multiplier approach that focuses on wider value generation through indirect supply chain impacts also helps consider the value of CCUS in terms of alignment with priorities in the UK's Industrial Strategy.

While not researched in detail here, we note that some further development of this type of approach and metric that is more in line with a fuller SCBA may be appropriate. For example, it is possible to develop CEA methods and metrics to reflecting different societal valuation methods and/or weights that may be placed on different types of jobs in different areas of the country. This may be important in a CCUS context where regional clustering of CCUS is the focus and, thus, spatially targeted government intervention and appraisal is likely to be relevant. Designing of further research on this type of development may be best made in consultation or by civil servants once the basic message of the type of multiplier and expenditure/cost metrics proposed here is fully understood and agreed.

Through our review of studies that have analysed the potential economic impact of CCUS using techno-economic, extension or economy-wide approaches, we have also explored the evolution of research on CCUS economics. We find that early studies focussed on analysis of a 'bottom up' nature, producing important data on deployment costs and information on how those could be brought down overall by using early publicly-supported investment to reduce risk for future projects. These studies did not seek to address questions of wider societal value head-on.

Later – and specifically in the UK context following the cancellation of the CCUS competition in November 2015 - the research questions asked in studies seem to have moved into relatively new territory. Extension studies sought to more robustly quantify the indirect GVA and jobs impacts of CCUS deployment, using economic multipliers in conjunction with more direct cost benefit data for various deployment scenarios. We conclude that this is a positive move and one that should be taken further, to incorporate fuller modelling of the economy-wide effects of CCUS deployment. A first step has been taken for CCUS already, with publication of a UK study on enhanced oil recovery with CCUS back in 2015. That study sits a little apart from other studies at the time as it was a joint industry project commissioned when the oil price was relatively high (providing a driver for industry to better understand the economics of EOR with CCUS). Recently, analysis with a similar multiplier approach has been reported for CO_2-EOR in the US (CURC, 2018). Additionally, two further pieces of recent research conducted in a UK context demonstrate how the economy-wide picture can be built for CCUS and also for hydrogen generating data that begin to get to the heart of the societal value case for CCUS, hydrogen and potential other options to enable a low carbon transition (Turner *et al.,* 2018a; Turner *et al.,* 2018b).

Our analysis for Scotland found that, while overall multiplier impacts should be expected to be lower than at UK level (due to the smaller size and greater openness of the Scottish economy), jobs in a broad range of Scottish industries may ultimately be supported if CCUS sustains just a few key CCUS-relevant ones. These include petrochemicals (a capture candidate industry *now*), gas supply (potential future capture linked to hydrogen) and onshore support for oil and gas extraction (linked to transport and storage services that could be provided by the off-shore oil and gas industry). The derivation of 'expenditure per job' metrics from multipliers was demonstrated. This was set up as a precursor to more formally CEA 'cost per job' metrics that would emerge from focussed scenario analysis using multipliers, and thus qualified in terms of the lack of scenario basis regarding a portfolio of CCUS roll-out activity that may require government support.

Based on our review of existing studies and our new analysis for Scotland, we conclude that the application of a full economy-wide analytical approach is essential for arriving at a robust societal value case for CCUS. In order to frame an economic route map for CCUS, knowledge and data from techno-economic analyses must be integrated with fuller economy-wide modelling, where the latter may ultimately require more sophisticated and flexible modelling techniques in order to capture a wider range of causal processes and outcomes. For example, the Industrial Strategy is concerned with improving competitiveness in a range of ways not limited to domestic supply chain development, and IO methods are not ideally suited to analysing price impacts. Similarly, if there is a need to consider fiscal measures and impacts, the IO database and base line multipliers should be embedded in the type of computable general equilibrium (CGE) models methods used for policy evaluation by Scottish Government and HM Treasury (and with developments for CCUS in this context proposed in Turner and Race, 2016).

This leads us to close this technical report by making the following three high-level recommendations:

1. ***Key metrics in the form of the type of 'cost per valued outcome' (e.g. cost per job) used in the Social Cost Effectiveness Analysis (CEA) recommended in the HM Treasury 'Green Book' should be considered future analyses of the value case for CCUS, as well as hydrogen and other low carbon technology options.***

IO multiplier analysis provides a first step in generating these metrics, with IO multipliers derived from national accounting data constituting a key input to studies focussed on societal value. Multiplier metrics can also form a key output of studies through statement of valued outcomes across the economy from expenditure and/or job creation directed to particular sectors. Moving to multiplier outcomes that can be presented in terms of public 'cost per' metrics for option appraisal as set out in the HM Treasury 'Green Book' will involve development and modelling of scenarios in IO or other economy-wide modelling frameworks employed for policy simulation and appraisal.

2. ***More generally, evidence generation should focus on informing decision makers regarding the source and determination of a wider societal costs and benefits likely to emerge from CCUS and both complementary and alternative low carbon options under different project and public support scenarios.***

This should include extending both to (a) a wide range of wider economic impacts across different sectors of the economy and key indicators emerging from the deployment and/or support of different options, and (b) how these impacts and the societal value associated with them may be reflected in appropriate and useful metrics. This may extend to combining simpler CEA 'cost per' approaches to more with approaches used in fuller social cost benefit analyses (SCBA) to better measure societal value achieved. This is likely to apply particularly (but not exclusively) where CCUS, linked solutions such as hydrogen development and any public support activity is likely to be spatially distributed and/or directed across different regions and/or industry clusters within Scotland/the UK.

3. ***To inform societal value analyses, more comprehensive and publicly available input-output (IO) reporting is necessary.***

IO provides a framework, based in national accounting practices and reporting, for considering interactions and interdependencies across the economy. When reported in the appropriate analytical form for multiplier analysis, it provides a simple and transparent economy-wide modelling framework to consider and evaluate scenarios and implied societal value generated by public support. Where a more sophisticated modelling approach is required to consider price and market, competitiveness and fiscal issues, it may be appropriate (for scenario and/or outcome appraisal) to extend analytical capacity via development of fuller economy-wide modelling approaches, including the computable general equilibrium, CGE, methods already employed by Scottish Government and HM Treasury.

References

BEIS, 2017a. 'Industrial Strategy: Building a Britain fit for the future', UK Department for Business, Energy and Industrial Strategy [online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664563/industrial-strategy-white-paper-web-ready-version.pdf .Referred to in this report as '**the Industrial Strategy**'

BEIS, 2017b. 'The Clean Growth Strategy': Leading the way to a low carbon future. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf .Referred to in this report ad '**the Clean Growth Strategy'**

BEIS, 2018. 'The UK Carbon Capture Usage and Storage Deployment Pathway: an Action Plan' UK Department for Business, Energy and Industrial Strategy [online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/759637/beis-ccus-action-plan.pdf

CCUS Taskforce, 2018. 'Delivering Clean Growth: CCUS Cost Challenge Taskforce Report', UK Department for Business, Energy and Industrial Strategy [online]. Available at: https://www.gov.uk/government/publications/delivering-clean-growth-ccus-cost-challenge-taskforce-report. Referred to in this report as **'the Taskforce report'**

CCUSA & TUC, 2014. 'The economic benefits of carbon capture and storage in the UK', CCUSA [online]. Available at: https://www.tuc.org.uk/sites/default/files/carboncapturebenefits.pdf

CURC, 2018. 'Making Carbon a Commodity: The Potential of Carbon Capture RD&D'. Available at http://www.curc.net/making-carbon-a-commodity-the-potential-of-carbon-capture-rdd .Referred to in this report as **'the US EOR study'**

Element Energy & Pöyry, 2015. 'CCUS Sector Development Scenarios in the UK'. ETI [online]. Available at: https://www.eti.co.uk/library/ccs-sector-development-scenarios-in-the-uk

ETI, 2015. 'Building the UK carbon capture and storage sector by 2030 – Scenarios and Actions'. Energy Technologies Institute [online]. Available at: https://www.eti.co.uk/insights/carbon-capture-and-storage-building-the-uk-carbon-capture-and-storage-sector-by-2030 .Referred to in this report as '**the ETI study**'

ETI, 2016. 'Reducing the Cost of CCUS – Developments in Capture Plant Technology'. Energy Technologies Institute [online]. Available at: https://www.eti.co.uk/insights/reducing-the-cost-of-ccs-developments-in-capture-plant-technology

HM Treasury, 2018. 'The Green Book: appraisal and evaluation in central government'. UK Government [online]. Available at: https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

IEA, 2009. Technology Roadmap - Carbon Capture and Storage 2009'. Available at: http://www.iea.org/publications/freepublications/publication/CCUSRoadmap2009.pdf Since superseded by IEA 2013: 'Technology Roadmap - Carbon Capture and Storage 2013' Available at: https://webstore.iea.org/technology-roadmap-carbon-capture-and-storage-2013

Port of Rotterdam Authority, 2018. 'Studying Feasibility of CCUS in Rotterdam'. Available at: https://www.portofrotterdam.com/en/news-and-press-releases/port-authority-gasunie-and-ebn-studying-feasibility-of-ccs-in-rotterdam

Pöyry (2018) 'Fully decarbonising Europe's energy system by 2050', [online] p.1-15. Available at: http://www.poyry.com/news/articles/fully-decarbonising-europes-energy-system-2050

SINTEF, 2018. 'Industrial opportunities and employment prospects in large-scale CO_2 management in Norway'. *SINTEF* [online]. Available at https://www.nho.no/contentassets/e41282b08ceb49f18b63d0f4cc9c5270/industrial-opportunities-ccs_english.pdf .Referred to in this report as '**the SINTEF study**'

Smith, M., Turner, K., Alabi, O., Dodds, P. and Irvine, J., 2017. The economic impact of hydrogen and fuel cells in the UK: a preliminary assessment based on analysis of the replacement of refined transport fuels and vehicles', White Paper published by EPSRC H2FC Supergen, [online]. Available at http://www.h2fcsupergen.com/download-economic-impact-hydrogen-fuel-cells-uk/

Summit Power, 2017. 'Clean Air, Clean Industry, Clean Growth: How Carbon Capture Will Boost the UK Economy'. Carbon Capture and Storage Association [online]. Available at: http://www.ccsassociation.org/news-and-events/reports-and-publications/clean-air-clean-industry-clean-growth/ .Referred to in this report as '**the East Coast study**'

Summit Power Caledonia UK Ltd., 2018. 'Caledonia Clean Energy Project: Feasibility Study Phase 2'. Available at https://summitpower.com/wp-content/uploads/2018/06/CCEP-Feasibilility-Final-Report-MAY-2018-SUMMARY-VERSION.pdf

Turner, K. 2015. 'Preliminary Study on Developing Economic Multipliers for CO_2-EOR Activity: An initial examination of developing a multiplier for CO_2-EOR to examine and compare financial benefit'. Scottish Carbon Capture and Storage [online]. Available at: http://www.sccs.org.uk/expertise/reports/co2eor-joint-industry-project .Referred to in this report as '**the CO_2-EOR study**'

Turner, K. and Race, J., 2016. 'Making the macroeconomic case for CCUS', *Carbon Capture Journal*, Future Energy Publishing, Vol. 54, pp. 14–15. Available at: https://pure.strath.ac.uk/portal/files/62682906/Turner_Race_CCJ2016_Making_the_macroeconomic_case_for_CCUS.pdf

Turner, K., Race, J., Alabi, O., and Low, R., 2018a. 'Making the macroeconomic case for near term action on CCUS in the UK? The current state of economy-wide modelling evidence', *University of Strathclyde,* [online]. Available at: https://strathprints.strath.ac.uk/63554/1/Turner_etal_IPPI_2018_Making_the_macroeconomic_case_for_near_term_action_on_CCUS_in_the_UK.pdf .Referred to in this report as '**the CEP brief**'

Turner, K., Alabi, O., Smith, M., Irvine, J., and Dodds, P., 2018b. 'Framing policy on low emissions vehicles in terms of economic gains: Might the most straightforward gain be delivered by supply chain activity to support refuelling?', *Energy Policy,* [online] 119, pp.528-534. Available at: https://www.sciencedirect.com/science/article/pii/S0301421518303033?_rdoc=1&_fmt=high&_origin=gateway&_docanchor=&md5=b8429449ccfc9c30159a5f9aeaa92ffb .Referred to in this report as '**the Hydrogen study**'

Turner, K., Katris, A., de Vries, F. P., & Low, R., 2018c. 'The Just Transition Challenge: Avoiding Carbon Leakage and Jobs Off-Shoring in Decarbonising International Supply Chains', *University of Strathclyde*, [online]. Available at: https://strathprints.strath.ac.uk/66207/

Turner, K., Katris, A., & de Vries, F. P., 2018d. 'Beyond Carbon Leakage: Off-Shoring of Employment and GDP in Decarbonizing International Supply Chains', *University of Strathclyde*, And [Online] .Available at: https://strathprints.strath.ac.uk/66208

United Nations Framework Convention on Climate Change [UNFCCC]. (2015). Paris agreement. Available at https://unfccc.int/sites/default/files/english_
paris_agreement.pdf

ZEP, 2018. European Zero Emissions Platform (ZEP) report: 'Role of CCUS in a below 2 degrees scenario' [online].Available at: https://tinyurl.com/CCUSBelow2degrees .Referred to in this report as '**the ZEP report**'

APPENDIX 1. FULLER REVIEW OF TECHNO-ECONOMIC STUDIES

A1.1. Energy Technologies Institute study

The ETI insight report 'Building the UK carbon capture and storage sector by 2030 – Scenarios and Actions' was produced in partnership with Element Energy and Pöyry and published in 2015. It draws together several strands of ETI work to set out three potential pathways to deployment and an assessment of the public support costs of each (these costs were largely to be met through the levy control framework, i.e. CfDs). The research extended previous modelling-based analysis, using three "ambitious but deliverable" scenarios to illustrate how the UK can build the CCUS sector by 2030. The scenarios were:

- Concentrated – a gas power plant-dominated scenario with concentration around two initial projects (this was the lowest cost scenario explored, with £14bn CfD costs and £21bn CAPEX spend out to 2030);
- Enhanced Oil Recovery-led – assumes a £20/t CO_2 price to EOR and support for this market pull from e.g. tax incentives (CfD costs of £14bn and CAPEX spend of £27bn out to 2030);
- Balanced – multiple regional clusters with store and technology diversity leading to risk reduction (this was the highest cost scenario explored, with a greater range of capture options and more diversity in geographic location implying higher financial cost, with £18bn CfD costs and £31bn capex spend out to 2030).

This study found that a UK CCUS sector could significantly reduce the costs of providing low carbon energy by the 2040s. Conversely, the study concludes that a delay in deployment could significantly increase costs of meeting emissions targets and if it stunted CCUS growth permanently it would lead to a doubling of emissions reduction costs overall in the economy.[12]

The role of CCUS was considered for the power sector, for capturing industrial emissions, for low carbon gas, and for delivering net negative emissions in combination with bioenergy. The pathway set out in the study suggests 10GW of capacity by 2030 and capital investment of £21-31bn, based on an assumed "efficient sharing of infrastructure and coordinated cluster/hub development" (ETI, 2015, p.4). Specifically, and in the context of the CCUS Commercialisation Programme at the time, the study estimated that a levy control framework commitment to CCUS in the region of £1.1-1.3bn per annum would be needed out to 2025 (in addition to support for two early commercialisation projects at Peterhead and White Rose), with further projects through the 2020s resulting in £2-3bn support costs per annum by 2030.

The two early commercialisation projects were seen in the study as key to unlocking future cost reductions. The study found that many cost reduction opportunities are UK-specific, suggesting that significant savings would not arise from waiting for cost reductions to be delivered in overseas projects. From the report itself, it is not clear how each component in each of the scenarios was costed. For example, what cost ranges and uptake rates were assumed for industrial CCUS in the Balanced scenario, or how far (and by what mechanism) increased oil and gas revenues were projected to reduce net CfD policy support cost in the EOR-led scenario.

In its report from a linked study on the costs of capture technologies, the ETI presents more detail on cost assumptions for aspects of the CCUS value chain (ETI, 2016). This study uses undiscounted capital

[12] We assume that this finding is arrived at through scenario analysis using the ETI's energy system cost-optimisation model. The study report states: "slower development of CCUS … would require advancing other potentially more costly and risky ways of cutting emissions (e.g. a substantial move away from gas heating in the 2020s)" (ETI, 2015, p. 16).

cost data for the building of a 50Mt/yr CO_2 CCUS network, taken from a study by Element Energy and Pöyry (Element Energy & Pöyry, 2015), along with techno-economic, 'bottom up' benchmarking data from studies for ETI undertaken by Amec Foster Wheeler Ltd and others (no reference provided in ETI (2016)) to explore the additional costs of adding CCUS to power production. It also draws on data on the impact of risk on project investability (provided to the ETI by Pöyry and URS (no reference in ETI (2016)) to inform analysis of how the LCOE could be reduced through staged deployment of CCUS to reduce risk to the second and third plants in the deployment sequence (ETI, 2016).

A1.2. Industrial Carbon Capture and Storage Roadmap (Atkins, Scottish Enterprise)

This study considers a scenario in which a pipeline of staggered investments is made in CCUS in Scotland in order to lower costs for CCUS deployment overall (i.e. over the whole timespan of deployment and averaged out across all CCUS investments).

Assessment was made of which industrial emitters (at the level of plants/facilities) are closest to feasibility for CCUS deployment, based on an assessment of CO_2 capacity, access to potential transport infrastructure and storage sites, and the type (and cost) of CO_2 capture technology that would be required. Sites were scored based upon this assessment across these criteria. Overall costs for deployment were considered in terms of how contingency costs for later projects (and, crucially, how risk is priced) could be brought down via a phased and structured approach.

The scoring of sites was based on: Capacity (tCO_2/yr); Distance from Feeder F8/10; Cost of CO_2 capture (£/tCO_2); Cluster potential (number of emitters within 10km); Maturity of CO_2 capture technology (this was a qualitative score). It appears that risk is also scored - though on a sliding scale of 1-5 rather than in cost terms.

The relative costs of carbon capture across different types of industrial facility in Scotland are estimated, based upon CO_2 capture cost data from previous studies, notably IEA (2009) and Element Energy (2010). These estimates are used to compare the relative cost effectiveness of CO_2 capture across potential project sites. Wider project costs appear to have been calculated for the recommended first stage 'enabling project' recommended in the report, but it is not clear how these were arrived at. For the recommended enabling project, estimated project costs are compared with the price of carbon, which is assumed to rise over time (based on the DECC (at that time) central case) and also with the avoided costs associated with decommissioning the off-shore storage assets in question. An assumption is made that there will be future reduced contingency cost for projects coming after the enabling project, but this does not appear to be quantified.

The study's estimates of avoided decommissioning and price-of-carbon costs are not 'socialised costs' of the type discussed in the ETI studies (where the overall system costs of not deploying CCUS, or delaying deployment of CCUS are considered). Rather, the Atkins study explores only the direct costs and benefits to the CCUS projects it covers.

The economic analysis appears therefore to have been relatively straightforward, and narrowly focused on the relative costs of capture for different industrial processes and therefore sites, and the particular costs of the potential CCUS enabler project described in the study.

Although completed in 2016, this study is clearly heavily influenced by the assumed successful delivery of at least one CCUS project under the subsequently cancelled competition. The framing for the 'enabling project' very much rests upon early, significant and up-front government intervention for establishing a 'first project'.

APPENDIX 2. FULLER REVIEW OF EXTENSION STUDIES

A2.1. The East Coast Network study

This study, 'Clean Air – Clean Industry – Clean Growth: How carbon capture will boost the UK economy' was prepared by Summit Power Caledonian UK Limited (SPC) in collaboration with Industria Mundum AG, Pale Blue Dot and the Centre for Energy Policy at Strathclyde (specifically involving one of the authors of this report, Turner), and published in 2017 (Summit Power, 2017).

The research takes as its starting point the need for new approaches if CCUS is to be realised, and assumes that the public sector will need to play a greater role in its development and in making a compelling economic case. It also notes the need for recognition amongst policy makers that CCUS will need to be deployed at scale from the 2030s onwards to achieve UK climate targets and a need for the first UK CCUS projects to be operating by the mid-2020s, enabling intelligent optionality on CCUS. Finally, the assumption is made that development and delivery of transportation and storage will require greater collaboration between government and industry, whilst capture projects (including power with CCUS) will be more industry-led.

In terms of the data and methods employed, the study builds on previous work done on CCUS in the UK, completed projects and ongoing CCUS project initiatives. These are combined with publicly available data and information sourced from Office of National Statistics (ONS), HM Treasury, Committee on Climate Change, ETI and Health and Risks of Air Pollution in Europe (HRAPIE). While the core method employed is an economic evaluation and social welfare assessment based on a high-level cost benefits analysis and a spreadsheet model that combine to envisage the potential amount of CCUS capacity in the UK. It assumes successive investments in CCUS projects and infrastructure, which evolve over time into a CCUS network. The CCUS investments are modelled over a 40 years (2020-2060) assessment period/window that is timed to coincide with the Committee on Climate Change projections for UK carbon emissions reductions targets. These are built out in phases in the analysis, and this provides the basis for scenarios that are generated to inform the economic analysis. Each investment is shown, in and of itself, to generate a significant net positive impact on the UK economy. This analytical approach is pragmatic, as it allows evidence to be brought to bear on a timescale for decision-making that is in line with the time periods under which decision makers actually operate. Demonstrating that the East Coast investments in phases 1 and 2 are cost-effective on their own terms and is therefore important.

Crucially, Summit Power (2017) attempt to quantify some of the economic and societal benefits from a viable evolution of UK network of CCUS investments, in particular job potential, GVA, Balance of Trade, health and well-being benefits. These are the type of benefits that we propose here could be measured as socially valued outcomes that could be assessed using cost effectiveness analysis. It is worth setting out in detail how the analysis was conducted for jobs and GVA, and this is most straightforwardly done using a direct quote:

> *"For new and retrofit investments direct Jobs were established based on the relative value of the labour component to the total value of the domestic content of each phase of investment CAPEX and OPEX. An average cost of employment has been applied to the labour component value to derive numbers of direct jobs. In retained industry the direct jobs were assessed based on an estimate of the degree to which direct jobs could be retained with CCUS solutions available in comparison to potential losses without a solution to reduce their CO_2 emissions. The estimated avoided losses were spread in time throughout the lifetime of the CCUS Investments to 2060 to reflect a gradual loss of*

industrial jobs in time. Indirect jobs were calculated based on publically available multipliers for each sector in most instances.

The approach to estimating GVA has been to use ONS statistical data "Output per Job" and applying this to the direct and indirect jobs created and retained by selecting the relevant Manufacturing and Services subsections and applying the published indices to Q1 2017 assuming constant productivity levels. Where mixed skills are required a blended approach was used to align output per job with the types of jobs involved and by applying a relative weighting (e.g. through design, EPC (engineering, procurement, construction) and commissioning / operation during project CAPEX phases)."
(Summit Power 2017, p.11)

The core finding is that there is a significant economic benefit to deployment of CCUS of £54bn GVA by 2060, with almost a quarter of a million jobs (225,600) created[13] or retained[14] (the split between created and retained jobs is not presented in the East Coast study report). The study concludes that the industries that stand to benefit include energy intensive industries (e.g. iron and steel, cement, chemicals and pharmaceuticals, fertilisers, refining and gas processing); power generation from fossil fuels; domestic and commercial heating including electrical and combined heat and power (CHP) and the emerging hydrogen economy for heat and transportation. It notes that CCUS also facilitates 'headroom' in the UK's emissions budget, via BECCUS, for aviation and shipping [and, one assumes, agriculture][15]. It projects further economic benefit from growth in the UK supply chain (manufactured goods and services); and significant export potential resulting in a positive balance of trade impact of £9bn through to 2060.

The assumptions made in the study about escalating CO_2 price mean that the 'export of CO_2' to a 3rd country looks like a very poor choice. According to the report, the costs of CCUS increase significantly from £34bn to £107bn if UK CO_2 is exported for storage in a 3rd country, reflecting the increasing volumes and escalating future projected cost of traded CO_2. Due to the wide range of uncertainty over future carbon traded, the study concludes that the balance of trade deficit could range from £40bn (low case) to £160bn (high case), making this approach inherently riskier. Relying only on 3rd party countries to transport and store UK CO_2 moves GVA out of the UK and leaves the UK without control over its storage solution and the price it would ultimately pay. Thus a core recommendation is the development of UK content based on the investment pathways described through the scenarios and phases (deployment charts) in the report.

Additional observations include: domestic content of CCUS projects is high especially in construction activities; and, export of services to other EU countries are important for additional economic benefit (every additional 5 $MtCO_2$/y of imported capacity would yield a positive £8bn impact on the Balance

---

[13] The number of direct jobs created is estimated using assumptions on domestic content (covering both investment and operation phases), wage components of domestic content and on a composite (covering a host of skill sets) cost of employment. The labour intensity during the Capex and Opex phases is estimated in terms of total costs and divided by an average cost of employment, taken as £45,000 per employee per year. Indirect jobs is calculated as a multiple on direct domestic jobs. See Appendices 5B and 5C of the East Coast study for details.

[14] Direct jobs retained are calculated based upon an assumption about the number of jobs in Industry and Refining that would be associated with the East Coast network and how many would be lost in the absence of CCUS starting from 2030-2060. Retained direct gas sector jobs are calculated assuming that jobs saved would be a multiplier of current oil and gas sector jobs based on the ratio of gas output required for Hydrogen under the East Coast scenario to current sector output. Indirect jobs were generally calculated based on ONS multipliers. See Appendices 5B and 5C of the East Coast study for details.

[15] The total 'headroom' is not quantified explicitly, but reference is made in Appendix 3 to an assumption of a maximum BECCUS capacity of around 43 $MtCO_2$/yr negative emissions by 2050.

of Trade by 2060). At the core of the study, assessment of the scenarios is based on a relatively straightforward assessment of quantified costs against benefits – the report discusses the potential strength of investment in CCUS based on the different scenarios, but lacks extensive discussion of the economy-wide value of such investment. The costs are largely direct and some assumptions are made about which are private costs and which are social and therefore should be met through public support.

In terms of indirect impacts, the study considers the economic value of CCUS investments to 'linked economies' – i.e. those directly impacted by the availability of a CCUS network[16]. As such, the study takes an important step towards setting out the full societal value of CCUS deployment, and brings multiplier-based metrics to bear in analysing the impact on sectors other than those directly in the CCUS supply chain. But it does not yet set out the full societal value case, which would involve demonstrating in a transparent way a fuller range and explanation of the nature of social costs and benefits across the economy, as well as the private costs and benefits. Even this would not in itself constitute a formal social cost benefit that could be aligned with the aforementioned Green Book methodology. This would be the domain and responsibility of civil servants formally supporting policy decision makers. Rather, the most the studies reviewed here can aim to do is inform that process.

In addition, the first East Coast Scenario: *Maximum use of existing infrastructure*[17] begins helpfully to build a link to current UK Industrial Strategy emphasis on protecting and boosting existing high value jobs. This aligns with the argument made in the CEP brief (Turner *et al.,* 2018a) that the most compelling narrative in the current UK policy context may be the 'sustained contribution' narrative. In turn, this narrative focusses on the potential role of CCUS in enabling the sustained economic contribution of sectors where we have already invested, from which we currently realise value, and from which we need to realise growing value. Again, the direct relation to themes in the Industrial Strategy is key.

A2.2. Other extension studies

The Caledonia Clean Energy Project (CEEP) study (Summit Power Caledonia UK Ltd., 2018) has a focus explicitly on Scotland. It places particular emphasis on risk and how staged deployment can bring down future risks and thus financing costs. It is a study of the potential of a gas-fired power plant with CCUS and as such lays considerable weight on CfDs as a support mechanism. The 'socio economic impact' it sets out relates to "direct, indirect and induced [GVA] impacts" and direct jobs (Summit Power Caledonia UK Ltd., 2018, p.2). The report presents a social cost-benefit analysis that suggests that benefits in terms of emissions reduction, inter-linked economies, industrial growth and health co-benefits outweigh costs by 5:1. It quantifies significant GVA added during design and construction, as well as direct jobs (1,200-1,800), indirect jobs (800-1,900) and induced jobs (500-800). Longer-term additional jobs are estimated at 300-600 direct and 600-1,000 indirect and induced.

The CCEP study uses a techno-economic model to estimate financial returns simultaneously for different scenarios and the required strike price for CfDs under each potential option. Wider socio-

[16] Viz: carbon capture, transport and storage including integration into the host plant facilities; new investments in Power Generation (both gas and biomass), Industry and Hydrogen plants; retained industry that may otherwise be lost in Chemicals and Pharmaceuticals, Iron and Steel, Cement, Fertiliser, Refining and the Gas extraction and processing Industries; and, the avoided costs of decommissioning of North Sea Assets.

[17] In full: Feeder 8 connection Teesside to Grangemouth, Feeder 10 connection Grangemouth to St Fergus, Reuse of Atlantic Cromarty/MGS pipelines to CNS. Start storage at Captain X. Initial quantities of CO_2 from Teesside shipped to Peterhead and on to St Fergus by pipeline. Feeder 11 between Grangemouth and St Fergus comes on stream from mid-2020's. This is scenario A. Note that scenario F is very similar, varying only in that initial quantities of CO_2 are transferred by pipeline from Teesside through accelerated Feeder 8 programme to Grangemouth instead of shipping to Peterhead. The jobs and GVA modelling described above were conducted based on scenario F.

economic impacts are assessed using societal cost benefit analysis, considering linked economies (see above), the potential for reduced economic activity in industrial sectors due to rising carbon costs, and the potential income from providing CO_2 storage for other European countries. Unfortunately, the publicly available summary report does not set out the method used to calculate the direct, indirect and induced economic impacts of the proposed project (Summit Power Caledonia UK Ltd., 2018).

The SINTEF study presents a series of quantified economic opportunities from CCUS for industry in Norway. Key metrics are: number of direct jobs created or for which competitiveness is increased in process industries; number of indirect jobs in process industries' supply chains; output and jobs from hydrogen production from natural gas using CCUS; maintained value in the oil and gas industry from CO_2 storage and transport jobs, both direct and indirect. The analysis suggests a total of 30,000 new direct jobs in Norway by 2050. Indirect jobs are calculated using multipliers based on IO accounts from Statistics Norway, with the multiplier for process industry jobs being 2. Full details of the methods used to calculate both direct and indirect jobs are presented in Appendix B of the study report (SINTEF, 2018).

The US EOR study aims to promote public-private partnership across the full RD&D cycle involved in developing carbon capture to support enhanced oil recovery. It models power sector output and EOR production before "using macroeconomic multipliers previously used in the literature and industry analyses" (CURC, 2018, p.5) to estimate macroeconomic benefits. The methodology is not detailed but the authors note (CURC, 2018, p.16, footnote 47) that "[T]he calculations were made using final demand multipliers for the Oil and Gas Industry…. applied on a regional basis to capture the contribution of CO_2-EOR in each of [the] five regions". Results are reported on an "annual incremental benefits" basis for "aggressive RD&D" (CURC, 2018, p.27) and distinguish between jobs and GDP related to power sector activity (carbon capture) and oil and gas industry EOR activity (carbon utilisation). In this regard, the CURC (2018) US EOR study approach bears similarities to that employed in the Turner (2015) CO_2-EOR study considered in the next section.

APPENDIX 3. FULLER REVIEW OF ECONOMY-WIDE STUDIES

Two studies are reviewed here. The first is the 'Preliminary Study on Developing Economic Multipliers for CO_2-EOR Activity' by Karen Turner (the CO_2-EOR study, Turner, 2015). This report focuses on CCUS in the context of enhanced oil recovery and contains the economic analysis that formed part of the Joint Industry Project led by Scottish Carbon Capture and Storage, published in March 2015. The second is the CEP brief entitled 'Making the macroeconomic case for near term action on CCUS in the UK? The current state of economy-wide modelling evidence' (Turner *et al*., 2018a). While the focus is explicitly on CCUS, hydrogen is considered in the context of a future activity enabled by CCS where jobs and other value creation may be leveraged by existing activity particularly but not exclusively linked to natural gas extraction and network distribution capacity already present and established in the UK economy.

The review in this section also includes reference to the European Zero Emissions Platform (ZEP) report: 'Role of CCUS in a below 2 degrees scenario', which is expected to constitute a key input to the European Commission's decision-making around its Mid-Century Strategy. This is on the basis that the ZEP report demonstrates that consideration of the economy-wide value of CCUS, again including focus on potential future hydrogen roll-out, is something being actively pursued at European level (and, as the SINTEF study shows, also by other countries with CCUS potential and a high-value oil and gas sector).

A3.1. CO_2-EOR study

This study uses multiplier analysis to assess the potential wider economic ripple effects of investment in CCUS infrastructure and activity linked to enhanced oil recovery in the UK off-shore sector. The CO_2-EOR report presents a full economy-wide analysis of the impact of CCUS as compared to offshore wind power as an alternative scenario for emissions reduction. Identified earlier as a relatively early CCUS economy-wide impact study (early 2015), this study sets out to test a method to establish what the **economic outcome** of CCUS would be under various scenarios, rather than simply what the economic co-benefit would be of technical or financial outcomes. This study also seeks to explore the economic implications for existing industries in a way that has increasing salience now in terms of understanding what CCUS might be able to deliver by way of sustaining existing high economic value sectors and jobs. As such, the study explicitly addresses the societal value (social cost-benefit) questions explored above, but with metrics reported focussing implicitly on the type of cost per job (CPJ) measures used to inform a more limited cost effectiveness analysis (CEA).

The CO_2-EOR study was part of a wider Joint Industry project led by Scottish Carbon Capture and Storage (SCCUS), the aim of which is to develop understanding of Enhanced Oil Recovery as a commercial use of CO_2 captured from power plants and industry. The overarching aim of the CO_2-EOR economics study is to demonstrate how multipliers for the UK can be identified and applied to understand the economy-wide impacts of CO_2-EOR plus upstream CCUS. The study considers how IO multiplier methodology may be applied in the context of considering alternative options for carbon-efficient energy supply. The study had initially set out to build out from the techno-economic data available from previous research to identify additional (new) IO supply chain information for what the impacts would be of actual deployment of CCUS and EOR. This proved not to be possible within the timeframe of the CO_2-EOR project. The study therefore takes existing IO data relating to coal-fired power generation and oil extraction as the proxies for CCUS and EOR activities, to provide what is argued by the author to be a robust starting point for the analysis (in a similar manner to Smith *et al*., 2017). However, it is also an approach that has since proven to be consistent both with applied extension studies for specific projects (e.g. CURC, 2018) and the 'sustained contribution' narrative developed through Turner *et al*. (2018a).

The CO_2-EOR study focuses particularly on output and gross value added (GVA) or GDP impacts but demonstrates the potential to extend this to other impacts, such as employment. The study uses experimental UK IO data in order to decompose multiplier effects across the economy, considering the additional market demand for oil as well as the activities of the carbon capture and transport sectors. In terms of market demand driving and CO2 transfer costs involved in EOR, the study is able to provide information on costs and activity levels derived from techno-economic analysis-derived for the scenarios considered.

Ultimately, the analysis in this study implicitly lays two important foundations. One is providing the basis for the 'sustained contribution' narrative taken up on the CEP brief (Turner *et al*., 2018a) and described in the next sub-section, by providing multipliers for existing industries that might be at risk from stringent climate policy, with potentially significant value (and carbon) leakage if these global industries relocated their UK operations overseas. In this way, the CO_2-EOR study provides a bridge in to the work in the CEP brief (Turner *et al*., 2018a) and the Hydrogen study (Turner *et al*., 2018b), as well as to the new analysis for Scotland provided in this report (see Section 5). However, it also implicitly takes an important step, not developed until the current research, in terms of establishing the basis for considering the type of metrics required to underpin what ZEP (2018) term 'just transition' narratives.

A key point to note is that the CO_2-EOR study calculates and examines the headline multiplier results in terms of the socially valued outcome (focussing on output and GDP rather than jobs) generated per pound of government spending. This is underpinned but not necessarily the same (depending on the mix of different types of spending and outcome generation involved) as the 'per pound of final expenditure that IO 'output' multipliers are generally reported. Thus, the study implicitly focuses on stating metrics in terms that could potentially inform decisions around inevitable government intervention/support to enable CCUS activity. In the EOR context (and the point above regarding the mix of spending and outcome generation involved), this is also set in terms of a further second round of spending stimulation in oil markets that further leverages the initial government spending (in this study, via CfD).

A3.2. The CEP brief - UK-level analysis

CEP's first core evidence on UK CCUS narrative development was in response to the UK Industrial Strategy, Clean growth Strategy and UK CCUS Cost Challenge Taskforce. CEP's CCUS policy brief (Turner *et al*., 2018a) centred on developing a 'sustained contribution' narrative, which focusses on the potential role of CCUS in enabling the sustained contribution of sectors where we have already invested, from which we currently realise value, and from which we need to realise growing value. Here, rather than use estimated UK IO data (as in the CO_2-EOR and hydrogen studies discussed above), Turner *et al*. (2018a) use headline sectoral employment multiplier data reported by ONS for BEIS.[18] This choice was motivated by the appeal of publicly available data provided via government sources as potentially being perceived as a more reliable source of evidence. However, in the absence of

[18] ONS IO-based employment multiplier data are available via archive at
http://webarchive.nationalarchives.gov.uk/20150908115359/http:/www.ons.gov.uk/ons/about-ons/businesstransparency/
freedom-of-information/what-can-i-request/published-ad-hoc-data/econ/december-2014/provisionalestimates-
of-type-uk-employment-multipliers-and-effects.xls

publicly accessible underlying IO tables, this came at the cost of not being able to analyse the sectoral composition of multiplier effects.

Turner *et al*. (2018a) use the reported IO based employment multiplier data to identify and consider sources of potential direct or indirect value associated with the introduction of CCUS. Specifically, the study focuses on multiplier metrics report on how many direct and indirect (supply chain jobs are associated with either £1million of demand for output of different sectors that may be CCUS-relevant (as potential capture industries or in potential delivery of carbon transport and storage). It also refers to a second headline employment multiplier that can be derived from the first: the total number of (direct and indirect) jobs supported throughout the economy per direct job directly supported within the industry in question.

The brief uses these multiplier metrics to consider the statement of an economic narrative set around safeguarding and creating high quality jobs, ensuring downstream competitiveness and building up domestic supply chain capacity and capability. It identifies two types of industries as being particularly relevant to this narrative in a CCUS context: the energy using/emitting industries that may engage in CO_2 capture, and the fossil fuel supplying oil and gas industry, where much of the skills, expertise and physical infrastructure that would be required to set up a CO_2 transport and storage network already exist. The emerging insight from examining the headline multiplier metrics is that, due to their capital intensity, jobs are difficult to create in CCUS-relevant industries, while, due to the strength of their domestic upstream supply linkages, the loss of any one job is likely to have relatively large knock-on negative effects on other jobs. However, Turner *et al*. (2018a) also report baseline multipliers for the gas production and distribution industry motivated by providing "a context to explore opportunities for stimulating innovation in the context of a wider set of narratives that may become more pertinent in considering CCUS, such as enabling a hydrogen industry" (Turner *et al*. 2018a, p.12).

The brief also introduced the notion of developing multiplier metrics to consider how cost impacts may impact competitiveness across the economy via downstream linkages. In particular, the argument is made that complex networks of direct and indirect relationships between sectors in this regard may provide route for the erosion of value created via upstream linkages (i.e. what is reported in conventional IO multipliers). This additional focus prompted questions around how and by whom would capture, transport and/or storage be paid for? In this regard, preliminary (experimental) analysis by Turner *et al*., (2018a) suggests that if CCUS is introduced in the power sector, the main direct price pressure is anticipated on price of electricity. This implies a cost ultimately bore by the consumers. There are also anticipated price pressures evident in more electricity-intensive sectors, including gas supply that would also impact consumers. Alternatively, if CCUS is introduced in the Petrochemical sector, the main and dominant price pressure would again be anticipated in the emitting industry. However, rather than impacting on UK consumers via that price pathway, Turner *et al.* (2018a) argue that the key impact may be in terms of potential negative competitiveness impacts on export prices given that about two thirds of UK petrochemical industry output is exported.

There are three main conclusions emerging from the brief. First, the strength of CCUS-relevant industries' domestic upstream supply linkages means that the loss of any one job is likely to have significant negative impacts across the wider UK economy. Secondly, there are likely to be major negative ripple effects on output and GDP in CCUS-relevant industries (in particular oil and gas and energy using process industries). Thirdly, price pressures suggest important but potentially very different patterns in terms of how CCUS may ultimately be 'paid for', with impacts on competitiveness of high value industries and consumer energy bills having different economic and political implications. Further investigation of these and other key issues in terms of how CCUS may be implemented in the UK will ultimately require fuller and more in-depth economy-wide analysis.

One of the key recommendations of the study is the urgency and need for appropriate data to shift the discussion on CCUS and for a clearer economic roadmap. This implies a need for future research in terms of analytical methods and more interrogative evidence to address data issues. Both of these concerns suggest a need for research to consider how industry data and/or output of techno-economic models can feed more advanced economy-wide models. The brief argues that this may ultimately involve build on the type of CGE economy-wide modelling approach used by HM Treasury (HMT). This would create opportunity to assess the relative merits of a range of CCUS development scenarios and policy options.