Preliminary Study on Developing Economic Multipliers for CO_2-EOR Activity

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Summary

Introduction

The aim of this study is to provide a preliminary assessment of how the economy-wide impacts of the introduction of enhanced oil recovery using CO_2 injection (CO_2-EOR) and up-stream carbon capture and storage (CCS) activities may be considered using 'multiplier' analyses. Multi-sector multiplier analysis, the simplest form of which is based on the use of input-output models, are commonly conducted particularly at the regional level within the UK to assess potential economy-wide impacts of economic disturbances, industry developments and public spending decisions (including the now regular carbon assessment of the Scottish Budget).

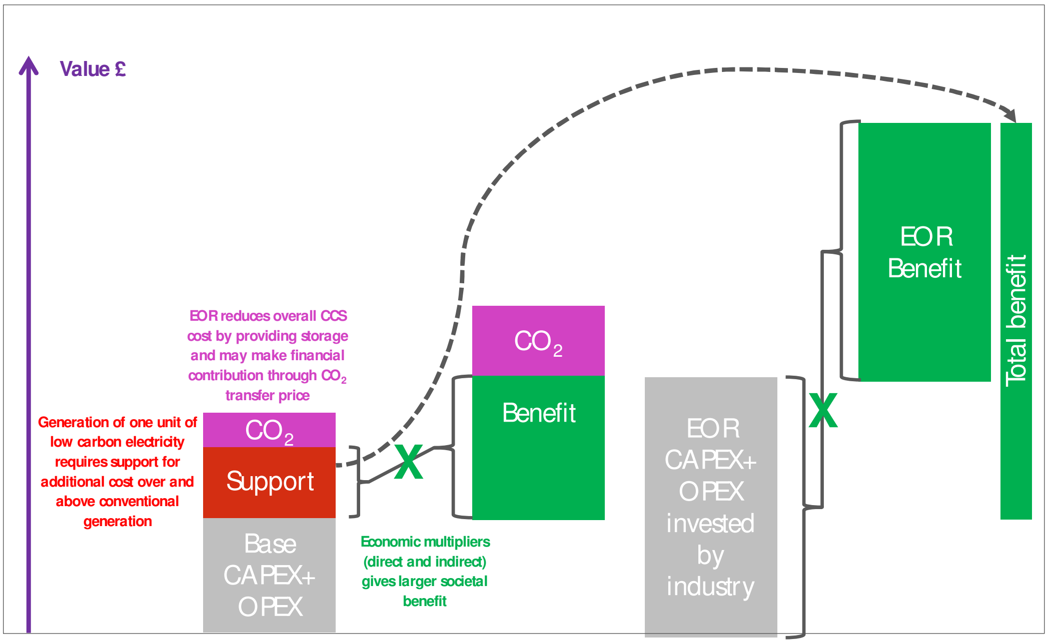
We focus on how/if input-output multipliers for the UK can/may be identified and used to compare economy-wide impacts (here focussing primarily on output and gross value added, GVA, or GDP impacts of three possible options, but with extension to other impacts, such as employment, being straightforward):

1. **Offshore wind supported by CfDs (Contract for Difference)**
2. **CCS with pure storage supported by CfDs in the coal-powered electricity generation sector**
3. **CO_2-EOR drawing on the carbon capture element of the CCS in (2) and partly replacing pure storage supported by CfDs.**

Multiplier methods

The full report explains the derivation of a range of useful multipliers from input-output accounts that are reported for a given accounting year. The central multiplier is the output multiplier for any given industry, which tells us the amount of output (generally reported in £million) that is generated throughout the economy (across all industries) per £1million of final consumption demand for the first industry's output. What is known as the Type I variant of this multiplier captures the direct effect of the £1million of final demand plus indirect effects in the industry's up-stream supply chain. The Type II variant also incorporates the additional, induced, impacts of household consumption financed through income from employment in industrial production. The chart below illustrates how multiplier analysis allows us to consider the total benefits through economy-wide impacts of CO_2-EOR activity.

Capturing the impact of CO_2-EOR activity using multipliers:



The key thing to understand in applying multipliers in scenario analysis is that any multiplier is basically a ratio: how much economy-wide return to we get per unit of direct demand/input requirement? Thus, in order to focus on the impact of government support through the CfD mechanism we articulate a multiplier relationship that is the ratio of the full Type II economy-wide output or GDP impact (calculated using the relevant industry multiplier) per £1 of support from Government. In Scenarios 1 and 2, where we focus on the government support as the only direct change in demand, this equates to the industry multiplier. However, in Scenario 3, where we have an additional (private sector) demand – scaled as what is required to cover the average cost of oil produced by CO_2-EOR methods – the impact of this demand is also included in the ratio of return to government spending. Here the government spending requirement is also reduced by (a) the reduced need for storage in CCS where EOR provides demand for captured CO_2, and by (b) any related transfer made from the Oil and Gas industry.

Data issues

Three central data issues are considered in the study:

(i) **Are the relevant activities captured in available input-output data (published as part of regional/national statistics)?**

(ii) **If not (i.e. if the activity in question is not yet carried out in a UK or Scottish context, or was not present in the latest input-output accounting year), can a proxy industry be identified to provide 'best guess' estimates of multiplier relationships?**

(iii) **If so, is the industrial breakdown in the UK and/or Scottish input-output accounts sufficiently detailed to permit consideration of specific multiplier effects for the activity in question?**

In the case of CO_2-EOR under Scenario 3 the answer to (i) is 'no' so that a proxy industry multiplier must be identified. Here we focus on the example of the existing Oil and Gas industry. In the case of CCS under Scenarios 2 and 3 the answer to (i) is also clearly 'no'. The proxy selected here is the existing coal-powered or gas-powered electricity generation sectors. Thus, the CCS analyses in Scenarios 2 and 3 relies on data for existing electricity generation activity. However, the answer to (iii) in these cases is is 'no' in the context of official input-output data published by ONS and the Scottish government respectively. While off-shore (and on-shore) wind and coal-powered generation activity are present in both the UK and Scotland, along with a range of other renewable and non-renewable technologies, the published input-output tables for both the UK and Scotland report only a single vertically (and horizontally) integrated Electricity sector, incorporating generation, transmission and distribution. However, we are able to draw on experimental UK input-output data for 2004 that identifies nine generation sectors in the UK case – including off-shore wind and coal-powered generation - that sell all of their output to a single electricity supply sector.

Scenario results

Note that, given problems of imperfect data in particular (but also various modelling issues discussed in the full report), the numerical results of this study should be regarded as provisional and illustrative rather than predictive results. Moreover, it is difficult to comment on what may constitute significant differences in multiplier values given the single year of data used, and where we are not sure whether capital expenditures at construction stages are present and impact the industry multiplier value for that year.

Key summary findings for the three scenarios are shown in the table below:

Summary scenario results

Scenario	Implied government intervention multiplier	
	Output	GDP
1. Off-shore wind	3.30	1.52
2. Coal-CCS	2.57	1.16
3. Coal-CCS with CO2-EOR	7.15	3.94

The results under Scenario 1, with off-shore wind supported by CfDs, suggest an economy wide impact of £3.30 in additional output and £1.52 in additional GDP (spread across/generated in multiple industries) for every £1 of government support. Under CCS with pure storage with CfDs, where the existing coal-powered electricity generation sector is taken as a proxy, the net economy-wide impacts in terms of both output and GDP remain positive but are smaller (£2.57 and £1.16 per £1 support respectively). However, the results of Scenario 3 suggest that if we consider the ‘bigger picture’ of the potential impacts delivered by CO_2-EOR through its implied demand for captured CO_2 a significantly greater economy-wide return is realised. Not only is the unit and overall cost of government intervention decreased (while still delivering the same return per £1 support of CCS activity). The new CO_2-EOR activity delivers an additional stimulus that ripples throughout the UK economy so that the output and GDP per £1 of government support of CCS activity rise to £7.15 and £3.94 respectively. In an appendix to the full report we report the results of sensitivity analyses for these results given different assumptions about key variables underpinning the scale of the EOR project and resulting impacts on CCS. We find that overall multiplier effects in Scenario 3 are most sensitive to what we assume about (a) the level of EOR demand for CO_2 (metric tonnes per annum); and (b) the time period (years) over which this demand occurs. Output and GDP multiplier results range from 4.33 and 2.22 respectively (where (a) is at its lowest value) to 9.32 and 5.25 (where (b) is at its highest value).

Note that the analyses here do not take account of any further impacts of additional tax revenues that would be generated as a result of expansion in the Oil and Gas and other industries that are positively affected. On the other hand, we also do not consider any further investment in any of the technologies that may be stimulated by the impacts of government support, or consequent expansionary effects and/or changing returns to capital or labour resulting from such investment activity. Moreover, we qualify our results given the limiting demand-driven nature of the input-output model. Our conclusions recommend development of a more sophisticated modelling framework to consider such issues, as well as a range of issues to be considered in improving the quality of data used to inform future multiplier analyses of the type carried out in this preliminary study.

Contents

1. Introduction

The aim of this study is to provide a preliminary assessment of how the economy-wide impacts of the introduction of enhanced oil recovery using CO_2 injection (CO_2-EOR) and up-stream carbon capture and storage (CCS) activities may be considered using 'multiplier' analyses. Multiplier analysis, in its simplest form is, based on the use of input-output tables and models, are commonly conducted particularly at the regional level within the UK to assess potential economy-wide impacts of economic disturbances (e.g. decreased tourism activity in Scotland following the foot and mouth outbreak and 9/11 attacks in 2001[1]), industry developments (such as potential on-shore wind generation in Wales[2]) and public spending decisions (including the now regular carbon assessment of direct, indirect and induced economic impacts of the Scottish Budget[3]).

However, in analysing the potential impacts of introducing CO_2-EOR and CCS to the Scottish and/or UK economies, we are faced with the problem that these activities do not currently exist and are, thus, not incorporated in existing input-output accounting data published as part of national or regional accounts. In the first instance, we may consider existing industry multipliers for the oil and gas extraction and electricity generation industries respectively where these activities may take place. We do so in the context of the motivation for this preliminary study, which is to permit consideration of appropriate multiplier *methodology* for analysing scenarios involving CO_2-EOR and/or CCS in the setting of the UK government Contract for Difference (CfD) framework to support development of low carbon energy sources (here focussing our comparison on the case of off-shore wind generation in the electricity sector), and to assess the current state of and required developments in data and methods for future work.

The remainder of this report is structured as follows. Section 2 is a non-technical overview[4] of the application of input-output multiplier methods used here to assess the impacts of CO_2-EOR, CCS and off-shore wind as an alternative low (or reduced) carbon energy supply options in the context of the UK CfD framework. Section 3 then goes on to consider the current state of Scottish and/or UK input-output data required to operationalise these methods in these particular cases. Sections 4, 5 and 6 then offer a very preliminary illustrative/speculative empirical analysis. This is based on experimental UK input-output data and data from a range of recent sources to inform the scale of demand boosts that feed multiplier effects under the different scenarios. Section 7 draws conclusions and makes recommendations for future data development and research activity.

2. Multiplier methodology for scenario analysis

Context – the three scenarios analysed in this study

The central aim of this pilot study is to consider how input-output multiplier methodology may be applied in the context of considering alternative options for carbon-efficient energy supply. We focus on how/if multipliers for the UK can/may be identified and used to compare economy-wide impacts (here focussing particularly on output and gross value added, GVA, or GDP impacts of three possible options, but with extension to other impacts, such as employment, being straightforward):

1. **Offshore wind supported by CfDs (Contract for Difference)**

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[1] See http://www.scotland.gov.uk/Resource/Doc/158289/0042862.pdf and http://www.scotland.gov.uk/Publications/2003/07/17383/22556

[2] See Economic Opportunities for Wales from Future Onshore Wind Development by WERU (Cardiff Business School) and Regeneris Consulting (file://psf/Home/Downloads/economic-opportunities-onshore-wind-wales-jan-2013-english%20(1).pdf.

[3] See http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Input-Output/CarbonAssessment.

[4] A more technical and general overview of input-output multiplier methods is provided in the Appendix.

2. **CCS with pure storage supported by CfDs in the coal-powered electricity generation sector**
3. **CO_2-EOR drawing on the carbon capture element of the CCS in (2) and partly replacing pure storage supported by CfDs**

Other studies[5] for the UK as a whole and the Scottish and Welsh regions have considered the direct and economy-wide impacts of construction and operational/maintenance phases for one or more of these low (or at least reduced) carbon energy supply options. Particularly where activities are new to the economy under study, this has involved extensive survey work on issues around supply chain requirements (including confidence in local suppliers to deliver). To engage in extensive primary data collection to inform a comprehensive analysis of different stages of industry/activity development is outside the scope of the current study and it is not clear that a great deal of value could be added at this time relative to the previous studies. Rather, here we focus attention on how multipliers may be used and developed to provide particularly policy makers with information to help them make decisions on the relative benefits in the form of economy-wide impacts of different options.

Specifically, we focus on the operation of the CfD framework in the operational/maintenance (i.e. post-construction) phases of off-shore wind electricity generation and CCS with pure storage in a coal-powered electricity generation setting (although required cover of fixed capital costs within long-run average costs is considered in scaling the required government support). We also consider the impacts of in the operational phase of CO_2-EOR activity where this (at least partly) replaces the storage requirement of the CCS process and delivers a transfer payment that combine to reduce the requirement for support via the CfD framework. Generally, while we cannot be certain that the input requirements for any one industry in a given input-output reporting year do not include capital expenditures note that the input-output framework is not ideally suited for assessment of investment activity. Input-output tables (e.g. see Fig.1 in Part 2 of the Technical Appendix) report the output that each industry produces for capital formation purposes (i.e. the supply of capital goods for investment purposes), it does not tell us much about what sectors are undertaking investment activities.

Derivation and interpretation of multipliers from an input-output accounting framework

In the Technical Appendix to this report we explain the derivation of a range of useful multipliers from input-output accounts that are reported for a given accounting year. The central multiplier is the output multiplier for any given industry, which tells us the amount of output (generally reported in £million) that is generated throughout the economy (across all industries) per £1million of final consumption demand for the first industry's output. (Note that final demand is the driver of input-output multipliers, a point we return to below). What is known as the Type I variant of this multiplier captures the direct effect of the £1million of final demand plus indirect effects in the industry's up-stream supply chain. The Type II variant also incorporates the additional, induced, impacts of household consumption financed through income from employment in industrial production.

So, for example, according the 2004 UK input-output framework used here (see Section 3) the UK Oil and Gas industry has a Type I output multiplier of 1.43, meaning that for every £1milion (or £1) of output produced by the industry to meet final (e.g. export demand), a further £0.43million (or 43 pence if we consider in single £1 units) of output is generated in the industry's UK supply chain. The Type II multiplier is 1.84, meaning that a further £0.41million (or 41 pence) is generated as a result of additional multiplier impacts through income and consumption effects resulting from the payment of wages in return for labour services (supplied by households) throughout this supply chain. By considering the value-added or (full-time equivalent, FTE) employment involved in producing outputs the required outputs throughout the supply chain, we are also able to report output-GDP and output-employment multipliers. For example, the UK Oil and Gas industry Type II GDP multiplier is 1.12 meaning that for every £1million final demand for Oil and Gas output, £1.12million of GDP is generated/supported

[5] For example, the Welsh on-shore wind study detailed in Footnote 2; 'Assessment of the Economic Impacts of the Captain: the Clean Energy Project' by Ricardo-AEA; 'Economic Impacts of CO_2 Enhanced Oil Recovery for Scotland' by Element Energy and partners.

throughout the economy; the Type II employment multiplier is 10.1, meaning that for every £1million final demand for Oil and Gas output, 10.1 FTE jobs are generated/supported throughout the economy. We can also consider, e.g. the total employment supported in this way by a given sector relative to the direct employment required per £1million of output, which is 1.1 FTE in the Oil and Gas sector, to generate an employment-employment multiplier (in this example 10.1/1.1=9.1), which tells us how many FTE jobs are supported throughout the economy for every one direct FTE in the industry itself.

Use of multipliers in scenario analyses – a note of caution

How do we use these multipliers in scenario analyses? A crucial point to note is that the conventional demand-driven input-output methods underlying commonly used multipliers imposes a particular causal sequence where any change in activity in the economy is driven by a change in final consumption demand. Final consumption demand takes the form of increased household spending, government final consumption, capital formation and external (export) demands. Thus, in order to apply a multiplier, we must state/translate any given change in activity in the form of a change in one of the sources of final consumption demand.[6] If we identify the value of a change in final demand, we may then simply multiply the value of the total (additional) direct final consumption demand for the output of the industry by its output multiplier(s). Thus, if we have a £10million increase in export demand for the output of the Oil and Gas sector (taking the multiplier values above), the Type II economy-wide output impact will be £18.4million (=10X1.84). The Type II GDP impact (value-added content of the additional outputs) will be £11.2million (=10x1.12) and the Type II employment impact will be 101 FTE jobs (=10x10.1).

The final demand driven feature of the input-output model is particularly problematic in the current context. For both CCS and any particular type of electricity generation the direct source of demand is intermediate. That is, from other producers rather than final consumers. In the case of CCS, demand for captured CO_2 will arise from another industry (e.g. here Oil and Gas), which uses the CO_2 to aid a production process (e.g. enhanced oil recovery). In the case of electricity generation, the direct source of demand is from the supply/distribution network, not the end/final consumer. In published input-output tables all electricity production and supply is aggregated in a single sector so that final consumers are identified. However, as discussed in the next section, in splitting generation activity out in an input-output framework, generators must be treated as selling all of their output to the supply/distribution sector as an intermediate consumer.

Thus, the question arises as to how we may use multipliers to consider the impact of activities such as CCS linked to coal- or gas-powered and off-shore wind-powered electricity generation where there is no clear final consumption demand.[7] As noted above, we need to think about how to articulate a change in final demand that drives the multiplier mechanism. Here, the CfD framework is interpreted as implying a government demand where government effectively purchases electricity from off-shore wind (and potentially CCS activity located within the coal-powered generation sector) through its 'top up' to the strike price. This in turn impacts how we use the multipliers.

Application of multipliers for the three scenarios to be analysed in this study

The key thing to understand in applying multipliers in scenario analysis is that any multiplier is basically a ratio: how much economy-wide return to we get for every direct demand/input requirement? In this section we explain how multiplier values for a given final demand requirement are built up from the basic industry multiplier. In the empirical analysis to follow, equation [4] is the preferred measure for

[6] The input-output models can be reconfigured to consider supply-driven or price changes but, because of the restrictive assumptions involved, such methods are not commonly applied in the context of policy analyses. Instead, input-output data are more commonly incorporated within more flexible and theory consistent computable general equilibrium (CGE) models where there is a need to analyse price and supply-side behaviour. We return to the issue of less restrictive modelling approaches in the final section of this report (even the conventional demand-driven model used here involves restrictive assumptions that impact the flexibility and reliability of the scenario analyses conducted here).

[7] In dealing with CO_2 a potential future area of research is to employ input-output and CGE modelling frameworks that build on the theoretical construct of considering final demand for the common resource of 'a clean environment' where CCS activity may be identified as a 'cleaning sector' that serves both this final demand also intermediate (producer) demand from the Oil and Gas industry for CO_2 as an input to EOR activity.

offshore wind or CCS only, while equation [5} is appropriate for considering combined CCS and EOR activity.

The output multiplier for any given industry, which, as explained in the Technical Appendix, is derived through analysis of the supply chain requirements, may also be 'backed out' by dividing the total (Type I or Type II) effect of any direct final demand requirement - given by the type of multiplier calculation explained above - by the initial direct demand. So (for the Type II case that we will focus on in the empirical analysis here) if we have applied a change in final demand for the output of any one industry to that industry's output multiplier to calculate the total impact, the multiplier may then be considered as follows:

[1] $$Industry\ mutiplier = \frac{Total\ Type\ II\ (direct+indirect+indusced\ effect)}{Direct\ final\ demand\ requirement\ for\ industry\ output} = \frac{A}{B}$$

For the simple example of a £10million increase in export demand above, [1] returns the Type II Oil and Gas output multiplier of 1.84 (=£18.4million/£10million). In the three scenarios analysed in the following sections, we wish to consider the economy-wide impacts/benefits arising from government intervention/support through the CfD framework. As explained above, this requires that we consider the nature of the final demand requirement. Input-output tables are reported in value terms (price multiplied by quantity). The CfD mechanism[8] involves government paying a (variable) top-up between the market price and a fixed price level, which is known as the 'strike price'. However, the conventional demand driven model considers quantities valued using price, not price on its own. Thus, we break the denominator on [1] into two parts, market demand (B_M) where the quantity is valued at market price and, where market price is less than the strike price that is required to provide the required return to cover all factor and capital costs (with the latter including repayment of investment costs), an implied government demand (B_G) where quantity is valued at difference required to make this return:

[2] $$Industry\ mutiplier = \frac{A_{M+G}}{B_M + B_G}$$

The return to the government intervention focuses on the impact of element B_G:

[3] $$Government\ intervention\ mutiplier = \frac{A_{M+G}}{B_G}$$

If the requirement under B_G falls, which may primarily be expected to happen because the gap between market and strike price closes as the industry develops, the benefit measured by what we have labelled as 'the government intervention multiplier' will rise as the benefit/economy-wide impact measured under A becomes more dependent on the market return within B_M.

However, we abstract from this in the empirical analysis below. This is partly due to a lack of data to model scenarios about what may happen over time particularly in the case of support via CfD for coal-powered generation with CCS (where CfDs have not yet been agreed). However, it is also due to the weakness of the demand-driven input-output model in analysing issues involving changing prices[9] and time/dynamics, where the input-output model is essentially a (fixed price) static framework with the timeframe covered a matter of judgement given conditions in the economy being modelled.[10]

Instead, we focus in our third scenario on how the requirement under B_G in CCS activity falls because the need for government intervention through CfD is reduced (in any given time period) by some other means. Here we consider the scenario where CO_2-EOR activity within the UK Oil and Gas industry draws on captured carbon thereby reducing the need to construct and thereby make returns on storage capacity in the CCS activity. In this way the Oil and Gas 'payment' for CO_2 removes closes part of the gap between the market price and the strike price.

In the first two scenarios, we focus directly on the multiplier effects associated with the actual government intervention at a given point in time. That is, we focus entirely on that component of the

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8 See https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/263937/Final_Document_-_Investing_in_renewable_technologies_-_CfD_contract_terms_and_strike_prices_UPDATED_6_DEC.pdf

9 In input-output tables and in our analysis below price is incorporated with quantity in value measures only and, with fixed technology embedded in the multipliers, there would not be any response to changing relative prices.

10 An excellent handbook on the use and limitations of input-output modelling is Miller, R. & Blair, P. (2009). *Input-Output Analysis: Foundations and Extensions*, Cambridge University Press, Cambridge.

economy-wide benefit, A_G, that results from the government demand implied by the intervention, rather than the full impact of market plus government demand for electricity from off-shore wind farms and CCS 'production'. The motivation for this was explained at the end of the preceding sub-section: that government demand implied by the use of the CfD mechanism is the only source of final demand that may be identified. This means that in Scenarios 1 and 2 we do not consider any demand under B_M so that [3] will return the industry multiplier as equating to the government intervention multiplier:

[4] $$Government\ intervention/industry\ mutiplier\ = \frac{A_G}{B_G}$$

Chart 1. Illustrating the basic government intervention multiplier captured by Equation [4]:

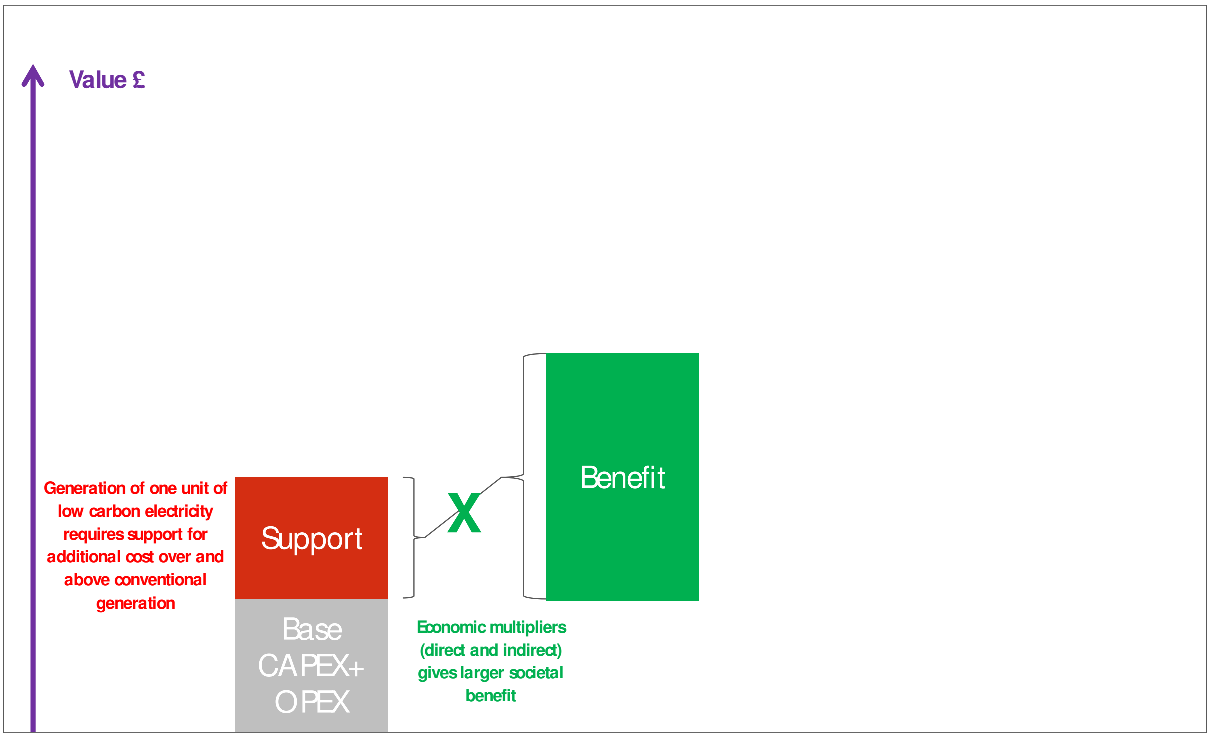


Chart 1 illustrates schematically how the support for low carbon electricity has an additional economic benefit through the multiplier for the cases of wind generation and CCS.

However, in the case of Scenario 3 we do consider a source of non-government demand and the resulting multiplier effects. Building on Scenario 2 we consider potential enhanced oil recovery using CO_2 sourced from carbon capture activity in the coal-powered electricity generation sector.[11] Given that we assume this carbon capture is made possible by the government intervention, we consider additional CO_2-EOR activity to in the Oil and Gas industry as an (albeit indirect) pathway for further economy-wide benefits of the CCS intervention to be realised. Therefore under Scenario 3, where we consider linked CO_2-EOR and CCS activity, our equation [3] becomes:

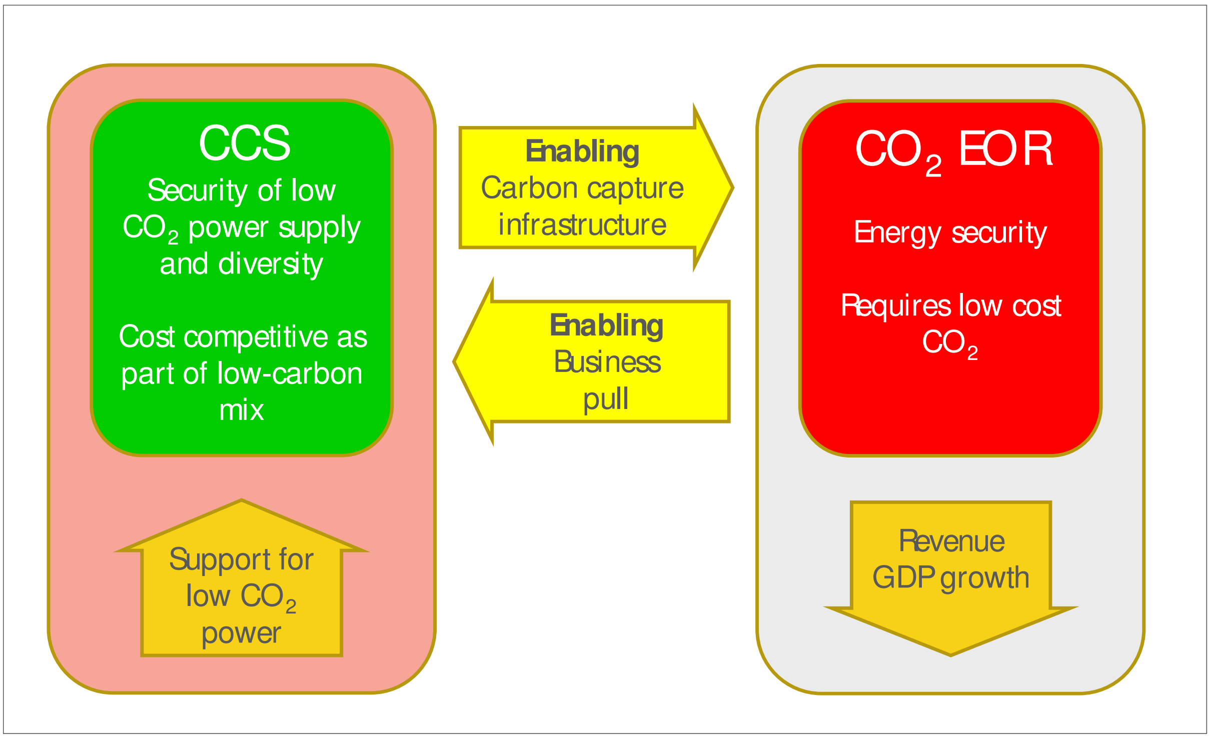
[5] $$Government\ intervention\ mutiplier = \frac{A_M^{EOR}+A_G^{CCS}}{B_G^{CCS}}$$

Here we have used the EOR and CCS superscripts to distinguish between demand for and impacts of changes in activity in the CO_2-EOR and CCS activities respectively. We continue to focus on the multiplier effects triggered by the government intervention in CCS (B_G^{CCS}) but introduce the economy-wide response to implied final demand required to support the costs of introducing CO_2-EOR activity in the Oil and Gas sector through inclusion of element A_M^{EOR} in [5]. In Section 6, we discuss how it is problematic in an input-output framework to consider the form that this final demand requirement may take but the key point in methodological terms is that it does not involve further government support (i.e. it is a private sector market demand).

[11] We could extend the analysis to gas-powered plants as well but the UK IO data used here do not separately distinguish this, as explained in the next section.

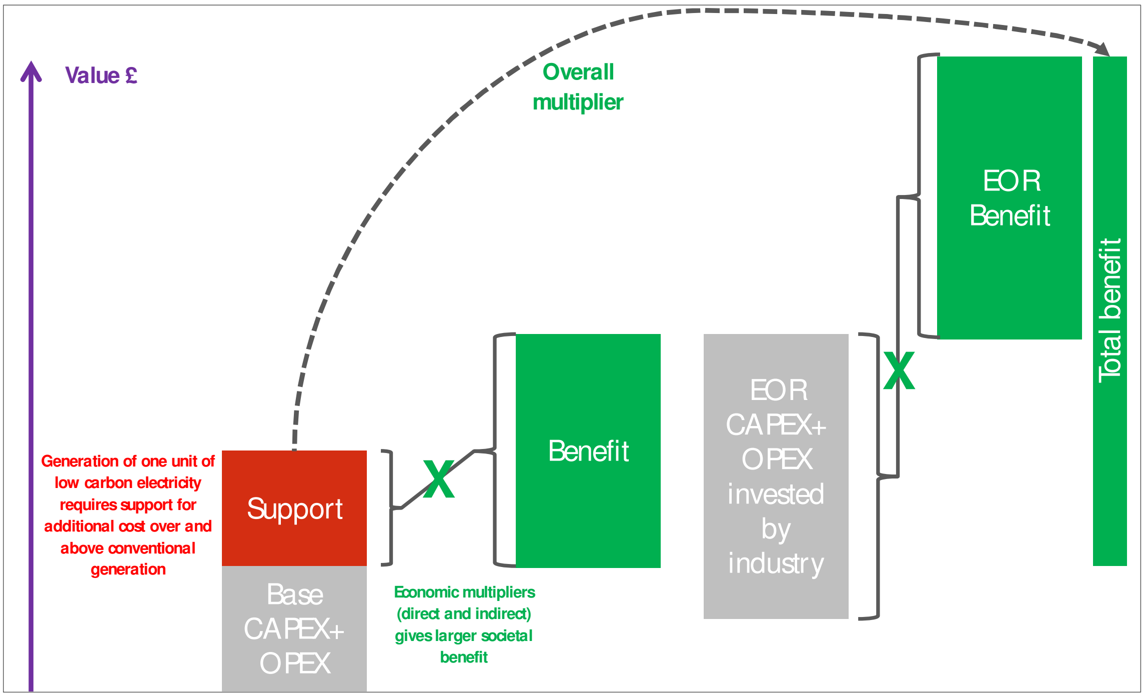
Through equation [5] we are capturing the fact that, unlike offshore wind generation, CCS creates the conditions which enable CO_2-EOR, in the manner illustrated in Chart 2:

Chart 2. Illustrating the relationship between CCS and CO_2-EOR:



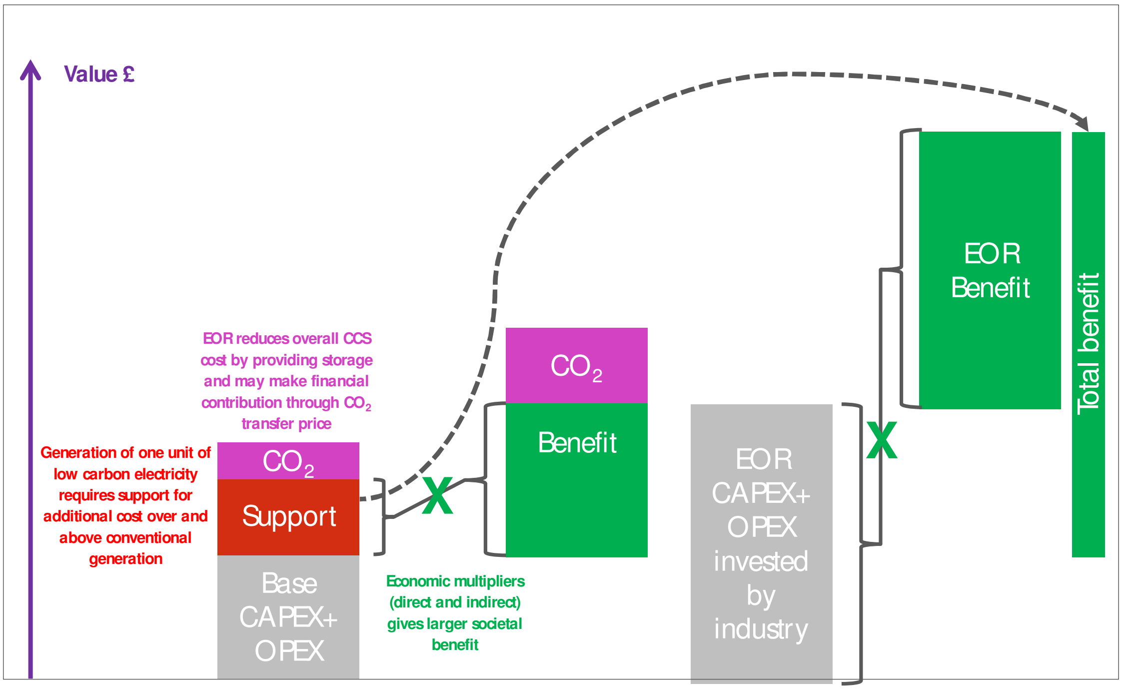
The Oil and Gas industry then brings further investment (without any additional support), which also has its own multiplier to give the overall impact on output, as illustrated in Chart 3:

Chart 3: Illustrating the overall multiplier relationship captured by Equation [5]:



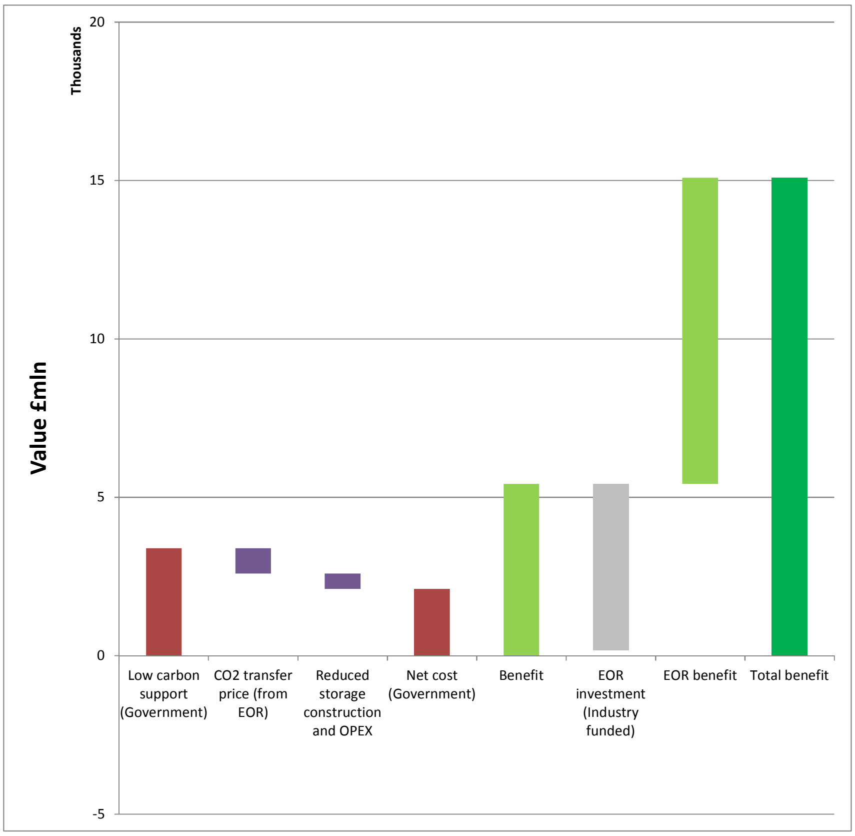
The overall multiplier is given by the ratio between the level of support (unchanged) and the total benefit, including the EOR benefit. A further subtlety of the analysis is the recognition CO_2-EOR will provide a reduction in the level of support required. While this reduces the total overall benefit slightly, the impact is to increase the multiplier because of the proportional reduction of support is larger than the total reduction in the benefit:

Chart 4: Illustrating the impact of the reduced government support requirement with a CO_2-EOR project:



This workflow is illustrated explicitly for Scenario 3 in Chart 4 using results from Section 6 below (noting the focus on the operational rather than construction phase of wind generation in particular in the empirical analysis).

Chart 5. Illustrating the impact of the CCS and CO_2-EOR workflow:



Ideally the multiplier values to inform the scenario analysis based on [4] and [5] in our empirical analyses would reflect actual off-shore wind electricity generation and CCS activities, and consideration of investing in and/or operationalising CO_2-EOR would reflect the actual input requirements involved. The next section considers the state of current input-output data, which is published periodically by ONS for the UK and the Scottish Government for Scotland.

3. Current state of required input-output data for Scotland and UK

The first practical step at this pilot stage is to identify the industry multipliers that may be used to consider the scenarios identified in Section 2. There are three central issues that must be considered in the current context:

- **(i) Are the relevant activities captured in available input-output data?**
- **(ii) If not (i.e. if the activity in question is not yet carried out in a UK or Scottish context, or was not present in the latest input-output accounting year), can a proxy industry be identified to provide 'best guess' estimates of multiplier relationships?**
- **(iii) If so, is the industrial breakdown in the UK and/or Scottish input-output accounts sufficiently detailed to permit consideration of specific multiplier effects for the activity in question?**

In the case of CO_2-EOR under Scenario 3 the answer to (i) is 'no' so that a proxy industry multiplier must be identified. Here we focus on the example of the existing Oil and Gas industry, but discuss how the introduction of EOR activity may impact the input requirements of the industry.

In the case of CCS under Scenarios 2 and 3 the answer to (i) is clearly 'no' as CCS activity is not yet operational in the UK. The best proxies at this time may be the existing coal-powered or gas-powered electricity generation sectors (in this study we focus on the former, for reasons explained below). Thus, the CCS analyses in Scenarios 2 and 3 relies on data for existing electricity generation activity, and thus (if we accept this proxy) shares the same data source as Scenario 1, where for the case of off-shore wind generation the answer to (i) is 'yes'. However, the answer to (iii) in these cases is 'no' in the context of official input-output data published by ONS and the Scottish government respectively. While off-shore (and on-shore) wind generation activity is present in both the UK and Scotland, along with a range of other renewable and non-renewable technologies, including coal and gas, the input-output tables for both the UK and Scotland report only a single vertically (and horizontally) integrated Electricity sector, incorporating generation, transmission and distribution.

However, recent research at the Fraser of Allander Institute, University of Strathclyde[12] has produced experimental data disaggregating the composite electricity sector in a UK IO tables reported for the accounting year of 2004.[13] This permits identification of nine generation sectors in the UK case – including off-shore wind and the coal and gas generation where CCS is currently being explored, though with gas- and oil-powered generation combined in the data - that sell all of their output to a single electricity supply sector.[14] This introduces complications in terms of the wider application of multipliers, given that the generators do not directly serve final consumption demands (as explained in Section 2 above). However, in the current context, where the CfD framework may be interpreted as implicitly creating a government final demand, the industry multipliers for generation are applied on an experimental basis to consider the economy-wide impacts resulting from the CfD intervention.

On the other hand, that the 2004 data relate to an accounting period just over a decade ago reflects a serious problem in terms of the years that input-output data are available for, particularly in the case of the UK national accounts. Generally, given the complexity and comprehensive nature of input-output data, there is always a lag of a few years in producing accounts. Nonetheless, the UK is a particularly problematic case. The main issue is that ONS do not regularly produce input-output data in the basic (producer) price symmetric format that is required for multiplier analysis. Rather, regular input-output reporting is limited to production of supply and use tables that do not distinguish domestic and imported supply chain requirements and are reported in purchaser prices only.[15] The latest year that symmetric tables were produced for is 2005 (and, before that, 1995); however, the 2005 tables are in a commodity (rather than industry) reporting format that is less useful for the type of multiplier analysis required here. ONS is apparently planning to produce symmetric tables for 2009 that may be available sometime later in 2015.

The Scottish Government, on the other hand, is a leader in the field of regional accounting in the analytical input-output format required for multiplier analysis. Nevertheless, the most recent year for which Scottish input-output tables are available is still only 2011.[16] However, we have decided not to use Scottish data in this study, despite the availability of tables for a more recent accounting period. This is due to the lack of sectoral breakdown or presence of activities that our scenarios focus on. First, as noted above, the published Scottish input-output tables only report a single vertically and horizontal electricity sector. Second, the oil and gas extraction industry in the Scottish input-output tables only covers limited on-shore activity (although work is currently being undertaken by the Scottish government on linking the Scottish input-output framework to off-shore activity in the North Sea). Off-shore activity (including in the North Sea) is accounted as taking place on the Continental Shelf region of the UK and only enters the Scottish input-output framework as an export demand (from the rest of the UK) for on-shore support activities. Moreover, for disclosure reasons, the extraction of other minerals is now included in the sector. On the other hand, both off-shore and on-shore activity is included in the oil and gas extraction sector of national UK input-output accounts.

Therefore, in the current study, we have elected to use the version the industry-by-industry symmetric

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12 See Chapter 4 of Winning, M. (2012) 'An analysis of UK climate change policy institutions and instruments', PhD thesis, University of Strathclyde.

13 The estimated 2004 UK input-output data (without electricity sector disaggregation) are available to download at http://www.strath.ac.uk/fraser/research/2004ukindustry-byindustryanalyticalinput-outputtables/

14 The Fraser of Allander Institute team have also produced an experimental input-output table for Scotland for the earlier accounting year of 2000 where a similar disaggregation is done for electricity. However, confidence is low (Winning, 2012) on the quality of the estimates and the table is reported at what is a relatively high level of aggregation (with only 8 non-electricity industries). Thus, we have decided not to exploit these data in the current study.

15 Input-output data produced by ONS may be accessed and downloaded at http://www.ons.gov.uk/ons/guide-method/method-quality/specific/economy/input-output/index.html

16 Scottish input-output tables for 1998 to 2011 may be accessed and downloaded at http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Input-Output/SymmetricTables

(analytical) UK input-output tables for the UK in 2004 with electricity sector disaggregation estimated by the Fraser of Allander Institute (FAI). The 2004 UK tables are reported for 123 SIC-classified industries, which grows to 132 with 9 different generation sectors broken out.

4. Scenario 1: Off-shore wind supported by CfDs

As explained in Section 3, we are able to identify an industry output-multiplier and related GDP and employment multipliers for off-shore wind electricity generation from the experimental 2004 UK input-output tables. These are reported, along with the corresponding multiplier values for all the other generation types and the supply/distribution sector in Table 1 below.

The results in Table 1 show that the UK off-shore wind generation sector may be expected to have relatively high domestic multiplier relationships given that only 5% of the total input requirement to the sector is reported to be imported (though this is common across the electricity sub-sectors and may be a function of how the experimental data were generated rather than a true reflection of each sub-sector's requirements). 49% of the input requirement is in terms of goods/services sourced from other UK industries while 44% is payments to labour and other sources of value-added (the remainder is taxes on products and production).

Reading along the off-shore row we can see that the Type I output multiplier value at 1.99 is relatively high among other electricity generation sectors (but not the highest – gas and oil powered generation has a multiplier of 2.28) and the supply sector itself. However, when we moved to Type II, not only does off-shore wind have the second highest (behind biomass) overall output multiplier of 3.30, the additional induced (household income and consumption) effects taking us to this are the second highest in the table, 1.31 or 40% of the total Type II multiplier. Large induced effects imply that the sector's supply chain is labour- and/or wage-intensive. The former maps to a relatively high Type II output-employment multiplier of 33.6 which equates to 4.7 full-time equivalent (FTE) jobs generated throughout the economy for every direct FTE job within the sector itself (though this latter figure, termed an employment-employment multiplier – is lower than for other, less directly labour intensive generation sectors such as coal or gas and oil, that have smaller overall output-employment multipliers).

Table 1. Multipliers for the UK electricity sector dervied from the 2004 UK industry-by-industry input-output tables

	Direct supply chain (£ per £1 total input)		Output multipliers (£ per £1 final demand)		GDP (basic prices) intensity/multipliers (£ per £1 output/final demand)			Employment (FTE) intensity/multipliers (FTE per £1m output/final demand)		
	Domestic	Imported	Type I	Type II	Direct	Type I	Type II	Direct	Type I	Type II
Electricity Supply	**0.69**	**0.05**	**2.27**	**2.93**	**0.24**	**0.81**	**1.15**	**1.7**	**7.8**	**15.6**
Generation - Nuclear	0.31	0.05	1.56	2.16	0.63	0.86	1.16	2.7	7.0	14.1
Generation - Coal	**0.49**	**0.05**	**1.86**	**2.57**	**0.44**	**0.79**	**1.16**	**1.7**	**8.9**	**17.3**
Generation -Gas + Oil	0.77	0.05	2.28	2.88	0.16	0.77	1.07	1.4	6.5	13.6
Generation - Hydro	0.23	0.00	1.45	2.48	0.75	0.94	1.46	7.1	12.1	24.2
Generation - Biomass	0.42	0.00	1.85	3.40	0.56	0.92	1.70	10.1	19.5	37.8
Generation - Wind On-shore	0.48	0.05	1.99	3.06	0.45	0.86	1.41	5.0	15.9	28.6
Generation - Wind Offshore	**0.49**	**0.05**	**1.99**	**3.30**	**0.44**	**0.86**	**1.52**	**7.2**	**18.1**	**33.6**
Generation - Other	0.32	0.05	1.63	3.06	0.62	0.88	1.61	10.1	17.0	33.9
Generation - Marine/solar	0.48	0.05	1.98	3.28	0.45	0.86	1.52	7.1	17.9	33.2

Table 2. Top 12 (out of 132) industries that the off-shore electricity generation sector sources inputs from

IOC	Sector description	Share of domestic intermediate inputs
88	Construction	78.05%
100	Financial intermediation, except insurance and pension funding	5.35%
90	Wholesale trade and commission trade, except of motor vehicles and motor cycles	4.26%
101	Insurance and pension funding, except compulsory social security	1.44%
58	Tanks, reservoirs and containers of metal; manufacture of central heating radiators and boilers; manufacture of steam generators	1.37%
107	Computer and related activities	0.89%
112	Architectural and engineering activities and related technical consultancy; technical testing and analysis	0.82%
34	Publishing, printing and reproduction of recorded media	0.80%
63	Other general purpose machinery	0.74%
99	Telecommunications	0.70%
97	Supporting and auxiliary transport activities; activities of travel agencies	0.46%
89	Sale, maintenance and repair of motor vehicles, and motor cycles; retail sale of automotive fuel	0.43%
	Others	4.70%

In terms of what type of upstream supply chain linkages give rise to these results, Table 2 shows that 78% of the value of intermediate inputs purchased by the off-shore generation sector from other UK industries is from the Construction sector. The underlying study[17] explains that ONS ABI survey data and primary data checks confirm that these are repair and maintenance rather than initial construction costs.

Table 3. Top 12 (out of 132) industries that off-shore electricity generation has Type II output multiplier linkages with

IOC	Sector description	Share of indirect and induced multiplier effects
88	Construction	25.57%
91	Retail trade, except of motor vehicles and motor cycles; repair of personal and household goods	5.90%
104	Letting of dwellings, including imputed rent	5.81%
90	Wholesale trade and commission trade, except of motor vehicles and motor cycles	4.73%
100	Financial intermediation, except insurance and pension funding	4.39%
92	Hotels and restaurants	3.78%
101	Insurance and pension funding, except compulsory social security	3.03%
89	Sale, maintenance and repair of motor vehicles, and motor cycles; retail sale of automotive fuel	2.22%
97	Supporting and auxiliary transport activities; activities of travel agencies	2.18%
121	Recreational, cultural and sporting activities	2.04%
114	Other business services	2.02%
103	Real estate activities with own property; letting of own property, except dwellings	1.87%
	Others	36.46%

Table 4. Top 12 (out of 132) industries that off-shore electricity generation has Type II output -employment multiplier linkages with

IOC	Sector description	Share of indirect and induced multiplier effects
88	Construction	25.95%
91	Retail trade, except of motor vehicles and motor cycles; repair of personal and household goods	12.76%
92	Hotels and restaurants	6.84%
90	Wholesale trade and commission trade, except of motor vehicles and motor cycles	4.88%
114	Other business services	4.25%
100	Financial intermediation, except insurance and pension funding	2.78%
89	Sale, maintenance and repair of motor vehicles, and motor cycles; retail sale of automotive fuel	2.62%
121	Recreational, cultural and sporting activities	2.44%
94	Other land transport; transport via pipelines	2.13%
116	Education	2.08%
97	Supporting and auxiliary transport activities; activities of travel agencies	1.96%
122	Other service activities	1.62%
	Others	29.67%

However, Table 2 only reports direct linkages. The multipliers introduce consideration of *indirect* industrial linkages (i.e. the supply chains of suppliers of any direct supplier). If we turn our attention to the composition of the Type II output multiplier in Tables 3, the importance of other industries (e.g. that Construction and other direct suppliers source their inputs from) becomes more apparent. The top 12 indirect linkages for the off-shore electricity generation sector in Table 3 - where we identify industry by their Input-Output Classification of IOC, which in turn maps to the Standard Industrial Classification SIC (2003 version for the 2004 UK accounts) - are the sectors of the economy that will benefit most if there

[17] Winning (2012) - see Footnote 12.

is an increase in activity in the off-shore wind sector.

A key factor underlying the strength of the off-shore wind Type II output-employment multiplier in Table 1 is the labour intensity of some of many of these sectors, particularly Construction and IOCs 90-92 (covering retail, wholesale activities and hotels, restaurants and catering). After Construction, IOCs 90-92 are the three strongest Type II employment linkages (Table 4) and the strength of the multiplier relationship with the off-shore electricity generation sector is mainly due to induced effects (i.e. impacts of employees throughout the supply chain spending wage income earned as a result of the stimulus provided by the off-shore wind sector) as well as the relatively labour intensity of the supply chain.

The multiplier values for the off-shore wind electricity generation sector in Table 1 and the decomposition in Tables 3 and 4 indicate the type of benefit that government may expect to realise in terms of the scale and composition[18] of economy-wide benefits for each £1 of expenditure to support the development of the sector. Note that this does not include any further impacts as a result of, for example, any further investment decisions that may be made. The multipliers here focus entirely on the impacts of the operation of current capacity (assuming that the supply chain now is structured as estimated in the 2004 UK input-output accounts used).

5. Scenario 2: CCS with pure storage supported by CfDs

The second scenario is less straightforward to analyse as CCS activity is not yet operational in the UK. This means that we do not have existing industry/activity multiplier data. The most straightforward proxy is to take the multiplier values for the electricity generation sector where the CCS activity takes place. This may be appropriate if the presence of CCS at coal- and/or gas-powered electricity plants provided a reason to maintain the use of these non-renewable sources for longer or rely more heavily on them than would otherwise be the case (i.e. that the presence of CCS affects activity levels in the host generation sectors). On the other hand, the problem with this approach is that the input requirements of new CCS activity are unlikely to correspond exactly with the existing electricity generation activity. For example, there will be additional construction activity in building units to capture CO_2 (*although this will not strictly feature as the type of operational cost recorded in year-on-year input-output accounts*), as well as additional fuel and labour inputs to run the CCS system. Moreover, there will be specific inputs for CCS such as the organic chemical amine that is used in the capture of CO_2.

We have focussed our analysis here on CCS linked to coal- rather than gas-powered electricity generation. There are two motivations for this. First, that the information used to inform our illustrative scenario analysis below is linked to the case of coal. Second, the experimental 2004 UK input-output data do not separately distinguish gas-powered generation; rather it is treated in a composite sector with oil-powered generation. From Table 1 we can see that the gas/oil generation sector has higher output but lower GDP and employment multipliers than the coal generation sector (largely because the latter is more directly value-added intensive and slightly more labour intensive).

Table 5 (below) reports the direct input requirements of the UK coal-powered electricity generation sector as reflected in the 2004 UK input-output tables. The key thing to note is the importance of the coal extraction sector in the direct supply chain, and this is carried forward (to a lesser extent) to the share of indirect and induced effects in the coal generation supply chain underlying the Type II output multiplier (2.57 from Table 1 above). This is an obvious feature of generation activity that will not be shared with CCS. We did experiment with the input requirements matrix that underlies the derivation of the multipliers, by removing the coal input and (somewhat arbitrarily) increasing construction, labour, fuel and organic chemical inputs (in line with the discussion above). However, while the composition of the multipliers changes the overall values (i.e. mapping to those in Table 1), the total values were not greatly changed. The Type I values were slightly higher while the Type II ones were slightly lower (reflecting the fact that the coal extraction industry has slightly weaker industrial but slightly stronger induced supply chain linkages than the coal-powered electricity generation sector). This is not to say that actual CCS activity would have similar supply chain linkages and multiplier relationships as the coal-powered electricity generation sector. Rather, that identifying the correct multiplier values will not be as simple as tinkering with obvious parts of the input mix. We return to this issue in the final section

[18] Note that Tables 3 and 4 show the composition of indirect and induced impacts, which are additional to the direct impact in the off-shore electricity generation sector itself. This is also true in the comparable tables for the other cases below.

of the report (in discussing future research priorities).

Table 5. Top 12 (out of 132) industries that the coal-powered electricity generation sector sources inputs from

IOC	Sector description	Share of domestic intermediate inputs
4	Mining of coal and lignite; extraction of peat	57.23%
86	Gas; distribution of gaseous fuels through mains; steam and hot water supply	16.49%
100	Financial intermediation, except insurance and pension funding	6.69%
90	Wholesale trade and commission trade, except of motor vehicles and motor cycles	5.63%
101	Insurance and pension funding, except compulsory social security	1.85%
58	Tanks, reservoirs and containers of metal; manufacture of central heating radiators and boilers; manufacture of steam generators	1.64%
112	Architectural and engineering activities and related technical consultancy; technical testing and analysis	1.16%
107	Computer and related activities	0.87%
34	Publishing, printing and reproduction of recorded media	0.78%
63	Other general purpose machinery	0.72%
99	Telecommunications	0.69%
110	Accounting, book-keeping and auditing activities; tax consultancy	0.53%
	Others	5.73%

Table 6. Top 12 (out of 132) industries that coal-powered electricity generation has Type II output multiplier linkages with

IOC	Sector description	Share of indirect and induced multiplier effects
4	Mining of coal and lignite; extraction of peat	18.10%
86	Gas; distribution of gaseous fuels through mains; steam and hot water supply	6.48%
90	Wholesale trade and commission trade, except of motor vehicles and motor cycles	6.40%
100	Financial intermediation, except insurance and pension funding	6.04%
91	Retail trade, except of motor vehicles and motor cycles; repair of personal and household goods	4.73%
104	Letting of dwellings, including imputed rent	4.64%
101	Insurance and pension funding, except compulsory social security	3.03%
92	Hotels and restaurants	3.02%
0	Electricity Supply	2.68%
97	Supporting and auxiliary transport activities; activities of travel agencies	2.45%
88	Construction	2.37%
89	Sale, maintenance and repair of motor vehicles, and motor cycles; retail sale of automotive fuel	2.16%
	Others	62.10%

Based on the coal-powered electricity generation proxy for CCS, the multiplier values for this sector in Table 1 and the decomposition for output in Table 6 indicates the type of benefit in terms of that government may expect to realise in terms of the scale and composition of economy-wide benefits for each £1 of expenditure to support the development of CCS activity. Generally, reading across the off-shore wind and coal generation rows of Table 1, and based on the latter as the proxy selected here for CCS, the multiplier values suggest that £1 spent to support off-shore wind is likely to generally yield a higher return in the form of economy-wide benefits (though subsequent tables show that the industrial composition of benefits will differ) than support of CCS. If we took the combined gas and oil generation sector multipliers as an alternative CCS proxy, the multipliers suggest a larger Type I output effect would be realised (i.e. a greater boost to UK industrial production levels) but all other multiplier impacts (including the GDP impacts of even Type I expansion) would still be smaller than in the off-shore wind case. One key issue with the data may be the low import share (see start of Section 4) in the underlying wind generation sector. If inaccurate, this will lead to overestimation of multiplier effects in the UK.

However, in the next section we raise the question as to whether the potential for CO_2-EOR activity in the Oil and Gas industry to create an demand for captured CO_2, thereby reducing the need for storage in the CCS process and the scale of the subsidy required for CCS to become economically viable, for example by hitting a potential 'strike price' (if CCS were to fall under the CfD framework).

6. Scenario 3: CO_2-EOR with CCS with pure storage supported by CfDs

Articulating the 'final demand shocks'

The final scenario involves articulating an illustrative scenario for the level of government support of CCS and how this may be reduced through the presence of CO_2-EOR activity in the Oil and Gas industry reducing the storage requirement and costs in the CCS process linked to coal-powered electricity generation. This is done so that the reduced government demand requirement may be sent against the impacts of increased industrial activity in generating an illustrative multiplier for the scenario. Table 6 reports the data used to quantify the potential reduction in government support.

Table 6. Data for reduced government support for CCS (scale of 'final demand shock)

Initial government support for CCS (applicable to Scenario 2):		
Sum of lifecycle incremental costs for CCS, which break down as follows:		
CAPEX	£457	million
OPEX (fixed)	£370	million
OPEX (variable)	£146	million
Fuel	£798	million
CO2 transport and storage costs	£1,618	million
	£3,389	**million**
Reduction in required support due to EOR under Scenario 3:		
Sum of reduction in storage costs and CO2 to EOR transfer price:		
Storage development cost of £6 per tonne times 80 mt CO2 to EOR (£480)		
CO2 transfer price of £10 times 80 mt CO2 (4 mt pa over 20 years) to EOR (£800million)		
Total: £1280million		
Reduced level of government support for CCS (applied in Scenario 3): £2109		

Sources for Table 6: See Technical Appendix Part 3.

The first figure (£3389m) is the one that may be used for a scaled scenario analysis under Scenario 2 (it would also be possible to introduce a scaled shock for support of off-shore wind electricity generation under Scenario 1). However, given the definition of the government intervention multiplier in equation [4] in Section 2, the multiplier relationships per £1 of government support would not be sensitive to scale in the demand-driven input-output framework.

However, under Scenario 3, where we are effectively (at least partly) replacing the need for government support for the storage element of CCS through the introduction of an activity that uses the captured CO_2 (here CO_2-EOR), this involves the introduction of two demand disturbances. However, the government intervention multiplier is stated in terms of the return to only one of these, the implied government demand. Table 6 gives us the figure used for the reduced government support for CCS £2109m (B_G^{CCS} in equation [5] in Secton 2). Table 7 then summarises how the figure for the demand disturbance representing the EOR project. The figure of £5250m for the positive demand shock required in the Oil and Gas industry (which would equate to B_M in the standard industry multiplier calculation in equation [2]) is what is required to cover the cost of producing additional barrels of oil using CO_2-EOR processes in the Oil and Gas Industry. Note that we do not attempt to articulate this demand shock in terms of what the full market value of delivering the additional barrels of oil may be. Nor do we explicitly attempt to focus on the actual capital formation activity that may be required in the provision of capacity for CO_2-EOR activity. This may involve a direct stimulus to other sectors that supply capital goods/services through a change in the 'gross domestic fixed capital formation' category of final demand in input-output. Rather, we consider the average (fixed and variable) costs of production and articulate this as a generic boost in demand for the output of the Oil and Gas industry required to cover these costs. Generally, Scenario 3 provides an example of how it can be difficult to articulate a change in activity in the form of the final demand shock required in the simple and transparent but quite restrictive demand-driven input-output model.

Below (with details in Part 3 of the Technical Appendix) we report results of sensitivity analyses that focus on the scale of the shocks introduced to this Scenario. However, before we consider the this, or the central case results based on the figures in Tables 6 and 7, we first consider the nature and value of the additional multiplier values required to introduce consideration of EOR activity.

Table 7. Data for new EOR activity (scale of 'final demand shock)

240 barrels produced at $35 per barrel
Production level based on:
3 barrels per tonne of CO2, assuming 80 tonnes (4 tonnes pa) of CO2 per annum over 20 years
Total cost/level of additional demand required: $8400million or £5526million at £1.60/£1

Identifying industry multipliers to calculate the impacts

The next question is what multiplier values to use in calculating the total Type II economy-wide impacts. For the implied government demand (Table 6) we proceed as under Scenario 2 using the coal-powered electricity generation multipliers in Table 1 to consider the impacts of supported CCS activity. However, for the required demand for new CO_2-EOR activity within the Oil and Gas industry (Table 7), we must decide whether the existing multipliers for this industry (see Table 8) are appropriate for use.

A key issue is that oil extraction using CO_2-EOR methods is likely to lead to a higher cost per barrel (which is already reflected in the figures for the direct demand requirement in Table 7) with higher expenditure on compression using gas and on corrosion-resistant materials for facilities and wells. Moreover, for the given plant/equipment, each unit is likely to be more labour and capital intensive, for example, possibly requiring three more workers to run carbon rather than water flooding processes. There are also likely to be more construction hours off-shore depending on whether existing facilities are fit for purpose or whether new facilities are required, with the latter having additional input requirements. Moreover, if there is a need to design new systems there will also be a need for new/additional technical/specialist services. Implicit within this discussion is the need to ultimately distinguish between construction and operational/maintenance phases. A recent study[19] considering the economic impacts of CO_2-EOR at different stages argues that once CO_2-EOR is operational there may only be "modest" additional work over and above the situation without CO_2-EOR, involving mainly inspection and maintenance work, as well as possibly compliance costs if CO_2-EOR fields are classified as CCS installations under the EU ETS.

The key point is that if/once CO_2-EOR activity begins in the UK Oil and Gas industry[20], the impacts on

[19] See report by Element Energy and partners commissioned by Scottish Enterprise at file://psf/Home/Downloads/Economic%20Potential%20of%20CO2%20EOR%20in%20Scotland%20(1).pdf

[20] One issue to note is that UK input-output accounting has now moved to the updated SIC2007 with adjustments to the IOC identification of industries, including separation of the extraction and support industries previously reported together in the 2004 IOC5

input requirements and costs will be reflected in the ABS survey returns that inform the input-output tables. There may be a question at that point as to whether it would be useful (particularly if considering CO_2-EOR activity as linked to/part of CCS activity under EU ETS) to distinguish a sub-industry, and that may be possible based on additional (to the standard ABS input) focussed survey (subject to disclosure/confidentiality considerations).

In the meantime, we can examine the underlying input-output data and composition of key multipliers to permit assessment whether CO_2-EOR activity is sufficiently represented by the current industry average. However, as in the discussion of coal generation and linked CCS above (where the latter is also currently absent), there would not seem to be a great deal of benefit to be gained in this pilot study from tinkering with the input mix to better reflect CO_2-EOR activity without good information to do so. Another suggestion (made by Stevan Croasdale from the Scottish Government's input-output team) is it may be more appropriate to identify one or more specialist support sector(s) that would have more similar features to what may be expected for CO_2-EOR. This may be explored in the future following feedback on this pilot study.

Table 8. Multipliers for the UK oil and gas extraction industry derived from the 2004 UK industry-by-industry input-output tables

	Direct supply chain (£ per £1 total input)		Output multipliers (£ per £1 final demand)		GDP (basic prices) intensity/multipliers (£ per £1 output/final demand)			Employment (FTE) intensity/multipliers (FTE per £1m output/final demand)		
	Domestic	Imported	Type I	Type II	Direct	Type I	Type II	Direct	Type I	Type II
IOC5 Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction	0.25	0.06	1.43	1.84	0.70	0.91	1.12	1.1	5.2	10.1

	GOS intensity/multipliers (£ per £1 output/final demand)			Wage income intensity/multipliers (£ per £1 output/final demand)		
	Direct	Type I	Type II	Direct	Type I	Type II
IOC5 Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction	0.64	0.73	0.83	0.06	0.18	0.29

Here, Table 8 reports a range of Oil and Gas industry multipliers, including the wage income and other value added, or gross operating surplus (GOS) that underlie the total value-added or GDP (at basic prices) multipliers. However, we focus on the output and GDP multipliers in our scenario analysis. In Tables 9-11 we examine the underlying input-output data to report the top 12 other industries with which the Oil and Gas industry (as reported in the 2004 UK input-output table) has the strongest direct and Type II output and GDP linkages.

First, Table 8 above reports a range of Type I and Type II multiplier values for the UK Oil and Gas industry for the accounting year of 2004. The key thing to note is that the sector has a lower requirement for domestically produced intermediates and a significantly higher value-added content (which mainly lies in its gross operating surplus) relative to the electricity generation sectors considered above. This means that the output multipliers are also lower. Moreover, the supply chain is also generally less labour- and wage-intensive so that the induced effects that move us from Type I to Type II multiplier values are less strong than observed for the electricity generation sectors.

Table 9. Top 12 (out of 132) industries that the Oil and Gas industry sources inputs from

IOC	Sector description	Share of domestic intermediate inputs
100	Financial intermediation, except insurance and pension funding	27.28%
88	Construction	15.02%
106	Renting of machinery and equipment without operator and of personal and household goods	6.46%
109	Legal activities	6.10%
5	Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction	5.30%
57	Structural metal products	4.09%
112	Architectural and engineering activities and related technical consultancy; technical testing and analysis	3.85%
90	Wholesale trade and commission trade, except of motor vehicles and motor cycles	3.14%
85(a)	Electricity Supply	2.58%
95	Water transport	2.35%
86	Gas; distribution of gaseous fuels through mains; steam and hot water supply	2.06%
101	Insurance and pension funding, except compulsory social security	1.98%
	Others	19.80%

Table 10. Top 12 (out of 132) industries that the Oil and Gas industry has Type II output multiplier linkages with

IOC	Sector description	Share of indirect and induced multiplier effects
100	Financial intermediation, except insurance and pension funding	11.88%
88	Construction	8.29%
91	Retail trade, except of motor vehicles and motor cycles; repair of personal and household goods	5.12%
104	Letting of dwellings, including imputed rent	5.03%
90	Wholesale trade and commission trade, except of motor vehicles and motor cycles	4.32%
92	Hotels and restaurants	3.29%
101	Insurance and pension funding, except compulsory social security	3.24%
106	Renting of machinery and equipment without operator and of personal and household goods	2.94%
109	Legal activities	2.68%
97	Supporting and auxiliary transport activities; activities of travel agencies	2.67%
114	Other business services	2.65%
5	Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction	2.43%
	Others	45.45%

However, the value-added intensity of the oil and gas extraction industry itself, and, albeit to a lesser extent, of several key industries within its supply chain, mean that the output-GDP (at basic prices) and output-GOS (gross operating surplus) multiplier effects are relatively high. A question in examining the input requirement and multiplier data here is whether CO_2-EOR activity may be expected to share the direct value-added intensity of the overall oil and gas industries and whether key (direct, indirect and/or induced) supply chain linkages are also likely to exist in high value-added sectors, such as those that move up the ranking in Table 11 when we focus on the composition of GDP multiplier effects.

Table 11. Top 12 (out of 132) industries that the Oil and Gas industry has Type II output-value added multiplier linkages with

IOC	Sector description	Share of indirect and induced multiplier effects
100	Financial intermediation, except insurance and pension funding	15.20%
104	Letting of dwellings, including imputed rent	8.73%
88	Construction	6.23%
91	Retail trade, except of motor vehicles and motor cycles; repair of personal and household goods	5.92%
90	Wholesale trade and commission trade, except of motor vehicles and motor cycles	3.72%
109	Legal activities	3.48%
5	Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction	3.39%
106	Renting of machinery and equipment without operator and of personal and household goods	3.26%
114	Other business services	2.90%
92	Hotels and restaurants	2.89%
112	Architectural and engineering activities and related technical consultancy; technical testing and analysis	2.79%
107	Computer and related activities	2.37%
	Others	39.11%

Results of the illustrative scenario analysis: overall multiplier impacts of (reduced) government intervention to support CCS and subsequent CO_2-EOR activity

The results of applying the industry multipliers to the final demand 'shocks' articulated above are reported in Table 12 below. The final two columns report the overall output and GDP multiplier effects of the two cases for Scenario 3 (calculated using equation [5] from Section 2) in comparison with those for Scenarios 1 and 2 (calculated using equation [4] from Section 2). This allows us to compare the potential return – in terms of economy-wide economic activity – per £1 of government support for off-shore wind and CCS activity, where the latter varies dependent on whether CO_2-EOR activity is present.

Table 12. Scenario 3 computation and results (with cmparisons to Scenario 1 and 2 multiplier impacts)

Scenarion 3 Summary of results							
Activity	Industry Type II multipliers		Value of final demand 'shock'	Total economy wide-impact		Implied government intervention multiplier	
	Output	Output-GDP		Output	GDP	Output	GDP
Coal-CCS	2.57	1.16	£2,109	£5,421	£2,441		
CO2-EOR	1.84	1.12	£5,250	£9,660	£5,863	7.15	3.94
			Comparison with Scenarios 1 and 2:				
						Output	GDP
				Scenario 1 (off-shore wind)		3.30	1.52
				Scenario 2 (CCS-coal without C02-EOR)		2.57	1.16

The key overall conclusion that may be drawn from this (very) illustrative and provisional analysis is that support via a framework like CfD may realise a greater return (again, in terms of economy-wide multiplier effects) when directed at off-shore wind electricity generation than CCS alone: the Type II output and output-GDP multipliers are £3.30 and £1.52 per £1 of government support respectively for off-shore wind compared to £2.57 and £1.16 for CCS. However, this changes if we consider the 'bigger picture' of the potential impacts delivered by CO_2-EOR through its implied demand for captured CO_2. Not only is the overall cost of government intervention decreased (while still delivering the same return per £1), the new CO_2-EOR activity delivers an additional stimulus that ripples throughout the UK economy. This combines with the CCS multiplier effect to deliver a Type II output multiplier impact of £7.15 per £1 of government support for CCS, and an output-GDP multiplier of £3.94 per £1.

In Appendix 3 we report the results subjecting of sensitivity analyses for these results given different assumptions about key variables impacting: (i) the size of the EOR project (in terms of production and investment); and (ii) the benefit to the CCS project through the volume of CO_2 transferred as well as transfer price and the reduction in storage cost. We find that multiplier effects are most sensitive to what we assume about (a) the level of EOR demand for CO_2 (metric tonnes per annum); and (b) the time period (years) over which this demand occurs. The output and GDP multiplier results range from 4.33 and 2.22 respectively - where (a) is at its lowest value- to 9.32 and 5.25 - where (b) is at its highest value.

In closing, it must be noted that the analysis here does not take account of any further impacts of additional tax revenues that would be generated as a result of expansion in the Oil and Gas and other industries that are positively affected. Nor do we consider any further investment in any of the technologies that may be stimulated by the impacts of government support, expansionary effects and/or changing returns to capital or labour. On this final point, we remind the reader of the various restrictive assumptions involved in using the demand-driven input-output model that have been highlighted at various points in this report. We now turn our attention to this and other recommendations for future research.

7. Conclusions and directions for future research

This report details a very preliminary study that has been carried out over a very short timeframe using quite limited data sources. However, it is hoped that the analysis is viewed as rigorous and transparent, both in terms of highlighting the problems in identifying economic multipliers for activities that are not clearly distinguished or present in current official input-output accounting data, and in considering the methods by which multiplier analysis may be applied to the scenarios considered.

The central but preliminary conclusion of this study is that CO_2-EOR activity has the potential to deliver significant economic impacts, particularly in terms of output and GDP throughout the economy, and, in so doing, increase the 'return' per £1 of government support for low or reduced carbon technologies through the CfD framework. However, fuller investigation is required on a number of issues.

Data availability and provision

First, in order to more accurately identify multiplier relationships on technologies such as the various forms of renewable electricity generation, CCS and CO_2-EOR (where these are either not distinguished in currently available national/regional input-output accounting data or are not currently present in the UK national or regional economies), there is a need to more carefully and comprehensively investigate the input requirements of these activities (which form the basis of the multipliers). This may involve examining input-output accounting data for other countries/from other studies where attempts have been made to decompose activities like electricity production and supply (generally treated as a single industry in published input-output accounts) and/or where activities such as CCS and EOR-CO_2 are present and incorporated in input-output or other accounting data that provide information on input requirements. Where existing data are not available, or are unlikely to provide a sufficiently accurate proxy for the Scottish and/or UK cases, there is a need to gather primary data directly from those carrying out the activities in question and perhaps also actors in their supply chains. Some other existing studies of the impacts of off-shore wind, CCS and CO_2-EOR have already carried out work in this area but there is potential to add further value, particularly through more detailed and transparent consideration of input-output accounting and multiplier modelling methods.

In terms of data, there is a need to interact with input-output data providers in the UK. One issue is in terms of the frequency of publication of input-output tables in the basic price symmetric industry-by-industry 'analytical' format required to build multiplier models. As explained in Section 3, ONS only publish input-output data for the UK in this form on an infrequent basis, which is part of the reason that this study has had to rely on experimental estimated UK data for 2004 (the author was involved in this estimation work, which was carried out at the Fraser of Allander Institute, University of Strathclyde). The other issue is detail of sectoral breakdown in input-output accounts. This is a global problem (i.e. not limited to the UK). While there is increasing attention on the activities of and wider economic growth implications of low carbon electricity generation technologies, electricity generation, transmission, distribution and trade continue to be recorded under a single code in the Standard Industrial Classification (35.1 in the 2007 SIC). On this basis, input-output accountants treat all electricity production and supply activities under a single input-output classification (IOC). Again, this is why the current study has had to rely on experimental data that separates different generation activities from the wider supply industry. Moreover, the lack of reliable Scottish estimates in this respect meant that the study could not draw on Scottish data for more recent years (although 2011 data for Scotland are used in the Technical Appendix below to illustrate the detailed methodology used here).

The other main issue in terms of data provision where the author believes that the Scottish Government is currently making progress is the treatment of the North Sea Oil sector. This is treated as taking place in a UK region called the Continental Shelf and is thus not captured within Scottish input-output accounting data. Moreover, particularly given the potential for increased on-shore oil and gas extraction activity, the reporting of all extraction activity within a single UK IOC is likely to become problematic. Indeed, while support activities have now been broken out of the combined sector considered here, this has come with inclusion of all mineral extraction in a single sector in UK and Scottish accounting. The Scottish Government are currently working on reporting data on North Sea activity in the Continental Shelf in input-output format that may be linked to the Scottish input-output framework in an inter-regional format.

In the absence of existing Scottish and/or UK input-output data for CCS and EOR activity, the first step for future research following on from this pilot study would be to conduct a bottom-up analysis of the input requirements of these processes (and of the destination of output to inform the new 'industry' rows). This would involve interviewing industry representatives regarding the breakdown of input costs for each CCS and EOR and mapping individual cost elements to existing intermediate supply sectors in the input-output framework. Essentially this would involve creating a new 'industry', or 'sub-industry' for each CCS and EOR, but linking them as appropriate to the existing electricity generation and oil and gas industry sectors.

Developing modelling techniques for scenario analysis

As well as questions regarding data/information, there is the issue of how best to analyse/model different types of activities and scenarios. There are several developments that could be made.

(a) Development of input-output methods to better consider CO_2 treatment activities such as CCS

In thinking about how CCS activity may be incorporated in an input-output framework for future multiplier analyses, and also as the basis for extension to more flexible and theory consistent 'computable general equilibrium' (CGE) models in the future (below), there is a potential avenue for development. At present, using environmentally extended input-output tables, CO_2 generation can be identified as second, currently unwanted, output from electricity generation and other sectors of the economy. However, in the presence of CO_2-EOR, CO_2 becomes an additional but *'wanted'* output from sectors where CCS activity takes place.

Analytically, there would seem to be two issues in moving to consideration of CCS relating to treatment of inputs and outputs respectively. The first is to identify the additional processes and the consequent input requirements for capture and storage of carbon (to allow us to populate a column for a sub-industry in an input-output table). The second is to investigate the nature of forward linkages and are these direct from generator to user (e.g. in the current project and Scenario 3 this would be the oil extraction industry and/or a CO_2-EOR sub-sector), what transportation/pipeline activity (construction and operation phases) are required etc.

Given that multiplier analysis requires a symmetric input-output table, identification of CCS activities (which may not be limited to electricity generation, but may involve different input requirements in other carbon generating industries where CCS is a possibility) may involve identifying/breaking out a separate 'industry'. This would suggest an interesting and original research area on its own and may involve development of early environmental input-output work in a seminal paper by the founder of input-output accounting and modelling, Wassily Leontief.[21] Leontief's early work involved identifying a 'cleaning sector' that disposed of pollution to supply a clean environment. Here, we would be looking at developing this to consider a sector that captures and stores CCS (so still supplying a clean environment) but also potentially supplying CO_2 as an input to processes such as CO_2-EOR.

(b) Relaxing the restrictive assumptions and requirements of the demand-driven input-output model through development of multi-sector computable general equilibrium (CGE) models

At various points throughout this report, problems arising from the restrictive assumptions and requirements of the conventional demand-driven input-output model most commonly used for multiplier analyses have been highlighted. There are several key issues:

1. **We are forced to articulate all scenarios in the form of a 'shock' to final demand expenditure**
2. **The model is silent on the impact of price changes and assumes that there are no constraints on supply (which would be one source of price changes/pressure). In this context it is difficult to model scenarios that involve changes in supply conditions, prices, returns to factors of production etc.**
3. **Public sector production activities are included among the industries identified, and government is identified as a final consumer, but there is no treatment of any taxes (other than recording taxes/subsidies on products and production[22]) and/or how additional revenues through income or other taxation may impact government spending decisions.**
4. **There is no treatment of time/dynamics in an input-output model. This means that we cannot consider the manner or speed with which how the economy adjusts to different disturbances, or how different disturbances may impact at different times, in different sequences (related or unrelated). This is particularly (but not exclusively) problematic where changing prices, returns and incomes may impact things like investment decisions.**

Particularly given the nature of the scenarios considered here, which have energy supply, price, subsidy and future investment decisions at their core, a key recommendation of this report is that future research should involve development of a CGE model for Scotland or the UK to estimate the total economy-wide impacts in the numerator of the multiplier calculations in equations [4] and [5]. Such a CGE model would build on existing models, and incorporate the enhanced input-output data recommended above in order to describe the baseline structure of the key industry activities (CCS and CO_2-EOR) and of the wider economy. However, development and use of a CGE framework will permit relaxation of the various assumptions that give rise to the four issues above. Both HM Treasury and the Scottish Government are already working with CGE models to analyse fiscal issues in particular. Moreover, research developing these more flexible and theory-consistent models to analyse energy and environmental issues tends to be well supported both by government and funders.

[21] Leontief, W. (1970). Environmental repercussions and the economic structure: an input-output approach. *Review of Economic Statistics*, 52: 262-277.

[22] Scenarios involving changes in these taxes/subsidies can only be modelled using the price or supply driven variants of the input-output system. However, the input-output model then becomes silent on quantities and/or demand is treated as passive.

Technical Appendix – Part 1: formal methodology

An input-output table reports the composition of output and input respectively for i=j=1, …, N industries and outputs. All units are expressed in terms of value (millions of British pounds sterling (£m) in the case study here). Reading along each row, x_i is the output of sector i, which is the sum of intermediate demands from each production sector j, and final consumption demand, yi, for the output of sector i. Where there are z=1, …, Z different types of final consumers, this may be represented in the following system of linear equations (e.g. representing industry rows in the sample input-output table in Figure 1 in part 2 of this technical appendix below):

[1]

$$
\begin{aligned}
x_1 &= x_{11} + x_{12} + \cdots + x_{1n} + y_{11} + \cdots + y_{1z} \\
x_2 &= x_{21} + x_{22} + \cdots + x_{2n} + y_{21} + \cdots + y_{2z} \\
x_n &= x_{n1} + x_{n2} + \cdots + x_{nn} + y_{n1} + \cdots + y_{nz}
\end{aligned}
$$

The first step in generating multipliers is to define matrix, **A**, of input-output coefficients with elements, $a_{i,j}=x_{ij}/x_j$, which relate the intermediate input requirement from sector i per unit of industry j total input (output). See Figure 2 in Part 2 below for an example. Substituting $x_{i,j}=a_{ij}x_j$, into [1] and re-arranging to state in terms of exogenous final demand y_z:

[2a]

$$
\begin{bmatrix}
(1-a_{11})x_1 & -a_{12}x_2 & \cdots & -a_{1n}x_n = y_{11} + \cdots + y_{1z} \\
-a_{21}x_1 & (1-a_{22})x_2 & \cdots & -a_{2n}x_n = y_{21} + \cdots + y_{2z} \\
\vdots & \vdots & \ddots & \vdots \\
-a_{n1}x_1 & -a_{n2}x_2 & \cdots & (1-a_{nn})x_n = y_{n1} + \cdots + y_{nz}
\end{bmatrix}
$$

In matrix notation – where bold font upper case denotes matrices; bold font lower case denotes vectors, while non-bold lower case implies a scalar - [2] is stated as:

[2b] $\mathbf{[I\text{-}A]X} = \mathbf{Y}$

Then output in the demand-driven input-output system is given by:

[3] $\mathbf{X} = \mathbf{[I\text{-}A]^{-1}Y}$

Where **Y** is the NxZ matrix of exogenous final consumption expenditures, **X** becomes an NxZ matrix of output supported by, or attributable to **Y**, or a change in final demand $\Delta\mathbf{Y}$ (where [3] would then model a change in output, $\Delta\mathbf{X}$**)**, through the transmission mechanism, the NxN matrix $\mathbf{[I\text{-}A]^{-1}}$, which is referred to as the Leontief inverse, or Type I multiplier matrix.[23] See Figure 3 in Part 2 below for an example. The Leontief inverse, which we also refer to as matrix **L** below, has elements b_{ij}, representing the output in each industry i that is required to meet final demand for commodity output j. The column totals of the Leontief inverse for each sector j are the total output multipliers (£million output throughout the economy required per £1million final demand for commodity output j), referred to as Type I output multipliers, taking account of direct and indirect supply chain requirements per unit of final demand for sector i output.

To introduce, for example value-added as an additional multiplier variable to the system, we define an Nx1 vector, **v**, of total value-added (income from employment plus gross operating surplus) generated in the N producing industries using the following expression:

[4] $\mathbf{v}=\boldsymbol{\varphi}.\mathbf{x}$

Where the Nx1 vector **x** is given by the output of i= 1,…, N producing industries. $\boldsymbol{\varphi}$ is a 1xN vector of direct output-hazardous waste coefficients with elements $\varphi_i=v_i/x_i$, where v_i is the total value added directly generated by production sector i in producing its output, x_i. The 1xN vector $\boldsymbol{\varphi}$ is then used to extend the demand-driven framework in [3] to permit consideration of total value-added generated in the economy, the NxZ matrix **V**, as attributable to the various types of final consumption expenditures captured in **Y**:

[5] $\mathbf{V}=\boldsymbol{\varphi}\mathbf{[I\text{-}A]^{-1}Y}$

Thus, the 1xN vector $\boldsymbol{\varphi}\mathbf{[I\text{-}A]}^{-1}$ with elements c_j representing the value-added generated across all N

[23] Miller, R. & Blair, P. (2009). *Input-Output Analysis: Foundations and Extensions*, Cambridge University Press, Cambridge.

production sectors to support one monetary unit (£million) of final demand for sectoral output j.

In order to decompose the sectoral composition of these multipliers, we break out the step of the matrix multiplication calculation of **φ[I-A]**$^{-1}$ by taking the value-added-output coefficient φ_i for each sector i and multiplying along the rows of the NxN output multiplier matrix, **[I-A]**$^{-1}$, or **L** (see Figure 4 in Part 2 below for an example):

[6]

$$\begin{bmatrix} \Phi_1 b_{11} & \Phi_1 b_{12} & \cdots & \Phi_1 b_{1n} \\ \Phi_2 b_{21} & \Phi_2 b_{22} & \cdots & \Phi_2 b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \Phi_n b_{n1} & \Phi_n b_{n2} & \cdots & \Phi_n b_{nn} \end{bmatrix}$$

Generating the Type II variant of this system involves moving z=household final consumption demand from the **Y** matrix into the production side of the system, i.e. the **A** and **L** matrices. We do this by adding a row to the A matrix with elements $a_{wi,j}$ representing payments by industry j to households in return for labour services (income from employment in the input-output table) as a share of total input/output. We add a column with elements $a_{i,W}$ representing household expenditure on the outputs of each sector i (which become 'inputs' to the household production of labour services) as a share of the total value of household wage income (the return to producing/supplying these services). This in turn expands the dimensions of the resulting multiplier matrices; however we do not generally include the additional 'output' in the household sector row in calculating the overall Type II multipliers (so that we are comparing effects in the production sectors in both cases). See Figure 5 in Part 2 for an example of the Type II output multiplier matrix.

It is also possible to calculate multiplier values for different types of final consumption expenditure or final consumption shocks. This is appropriate when, for example, we are considering the construction phases of a new operation and are interested in capital expenditure to support an industry rather than the activity of the industry itself. The multiplier effect is then calculated ex post (after considering capital expenditures in a range of industries supplying capital goods, each of which has a multiplier of its own) by taking the total value of the additional final consumption demand and introducing this to the core equations (3) or (5). If we then divide the total impact (Type I or Type II) by this direct impact, we have the final consumption multiplier. So, for example, in the output case using equation (3) for a change in final demand in the form of gross domestic fixed capital formation (GDFCF) we have:

(7)

$$Multiplier\ for\ a\ change\ in\ final\ demand\ by\ z = GDFCF$$

$$= \frac{[\mathbf{I} - \mathbf{A}]^{-1} \Delta \mathbf{y_z}}{\Delta \mathbf{y_z}}$$

Technical Appendix – Part 2: detail on practical application of methodology

The publication of input-output tables describing the composition of economic activity in terms of purchases and sales between industries and between industries and consumers is recommended for all countries under the UN System of National Accounts (SNA)[24] and required of EU member states under the Eurostat statistical reporting framework[25]. Input-output tables published for national accounting purposes are reported in terms of the value of transactions. For the purpose of conducting multiplier analyses, 'analytical' input-output tables are required. These are reported for a given accounting year using basic (producer) prices in the form of a symmetric industry-by-industry[26] matrix where inputs (reported in columns) balance against outputs (reported in rows) for each sector. Each industry is identified by an input-output classification (IOC) allocated on the basis of the Standard Industrial Classification (also used in the classification of firms under the Annual Business Survey, ABS, which provides survey input for the construction of input-output tables in the UK).

Reading along the row of the input-output table (see Figure 1 for an example), output for a given industry is broken down between (a) intermediate sales to other domestic industries and (b) final sales to different types of (domestic and external) final consumers (current production and capital formation). External industries are treated as final consumers (within export demands) in the input-output table for any one country.[27] Reading down the column for each industry, inputs are broken down into (a) intermediate purchases from other domestic industries (b) non- (locally) produced inputs, distinguishing imports, net taxes on products and production and payments to primary inputs broken into wage incomes and all other returns (often classed as 'gross operating surplus').

Examination of an input-output table like the one in Figure 1 tells us about **direct** transactions. In Figure 2 and the worked example below, one basic thing we can do is consider each industry's intermediate purchases from other domestic industries in terms of direct input requirements stated as a share of its total input requirement. So, for example, reading down the column for the 'Mining and Quarrying' industry we can see that in 2011 7.4% of the total inputs to the sector were direct purchases from the (aggregated) 'Professional & Support Activities' industry.

Multiplier analysis, however, is concerned with **indirect** requirements leading to 'ripple' or 'knock-on' effects in the industry's supply chain. Conventional multiplier values depend on what industries/sectors in the (e.g. Scottish or UK) economy the target industry/activity sources its inputs from – its backward linkages – and, in turn the strength of the backward linkages of the supplying industries.[28] It imposes a particular causal sequence, with final consumption demands (reported in the latter part of each industry's row – see Figure 1) driving quantity decisions in each industry and its supply chain (reported in each column in Figure 1). Thus, any direct change in activity must be motivated by a change in final demand and domestic multiplier values are calculated using the portion of the industry-by-industry input-output table that reports domestic inter-industry (intermediate) sales and purchases.

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[24] See http://unstats.un.org/unsd/EconStatKB/KnowledgebaseArticle10053.aspx

[25] See http://ec.europa.eu/eurostat/web/esa-supply-use-input-tables

[26] Symmetric analytical input-output tables may also be reported on a product-by-product basis.

[27] In an international input-output table, industrial export demands are distinguished from final consumption demands: see the OECD inter-country input-output project at http://www.oecd.org/trade/input-outputtables.htm and the EU FP7 funded World Input-Output Database (WIOD) project at http://www.wiod.org/new_site/home.htm.

[28] It is also possible to construct price and supply multipliers that account for forward linkages in the economy.

Figure 1. Aggregated version of the Scottish industry-by-industry input-output table for accounting year 2011

	Input of Industry													Final demand							
Industry	Agriculture, Forestry & Fishing	Mining & quarrying	Manufacturing	Energy supply	Water & waste	Construction	Distribution, hotels & catering	Transport, storage & communication	Financial, insurance & real estate	Professional & support activities	Government, health & education	Other services	**Total intermediate consumption**	Consumers	Government	Gross capital formation	Exports - Non-residents	Exports - RUK	Exports - RoW	**Total final demand**	**Total demand for products**
Agriculture, forestry & fishing	432	3	1,002	7	1	18	111	8	3	3	14	2	**1,603**	885	0	141	20	740	409	**2,195**	**3,798**
Mining & quarrying	9	351	186	152	4	223	66	23	19	29	36	3	**1,102**	174	0	113	9	6,249	1,047	**6,593**	**7,694**
Manufacturing	417	318	5,201	199	69	1,644	1,177	776	169	199	1,684	83	**11,836**	4,913	0	1,765	176	7,487	10,326	**24,667**	**36,503**
Energy supply	42	322	689	3,619	20	95	238	103	128	99	287	42	**5,684**	2,241	0	62	6	1,580	126	**4,016**	**9,700**
Water & waste	19	10	80	32	293	20	34	17	40	25	227	15	**814**	852	544	15	1	294	300	**2,006**	**2,820**
Construction	50	475	149	80	55	4,215	582	211	1,307	109	454	41	**7,729**	308	0	9,497	9	1,232	174	**11,221**	**18,950**
Distribution, hotels & catering	185	94	1,465	132	36	441	635	306	252	175	778	47	**4,547**	15,190	22	729	1,641	1,978	1,807	**21,368**	**25,914**
Transport, storage & communication	103	291	606	36	60	254	2,155	2,243	1,083	445	943	86	**8,307**	3,578	117	468	109	2,748	1,509	**8,529**	**16,836**
Financial, insurance & real estate	94	56	188	42	28	230	764	187	2,770	139	611	40	**5,148**	15,088	0	490	40	7,894	2,184	**25,697**	**30,845**
Professional & support activities	86	570	712	118	94	951	1,136	868	1,280	2,474	1,339	271	**9,899**	760	42	1,012	35	4,618	2,116	**8,572**	**18,471**
Government, health & education	8	26	104	23	12	115	107	247	489	848	3,090	46	**5,115**	4,499	30,038	283	21	479	230	**35,550**	**40,665**
Other services	9	33	35	14	5	14	91	114	130	109	257	362	**1,175**	3,105	388	44	115	271	126	**4,027**	**5,203**
Total domestic consumption (purch prices)	**1,454**	**2,550**	**10,417**	**4,456**	**678**	**8,221**	**7,096**	**5,103**	**7,671**	**4,654**	**9,622**	**1,037**	**62,959**	**51,584**	**31,131**	**14,618**	**2,183**	**34,572**	**20,353**	**154,440**	**217,400**
Imports from Rest of UK	817	965	8,456	1,326	305	2,098	3,210	2,491	4,301	2,309	4,179	459	**30,916**	13,383	0	3,776	596	3,971	3,119	**24,844**	**55,760**
Imports from Rest of World	171	221	4,268	812	113	562	818	668	543	384	1,683	111	**10,354**	4,458	0	1,485	295	2,982	56	**9,275**	**19,629**
Total intermediate consumption (purch prices)	**2,441**	**3,736**	**23,141**	**6,594**	**1,096**	**10,881**	**11,124**	**8,262**	**12,515**	**7,347**	**15,484**	**1,608**	**104,229**	**69,425**	**31,131**	**19,880**	**3,073**	**41,524**	**23,527**	**188,560**	**292,789**
Taxes on products	**88**	**135**	**531**	**159**	**107**	**55**	**487**	**445**	**657**	**68**	**1,656**	**91**	**4,480**	**7,987**	**0**	**2,068**	**478**	**0**	**0**	**10,533**	**15,013**
Taxes less subsidies on production	-611	9	194	173	52	80	1,016	178	139	140	38	87	**1,494**								
Compensation of employees	471	1,118	8,393	715	737	5,194	8,891	5,843	4,330	7,556	20,357	1,941	**65,546**								
Gross operating surplus	1,409	2,696	4,244	2,060	827	2,739	4,396	2,109	13,204	3,360	3,129	1,476	**41,650**								
Gross value added at basic prices	**1,269**	**3,823**	**12,831**	**2,947**	**1,616**	**8,014**	**14,303**	**8,129**	**17,674**	**11,056**	**23,525**	**3,504**	**108,690**								
Total output at basic prices	**3,798**	**7,694**	**36,503**	**9,700**	**2,820**	**18,950**	**25,914**	**16,836**	**30,845**	**18,471**	**40,665**	**5,203**	**217,400**								

Source: http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Input-Output/SymmetricTables

Figure 2. Scottish aggregated (12-sector) IO accounts: direct input requirements (A-matrix)

	Agriculture, forestry & fishing (Section A)	**Mining and quarrying (Section B)**	Manufacturing (Section C)	Energy supply (Section D)	Water and waste (Section E)	Construction (Section F)	Distribution, hotels and catering (Sections G, I)	Transport, storage and communication (Sections H, J)	Financial, insurance and real estate (Sections K, L)	Professional and support activities (Sections M, N)	Government, health and education (Sections O-Q)	Other services (Sections R-T)
Agriculture, forestry and fishing	0.114	**0.000**	0.027	0.001	0.000	0.001	0.004	0.000	0.000	0.000	0.000	0.000
Mining and quarrying	0.002	**0.046**	0.005	0.016	0.001	0.012	0.003	0.001	0.001	0.002	0.001	0.001
Manufacturing	0.110	**0.041**	0.142	0.020	0.025	0.087	0.045	0.046	0.005	0.011	0.039	0.016
Energy supply	0.011	**0.042**	0.019	0.373	0.007	0.005	0.009	0.006	0.004	0.005	0.007	0.008
Water and waste	0.005	**0.001**	0.002	0.003	0.104	0.001	0.001	0.001	0.001	0.001	0.006	0.003
Construction	0.013	**0.062**	0.004	0.008	0.020	0.222	0.022	0.013	0.042	0.006	0.011	0.008
Distribution, hotels and catering	0.049	**0.012**	0.040	0.014	0.013	0.023	0.024	0.018	0.008	0.009	0.019	0.009
Transport, storage and communication	0.027	**0.038**	0.017	0.004	0.021	0.013	0.083	0.133	0.035	0.024	0.023	0.016
Financial, insurance and real estate	0.025	**0.007**	0.005	0.004	0.010	0.012	0.029	0.011	0.090	0.008	0.015	0.008
Professional and support activities	0.023	0.074	0.020	0.012	0.033	0.050	0.044	0.052	0.042	0.134	0.033	0.052
Government, health and education	0.002	**0.003**	0.003	0.002	0.004	0.006	0.004	0.015	0.016	0.046	0.076	0.009
Other services	0.002	**0.004**	0.001	0.001	0.002	0.001	0.004	0.007	0.004	0.006	0.006	0.070

Figure 3. Scottish aggregated (12-sector) IO accounts: Type I output-multplier matrix and value-added (GDP at basic prices) coefficients

	Agriculture, forestry & fishing (Section A)	**Mining and quarrying (Section B)**	Manufacturing (Section C)	Energy supply (Section D)	Water and waste (Section E)	Construction (Section F)	Distribution, hotels and catering (Sections G, I)	Transport, storage and communication (Sections H, J)	Financial, insurance and real estate (Sections K, L)	Professional and support activities (Sections M, N)	Government, health and education (Sections O-Q)	Other services (Sections R-T)	Value-added per £1m total input/output
Agriculture, forestry and fishing	1.13	**0.00**	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.49
Mining and quarrying	0.00	**1.05**	0.01	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.50
Manufacturing	0.16	**0.07**	1.18	0.05	0.04	0.14	0.07	0.07	0.02	0.02	0.06	0.03	0.35
Energy supply	0.03	**0.08**	0.04	1.60	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.29
Water and waste	0.01	**0.00**	0.00	0.01	1.12	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.55
Construction	0.03	**0.09**	0.01	0.02	0.03	1.29	0.04	0.02	0.06	0.01	0.02	0.01	0.42
Distribution, hotels and catering	0.07	**0.02**	0.05	0.03	0.02	0.04	1.03	0.03	0.01	0.01	0.03	0.01	0.51
Transport, storage and communication	0.05	**0.05**	0.03	0.01	0.03	0.03	0.11	1.16	0.05	0.04	0.04	0.03	0.47
Financial, insurance and real estate	0.04	**0.01**	0.01	0.01	0.01	0.02	0.04	0.02	1.10	0.01	0.02	0.01	0.57
Professional and support activities	0.04	0.10	0.03	0.03	0.05	0.09	0.07	0.08	0.06	1.16	0.05	0.07	0.59
Government, health and education	0.01	**0.01**	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.06	1.09	0.01	0.58
Other services	0.00	**0.01**	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	1.08	0.66
Type I output multiplier	**1.56**	**1.50**	**1.41**	**1.79**	**1.34**	**1.67**	**1.39**	**1.43**	**1.35**	**1.35**	**1.33**	**1.27**	

Figure 4. Scottish aggregated (12-sector) IO accounts: Type I output-value-added multplier matrix

	Agriculture, forestry & fishing (Section A)	**Mining and quarrying (Section B)**	Manufacturing (Section C)	Energy supply (Section D)	Water and waste (Section E)	Construction (Section F)	Distribution, hotels and catering (Sections G, I)	Transport, storage and communication (Sections H, J)	Financial, insurance and real estate (Sections K, L)	Professional and support activities (Sections M, N)	Government, health and education (Sections O-Q)	Other services (Sections R-T)
Agriculture, forestry and fishing	0.56	**0.00**	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mining and quarrying	0.00	**0.52**	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Manufacturing	0.05	**0.02**	0.41	0.02	0.01	0.05	0.02	0.02	0.01	0.01	0.02	0.01
Energy supply	0.01	**0.02**	0.01	0.46	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Water and waste	0.00	**0.00**	0.00	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Construction	0.01	**0.04**	0.00	0.01	0.01	0.54	0.01	0.01	0.03	0.01	0.01	0.01
Distribution, hotels and catering	0.03	**0.01**	0.03	0.01	0.01	0.02	0.53	0.01	0.01	0.01	0.01	0.01
Transport, storage and communication	0.02	**0.03**	0.01	0.01	0.02	0.01	0.05	0.55	0.02	0.02	0.02	0.01
Financial, insurance and real estate	0.02	**0.01**	0.01	0.01	0.01	0.01	0.02	0.01	0.63	0.01	0.01	0.01
Professional and support activities	0.03	0.06	0.02	0.02	0.03	0.05	0.04	0.05	0.04	0.69	0.03	0.04
Government, health and education	0.00	**0.01**	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.03	0.63	0.01
Other services	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.71
Type I output-value added multiplier	**0.75**	**0.72**	**0.52**	**0.55**	**0.72**	**0.71**	**0.70**	**0.68**	**0.75**	**0.78**	**0.74**	**0.80**

Figure 5. Scottish aggregated (12-sector) IO accounts: Type II output-multplier matrix

	Agriculture, forestry & fishing (Section A)	**Mining and quarrying (Section B)**	Manufacturing (Section C)	Energy supply (Section D)	Water and waste (Section E)	Construction (Section F)	Distribution, hotels and catering (Sections G, I)	Transport, storage and communication (Sections H, J)	Financial, insurance and real estate (Sections K, L)	Professional and support activities (Sections M, N)	Government, health and education (Sections O-Q)	Other services (Sections R-T)	Household expenditure
Agriculture, forestry and fishing	1.14	**0.01**	0.05	0.01	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.03
Mining and quarrying	0.01	**1.05**	0.01	0.03	0.01	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.01
Manufacturing	0.20	**0.12**	1.24	0.08	0.10	0.22	0.15	0.15	0.06	0.12	0.16	0.11	0.17
Energy supply	0.05	**0.10**	0.07	1.62	0.05	0.06	0.06	0.06	0.03	0.06	0.08	0.06	0.10
Water and waste	0.01	**0.01**	0.01	0.01	1.13	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Construction	0.04	**0.10**	0.03	0.03	0.05	1.31	0.06	0.05	0.07	0.04	0.05	0.04	0.05
Distribution, hotels and catering	0.16	**0.12**	0.17	0.09	0.15	0.21	1.20	0.20	0.10	0.21	0.25	0.18	0.36
Transport, storage and communication	0.09	**0.10**	0.08	0.04	0.09	0.10	0.18	1.24	0.09	0.12	0.13	0.10	0.15
Financial, insurance and real estate	0.13	**0.12**	0.14	0.08	0.15	0.20	0.21	0.20	1.19	0.22	0.25	0.19	0.38
Professional and support activities	0.07	0.13	0.06	0.05	0.08	0.12	0.10	0.12	0.08	1.21	0.10	0.11	0.08
Government, health and education	0.04	**0.05**	0.05	0.03	0.05	0.07	0.07	0.08	0.05	0.13	1.16	0.07	0.12
Other services	0.02	**0.03**	0.03	0.02	0.03	0.04	0.04	0.05	0.02	0.05	0.06	1.11	0.08
Income from employment	0.37	0.40	0.47	0.25	0.51	0.66	0.66	0.69	0.34	0.77	0.88	0.66	1.43
Type II output multiplier	**2.33**	**2.33**	**2.41**	**2.31**	**2.41**	**3.05**	**2.77**	**2.88**	**2.07**	**2.96**	**3.17**	**2.66**	

Source for Figures 2-5: author’s calculations from Figure 1 data

Beginning with the derivation of the matrix of direct input requirement coefficients reporting (in a column for each industry) intermediate purchases as a share of total industrial input (as in Figure 2), then applying a series of simple mathematical routines (detailed in the Technical Appendix), the basic Type I output multiplier matrix is derived. See Figure 3 below continuing the example from Figures 1 and 2. Within this matrix, each cell in the column for each industry tells us the total output that much be produced in that and each of the other industries in order to meet one monetary unit (£1million in the Scottish and UK case) of final demand for the output of the first industry. Continuing with the 'Mining and Quarrying' example, Figure 3 reports that for every £1million of demand for this industry's output, £0.1million of output is generated in the 'Professional and Support Activities sector'. This includes both the direct effect capture in the corresponding cell in Figure 2, and the indirect multiplier impacts of ALL sectors that supply 'Mining and Quarrying' themselves relying on the services of 'Professional and Support Activities'. The column total for each industry gives us the total output multiplier value for that industry (total output in the economy required per £1million of final demand for industry output). For 'Mining and Quarrying', this total is 1.50, so that (based on the figures reported for the accounting year of 2011) for every £1million of final demand for the sector's output, £1.5million of production is required throughout the economy. The direct effect (the £1million final demand) is reflected in the own-sector multiplier effect (1.05) with the remaining £0.5million (including the other £0.05million within the 'Mining and Quarrying' cell) being the indirect supply chain effects.

Moreover, from within the input-output table we have information on the wage income and gross operating surplus (or 'other value added') generated in each industry (see lower portion of Figure 1). This allows us to calculate output-intensities for these variables in each supplying industry and apply these to the output figures along the rows in in the basic multiplier matrix. Thus, we are able to generate additional multipliers for each industry; for example, output-value-added or GDP (at basic prices) multipliers so that we can consider the GDP generated in each and all industries per £1million of final demand for a given industry's output.

To the right of Figure 3 we report the output-value-added coefficients for the sample 12-sector case. Here we can see that the (aggregated) 'Professional and Support Activities' sector has the second highest output-GDP intensity, with £0.59million of value added per £1million total input/output, while the figure for 'Mining and Quarrying' equates to £0.5million. When we multiply the value-added intensities along the rows of the output multiplier matrix (capturing total output requirements of each industry), we can see that the GDP multiplier effect in 'Professional and Support Activities' for every £1million of 'Mining and Quarrying' produced to meet final demands is £0.06million. The total GDP multiplier effect is given by the column total for 'Mining and Quarrying', which equates to £0.72million of GDP generated throughout the Scottish economy for every £1million of industry output supplied to final demand. We can then use the multipliers to estimate the full multiplier impacts of any projected change so that, for example, an export demand boost to 'Mining and Quarrying' of £20million would lead to a boost of (1.5*20) £30million in total Scottish output and (0.72*20) £14.4million in Scottish GDP.

Similarly, where external data on industry-level employment, CO_2 or any other variable of interest that can reasonably be related to output are available, we can derive output intensities and apply these to the basic multiplier matrix to calculate a range of useful and interesting multiplier values that may then be used in scenario analyses. The Scottish government routinely reports employment, wage income and gross value-added multipliers in addition to the basic output ones.[29] We report and consider a greater range of multiplier values in the more detailed scenario analyses in Sections 4-6 below.

However, there is one more important step in considering the total multiplier impact of any industry (e.g. the aggregate 'Mining and Quarrying' industry in the 12-sector example in this section) on the economy in question (Scotland in this example). The steps so far only take into account the value of the direct demand stimulus and the indirect industrial supply chain impacts. This is commonly referred to as a **Type I** multiplier analysis. However, whenever activity is boosted it is reasonable to assume that labour requirements will also be increased, leading to a wage income boost in the household sector. Households may then go out and spend their additional income on a range of locally produced outputs,

[29] See http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Input-Output/Mulitipliers for examples. A full account of how the Scottish Government apply the methodologies outlined here can be found at http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Input-Output/MultiplierMethodology

leading to further multiplier effects. In input-output multiplier analysis this is incorporated by extending the direct input requirements matrix in Figure 2 for the 'income from employment' generated. In the 'Mining and Quarrying' industry this would give us an additional column entry of 0.145 (1,118/7,694 from Figure 1). Here we are treating households as if they are a production sector (producing labour services) rather than a final consumption sector, so a corresponding column is added to the direct requirements matrix that reports household expenditures on local outputs as inputs to producing the total value of labour services.

We then go through the process of recalculating the output multiplier matrix to conduct what is commonly referred to as a **Type II** multiplier analysis. See Figure 5 for a continuation of the worked 12-sector Scottish 2011 example. Note that all entries have grown because the resulting **induced** (income and consumption) effects have spread throughout the system. The total output multiplier value for the 'Mining and Quarrying' industry grows from 1.50 to 2.33 so that for every £1million of final demand for the sector's output, £2.3million of production is required throughout the economy, with £0.13million of this in the 'Professional and Support Activities' sector. This is an increase of £0.03million in induced effects relative to the £0.1million reported above in the Type I case. Overall in this example, induced effects are important, accounting for 36% of the total multiplier ([2.33-1.50]/2.33), compared to 21% for indirect effects and 43% for the initial direct effect. If we carry through to the GDP multiplier analysis, while the full matrix is not reported above, the impact in the example of the 'Professional and Support Activities' sector is £0.075million (0.59 in the last column of Figure 3 times 0.13) in Figure 5. The total Type II output-GDP multiplier for 'Mining and Quarrying' is £0.94million, with the £0.22million increase on the Type I output-GDP multiplier in Figure 4 (£0.72million) due to the inclusion of induced effects in the Type II case.

Again, we can then use the multipliers to estimate the full multiplier impacts of any projected change so that. Taking the example of an export demand boost to 'Mining and Quarrying' of £20million, the total impact on Scottish output would now be (2.33*20) £46.6million and the total boost to GDP would be (0.94*20) £18.8million. the (here Type II) final demand multiplier for this specific shock is calculated by taking the full direct plus indirect plus induced effects of the shock – e.g. the £46.6 million change in total output – and dividing by the initial direct impact – e.g. the £20million in this example. In this case the final demand multiplier is the same as the industry multiplier because the direct shock is limited to one sector. However, this may not be the case.

For example, suppose we are concerned with the impacts of, for example, an increase in capital expenditure to facilitate construction of a new plant, and this involves – following the current example based on the aggregated Scottish data in this appendix - £40million of capital expenditure on the outputs of the Manufacturing sector and a further £60million on the outputs of the Construction sector, the Type II final demand multiplier for this £100million capital expenditure is determined using the Type II output multipliers for the Manufacturing and Construciton sectors reported in Figure 5: [(40*2.41)+(60*3.05)]/100 = 2.8.

There are some important qualifications that should be noted, however, in using input-output based multiplier methods for 'what if' scenario analysis. First, the assumptions of the demand-driven input-output framework mean that all multiplier values reflect the average input mix in the accounting year that the tables are reported for and a simple constant returns to scale production technology. Second, there is no consideration of any constraints on supply that may impact on relative prices. Third, the multiplier effects focus on supply chain linkages only. Any boost to government revenues and the impacts of any subsequent increase in government consumption are not considered. Note that from Figure 1, government final consumption is an element of final demand, which does not change unless we decide to introduce some exogenous shock in government spending.

Nonetheless, it is possible to consider additional revenue impacts of any change if we can identify the total amount of additional revenue to be spent and where (in what industries) it is spent. This can then be introduced to the input-output model as an additional final demand shock. As explained above, the total impacts of any final expenditure (direct plus indirect, or direct plus indirect plus induced) divided by the initial direct demand then give us a final consumption multiplier. For example, in the case of the 2011 data in Figure 1, the base year government final consumption reported (total local spend and pattern of that spend – both may be changed in a scenario analysis) gives a final consumption output multiplier of 1.33 for the Type I case and 2.37 for the Type II case. This may be extended to any additional variable based on the direct value-added or employment intensities of each of the sectors that government directly and indirectly makes expenditures in.

Generally, though, where the assumptions of the input-output framework are considered to be too restrictive, and/or a fuller analysis of any price and/or revenue changes is required, it is advisable to consider more sophisticated modelling options. For example, computable general equilibrium (CGE) models retain input-output information as a core element of their database (describing the initial structure of the economy) but adopt assumptions and specifications that may be considered to be both more theory-consistent and realistic. The Scottish Government have recently adopted the AMOS CGE modelling framework developed by the Fraser of Allander Institute at the University of Strathclyde.[30] However, input-output based multiplier analysis remains popular with non-academic user communities under many circumstances reflecting the fact that the practical impacts of restrictive assumptions may be minimal and must be set again the transparency and analytical rigour of input-output modelling approaches.

[30] See http://www.scotland.gov.uk/Resource/0038/00388940.pdf for an example of the Scottish Government's application of the AMOS CGE modelling framework.

Technical Appendix Part 3: Data and method used to inform scale of ‘shock’ in Scenario 3

Cost of carbon capture and storage

The total construction and operating cost for carbon capture and storage for a coal fired station with an annual electrical output equivalent to a reference unabated 600MWe coal fired power station has been calculated, based on the 2012 DECC Electricity Generation Cost Model – see reference [a] below. The incremental costs for carbon capture for a power are calculated using the following methodology:

- **A base case 600 MW Advanced SuperCritical coal plant with Flue Gas Desulphurisation was costed based on the technical data for the Med case of an nth of a kind plant as detailed in the table on p45 of [a], for a 30 year plant life (to be equivalent to the plant with CO_2 capture). The coal purchase OPEX was based on the defined efficiency and a coal cost of £3/GJ, from the mid-price DECC estimate [b].**
- **For the CCS case a 617MW Advanced SuperCritical coal plant with oxy-combustion was assumed, which gives an equivalent annual generation of electricity as the unabated case after uptime differences are included. The total cost was calculated based on the technical data for the Med case of an nth of a kind plant as detailed in the table on p49 of [a], for the stated 30 year life, using the same assumption about coal purchase price. The CO_2 captured that required storage was calculated from the CO_2 generated (scaled from the ZEP hard coal plant with 0.759 t/MWh for a net full load plant efficiency 46%, p30 [c])**
- **Based on the total cost for the separate plants, an incremental could then be calculated, split between CAPEX, Fixed OPEX, Variable OPEX, Coal purchase and CO_2 transport and storage costs**

The input data and intermediate steps are summarised in Table A1 over the page.

References:
[a] “Electricity Generation Cost Model – 2012 Update of Non Renewable Technologies, DECC, August 2012”
[b] “DECC Fossil Fuel Price Projections”, 6915-fossil-fuel-price-projections.xls
[c] “The Costs of CO_2 Capture, Post-demonstration CCS in the EU”, ZEP, http://www.zeroemissionsplatform.eu/downloads/812.html

Table A1 Calculation of incremental costs for CCS for plant with output equivalent to 600MW unabated plant

Power generation		ASC with FGD	ASC with Oxy Comb CCS
Reference		Page 45	Page 49
FOAK or NOAK		NOAK	NOAK
Scenarion Low, Med, High		Med	Med
Reference case electrical capacity	MW	1600	800
Pre-licencing costs, Technical and design	£/kW	20	23
Regulatory + licencing + public enquiry	£/kW	0.2	0.5
EPC cost (excluding interest during construction) – variability and uncertainty	£/kW	1,600	2284.5
Infrastructure cost	£'000	7,500	7500
O&M fixed fee	£/MW/yr	35,000	52586
O&M variable fee	£/MWh	1	2
Insurance	£/MW/yr	2,400	3599
Connection and UoS charges	£/MW/yr	4,513	4323
CO2 transport and storage costs	£/t	12	12
Efficiency	-	44%	36%
Operating life	Years	30	30
Availablity	-	92.8%	89.9%
CO2 capture efficiency		0%	95%

CO2 intensity of plant	t/MWh	0.794	0.970
Operating time/year	Hours	8129	7875

		Base	Abated	Incremental
CAPEX	£/kW	1620.2	2308.0	687.8
OPEX (Fixed)	£/MW/year	41,913	60,508	18595.0
OPEX (Variable)	£/MWh	1.0	2.0	1.0
Fuel	£/MWh	24.5	30.0	5.5
CO2 transport and storage OPEX	£/t	0.0	12.0	12.0

Reference plant, unabated MW		600	619	Abated plant capacity to give equivalent MWh/year
		-		
Annual CO2 production rate	mtpa	3.87	4.73	
Annual CO2 capture rate	mtpa	0	4.49	
Total electricity generated over plant life	MWh	146327040	146327040	
Total CO2 captured over plant life	mlnt	0	135	
CAPEX	£mln	972	1429	
OPEX (fixed)	£mln	754	1124	
OPEX (variable)	£mln	146	293	
Fuel	£mln	3592	4390	
CO2 transport and storage costs	£mln	0	1618	
Total	£mln	5465	8854	

The total lifecycle costs are summarised in Table A2:

Table A2 Summary of lifecycle costs for CCS (£million)

Lifecycle costs £mln	
CAPEX	457
OPEX (fixed)	370
OPEX (variable)	146
Fuel	798
CO2 transport and storage costs	1618
Total	**3389**

EOR costs and impact on CCS

An EOR project is considered which draws CO_2 from the stream captured by the CCS system. Two areas need to be considered:

- **The impact on CCS through transfer payments for CO_2 and the reduced requirement for storage, since any CO_2 sent to the EOR project no longer requires storage capacity to be developed by the CCS project.**
- **The investment in OPEX and CAPEX required to execute an EOR project.**

The base case EOR project is assumed to require a total import of 80mln tonne CO_2, taking 4mtpa for 20 years from the 4.5mtpa captured by the CCS system. This corresponds to around 60% of the total stream captured by the plant. The EOR project pays £10/tonne for the CO_2 to the CCS project, in line with the conclusions of [d], which considered a transfer price in the range -10 to +10 £/tonne as the most likely scenario for linked CCS and EOR projects. The reduced storage requirement for CCS is taken in the base case to result in a cost saving of £6/tonne to the CCS project, half the assumed storage and transport cost in [a].

This creates a reduction in the CCS cost from 3389 £mln to 2109 £mln, from the lifecycle 800 £mln transfer price for CO_2 to the EOR project and 480 £mln from the reduction in storage and transport. ***Taking the difference between £3389 and £480 gives us the £2109 required government support, or the 'final demand shock' for the Coal CCS element of the activity in Table 12 in the main text.***

The EOR project is assumed to realise 3stb for each imported tonne of CO_2, at an undiscounted UTC of 35$/stb, corresponding to a total investment of 8400 $mln. ***Converting from US dollars to GBP £ using an exchange rate of $1.6/£1, this gives us the £5250 for the 'final demand shock' for the CO_2-EOR element in Table 12 in the main text.***

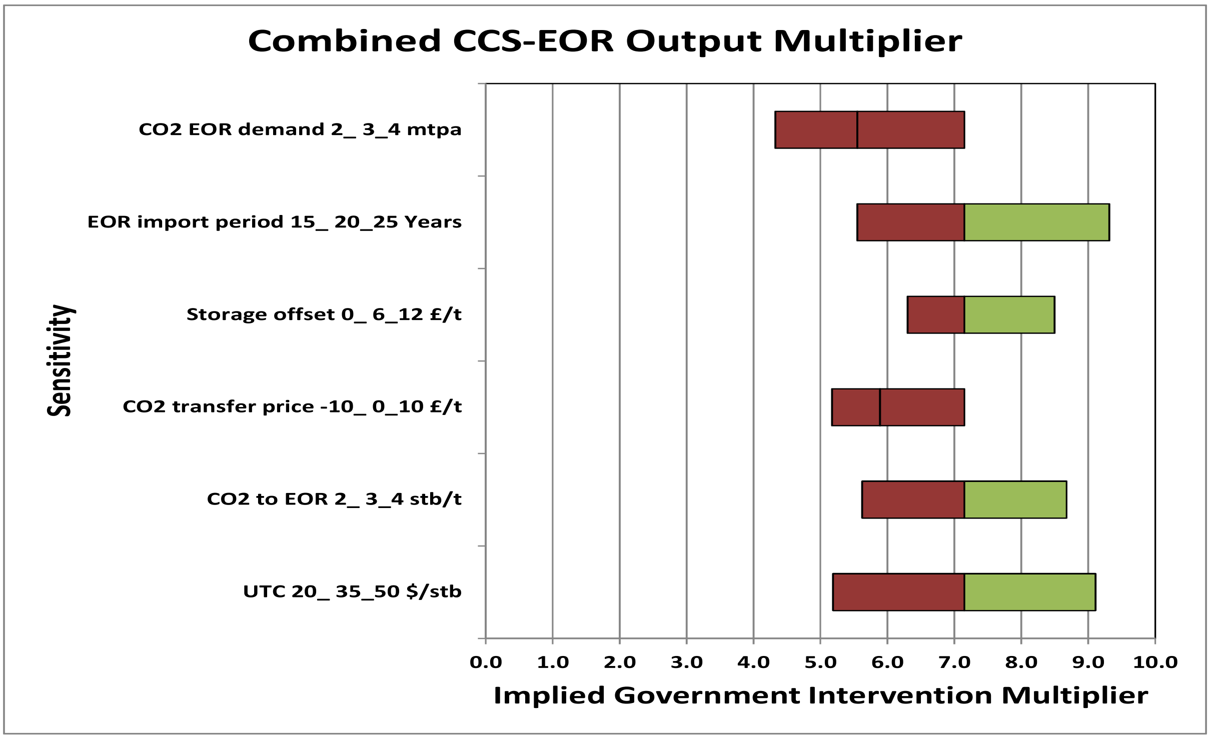
Sensitivity analysis

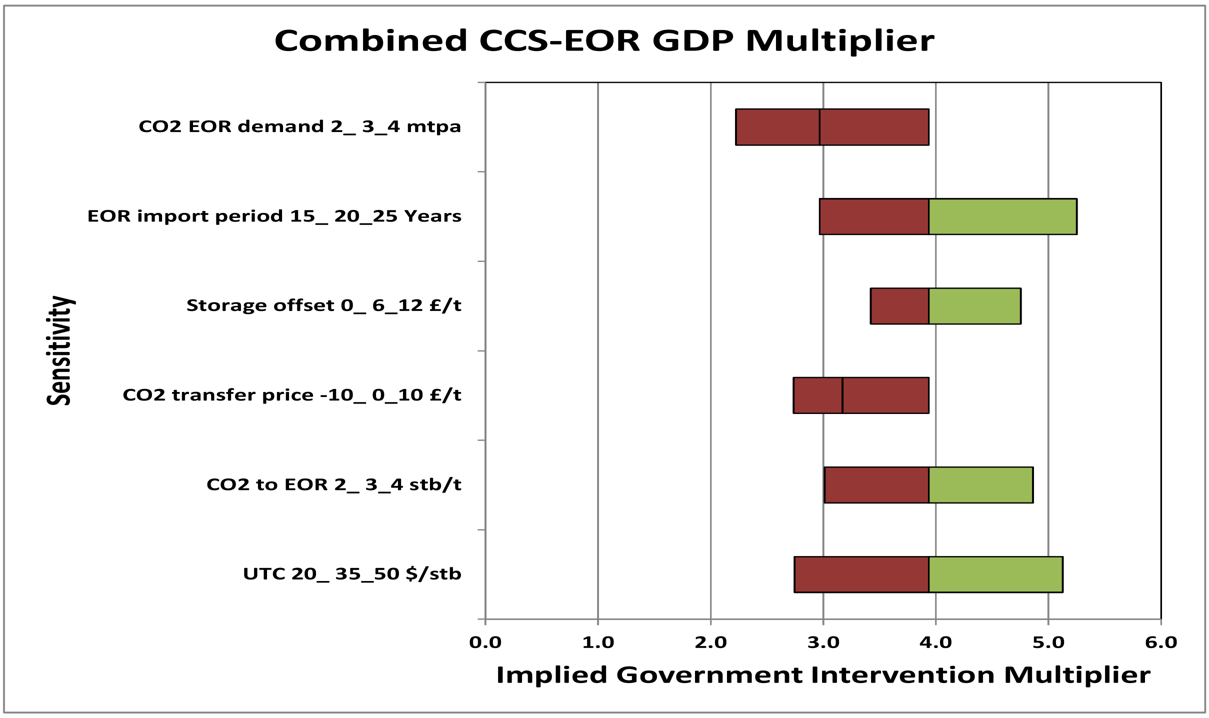
The sensitivity of the analysis to key input assumptions is addressed in the following analysis. Table A3 describes the sensitivities, which impact the size of the EOR project (in terms of production and investment) and the benefit to the CCS project through the volume of CO_2 transferred and the assumptions about transfer price and the reduction in storage cost. The sensitivities considered are summarised in Table A3, where the base case assumption is highlighted in bold font.

Table A3. Values assumed for key variables in sensitivity analysis

Parameter	L	M	H
EOR UTC ($/stb)	20	**35**	50
Efficiency of CO_2 EOR (stb/tonne CO_2)	2	**3**	4
CO_2 transfer price (£/tonne)	-10	0	**10**
Storage offset (£/tonne)	0	**6**	12
EOR import time (Years)	15	**20**	25
CO_2 EOR import rate	2	3	**4**

Adjusting the size of the 'final demand shocks' in Table 12 of the main text gives output multipliers in the range 4.3 to 9.3 and GDP multipliers in the range 2.2 to 5.2, demonstrating the enhancement from EOR across a wide range of assumptions, relative to CCS alone. These are illustrated in the two figures below:


Combined CCS-EOR Output Multiplier
Sensitivity
CO2 EOR demand 2_ 3_4 mtpa
EOR import period 15_ 20_25 Years
Storage offset 0_ 6_12 £/t
CO2 transfer price -10_ 0_10 £/t
CO2 to EOR 2_ 3_4 stb/t
UTC 20_ 35_50 $/stb
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Implied Government Intervention Multiplier


Combined CCS-EOR GDP Multiplier
Sensitivity
CO2 EOR demand 2_ 3_4 mtpa
EOR import period 15_ 20_25 Years
Storage offset 0_ 6_12 £/t
CO2 transfer price -10_ 0_10 £/t
CO2 to EOR 2_ 3_4 stb/t
UTC 20_ 35_50 $/stb
0.0
1.0
2.0
3.0
4.0
5.0
6.0
Implied Government Intervention Multiplier