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Framing policy on low emissions vehicles in terms of economic gains: Might the most straightforward gain be delivered by supply chain activity to support refuelling?

Karen Turner[a,*], Oluwafisayo Alabi[a], Martin Smith[b], John Irvine[b], Paul E. Dodds[c]

[a] Centre for Energy, University of Strathclyde International Public Policy Institute, McCance Building, 16 Richmond Street, Glasgow G1 1XQ, UK
[b] St Andrews Centre for Advanced Materials, School of Chemistry, University of St Andrews, Purdie Building, North Haugh, St Andrews KY16 9ST, UK
[c] Bartlett School of Environment, Energy & Resources, Faculty of the Built Environment, University College London, Gower Street, London WC1E 6BT, UK

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ABSTRACT

A core theme of the UK Government's new Industrial Strategy is exploiting opportunities for domestic supply chain development. This extends to a special 'Automotive Sector Deal' that focuses on the shift to low emissions vehicles (LEVs). Here attention is on electric vehicle and battery production and innovation. In this paper, we argue that a more straightforward gain in terms of framing policy around potential economic benefits may be made through supply chain activity to support refuelling of battery/hydrogen vehicles. We set this in the context of LEV refuelling supply chains potentially replicating the strength of domestic upstream linkages observed in the UK electricity and/or gas industries. We use input-output multiplier analysis to deconstruct and assess the structure of these supply chains relative to that of more import-intensive petrol and diesel supply. A crucial multiplier result is that for every £1million of spending on electricity (or gas), 8 full-time equivalent jobs are supported throughout the UK. This compares to less than 3 in the case of petrol/diesel supply. Moreover, the importance of service industries becomes apparent, with 67% of indirect and induced supply chain employment to support electricity generation being located in services industries. The comparable figure for GDP is 42%.

1. Introduction

Like many countries around the world, in the summer of 2017 the UK Government declared a commitment to ban the sale of new petrol and diesel powered vehicles by 2040 (DEFRA, 2017), one that was effectively accelerated by eight years to 2032 at devolved level by the Scottish Government (2017). While the headline around this UK commitment is primarily set in the context of reducing roadside emissions of nitrogen dioxide (and other roadside emissions), the link between improving local air quality and reducing greenhouse gas emissions is explicitly drawn with the statement that "the UK Government will continue to develop solutions which reduce NO_2 and carbon" (DEFRA, 2017, p.1). However, the traditional trilemma of clean, secure and affordable energy is increasingly recognised as having a fourth axis in terms of maximising economic growth. This paper explores this new axis in the context of the UK's new Industrial Strategy (HM Government, 2017), where opportunities for domestic supply chain development, particularly in the context of the nation's exit from the EU, are emphasised. This policy framing is present in a special 'Automotive Sector Deal' that focuses on the shift to low emissions vehicles (LEVs), but with the strategy in this respect giving attention to domestic supply chain activity to support vehicle and battery production and innovation. We argue that supply chain activity to support refuelling/powering of battery/hydrogen vehicles may offer a more straightforward source of economic gains.

In this paper, we present the first attempt to assess the economy-wide economic impacts of moving to electric vehicles using a relatively straightforward and transparent input-output multiplier approach that establishes the extent to which strong domestic supply chains may develop around electric vehicle power trains. Given that domestic supply chain development may be more challenging in the context of manufacturing electric vehicles and batteries, we focus in this first instance on how they may be fuelled. In particular, our approach assesses the benefit of adopting electric power trains against the losses of abandoning current fossil fuel power trains. In this respect our analysis is based on the fact that the UK electricity and gas supply chains that will play a role (directly or indirectly) in refuelling electric cars and/or their batteries already have much stronger upstream linkages within the domestic economy than is the case with petrol and diesel.

The remainder of the paper is structured as follows. In Section 2, we

* Corresponding author.
E-mail address: karen.turner@strath.ac.uk (K. Turner).

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review the existing literature around the economic impacts of electric vehicles, which is largely limited in focus to techno-economic analysis of impacts at household or distribution grid levels, and consider how this may be extended to consider wider economic impacts, with specific focus on supply chain impacts. In Section 3 we then introduce the input-output multiplier method applied to this end in the current paper. Section 4 describes the UK dataset used for analysis in Section 5. Conclusions and implications for policy are considered in Section 6, along with our thoughts on how research may progress in the area of considering the wider economic impacts of a large scale shift to electric vehicles.

2. How should we consider the wider economic impacts of a shift to electric vehicles?

There is a growing literature that focuses on the economic and environmental impacts of the uptake of different types of hybrid, 'plug-in' battery and fuel cell electric vehicles. This is largely focussed on what may be considered micro-level or single sector level. For example, Granovskii et al. (2006) conduct an analysis that considers impacts at production and utilisation stages on the price of different vehicles and fuels over the vehicle life and driving range, and on associated greenhouse gas and air pollution emissions. Shiau et al. (2009) focus attention on hybrid vehicles with attention to the impact of the weight of batteries and charging patterns on both running and life-time costs, as well as on GHG emissions. Green et al. (2011) also focus on hybrid vehicles, but broaden focus to the level of distribution networks to consider economic impacts for both producers (of electricity) and consumers (using the vehicles). The OECD/IEA, EU and many nation states have commissioned a significant number of reports focussing on economic, technical and/or environmental aspects of switching away from fossil-fuelled transport (for example, Dodds and Ekins, 2014; E4tech and Element Energy, 2016; IEA, 2017; Office for Low Emissions Vehicles, 2011). These publications tend to focus on or report from 'bottom-up' studies, seeking to quantify variables such as the probable cost of producing vehicles, the cost of providing infrastructure and the likely consumer costs of refuelling (hydrogen) or charging, along with consideration of total lifetime vehicle and environmental costs.

The key advantage of these 'bottom up' types of study is that they capture and incorporate a high level of detail on characteristics, technical features and related costs of different vehicle, vehicle use and refuelling options. This constitutes a necessary part of the wider evidence base for understanding the potential impacts of what are expected to be large-scale shifts towards electric vehicles in many countries. However, such analyses do not attempt to consider what the supply chain and wider inter-sectoral and macroeconomic impacts may look like. The outcome is a rich but limited evidence base: smaller scale 'bottom-up models', while capturing a high degree of micro-level detail on the technological characteristics of supply and use behaviour and activity, do not capture macro-level phenomena such as indirect market and supply chain responses. Thus, in considering the wider economic impacts of low carbon developments such as large scale shifts to electric vehicles, there is a real need to introduce some extent of 'top-down' economy-wide analysis to the evidence base that informs policymakers.

The most commonly used (by both academic and policy communities) 'top-down', multi-sector, economy-wide modelling approach, applied to both energy and non-energy related policy problems is applied or computable general equilibrium (CGE) analysis. At UK government level, CGE modelling has been more traditionally used for fiscal analysis, with limited application to date on energy or climate policy issues (fuel duty analysis in HMRC/HMT (2014), and carbon budgeting work, for example see HoC EAC, 2010). On the other hand, the CGE approach has been extensively developed to consider environmental and energy issues (see, for example, the recent review by Babatunde et al., 2017). Moreover, CGE methods can, and indeed already have (see, for example, Li et al., 2017) been applied to consideration of issues around the roll out of electric vehicles.

A simpler, first stage analysis to help policymakers start to think about the type of supply chain issues involved in such a shift can be achieved using a more basic multi-sector economy-wide modelling framework, termed input-output (IO) multiplier analysis. IO methods have been applied in various supply chain contexts (see for example, Albino et al., 2002, on process analysis to help improve design and management of supply chains at local level in the context of global sustainable development) and combined with life cycle analysis for multi-objective analysis of new technologies (see for example, You et al., 2012, on biofuel supply chains).

The greatest and most transparent explanatory power of IO methods in an applied policy context is often located in the more fundamental construction and analysis of industry level 'multipliers' (see Miller and Blair, 2009). IO multiplier analysis of direct, indirect and induced supply chain impacts of industry-level activity has a long history (starting with Leontief, 1936), particularly in the regional science literature. In recent years, these methods have also been applied to assessing impacts of different energy-using activities, such as electricity generation (e.g. Allan et al., 2007, on alternative renewable and thermal technologies) and low carbon 'bioenergy' industries (e.g. see Henderson et al., 2017, on wood pellet manufacturing). In this paper we calculate and decompose industry multipliers for different energy/fuel supply industries in the UK to consider the nature and extent of likely supply chain impacts of the shift in fuel demand that would accompany a roll out of electric vehicles in the UK.

3. Input-output multiplier method

The most straightforward and transparent way to get a clear and simple picture of the structure of direct, indirect and induced supply chain linkages supported by demand for the output of any given industry is to work with an input-output (IO) accounting and modelling framework. IO data are produced for most developed countries under the United Nations System of National Accounts.[1] IO tables describe the structure of the economy in a given year in terms of each and all industries therein (with industries/industry groupings categorised by the Standard Industrial Classification, SIC) that: (a) sell to one another, to domestic consumers (domestic households, government and capital formation) and to exports; and, (b) how much they pay out in terms of incomes to labour and other value-added, and in imports and net taxes on products and production.

Through a series of straightforward mathematical (matrix algebra) processes a simple and transparent demand-driven IO model (originating with Leontief, 1936; detailed exposition in Miller and Blair, 2009) can be developed to conduct multiplier analysis of domestic supply chain interdependencies. This model focuses on how gross output in the economy and/or key variables such as gross-value added (GDP) and employment are determined by final (or end-use) demands via vectors of industry output multipliers.

For the analysis and decomposition of industry-level multipliers reported in this paper, we decompose the traditional headline industry multipliers to consider two core underlying matrices. The first, directly derived from the IO table, is the matrix of input-output coefficients, or symmetric **A**-matrix, with elements a_{ij}, $= x_{i,j}/x_j$ that (in the column) for any industry j, record the total direct input requirement from each other industry i as a share of the total input requirement, x_j (for i = j = 1,..,N industries). Where we are interested in induced (consumption and income) multiplier elements, **A** includes a row for payments to labour

[1] Information on IO accounting under the United Nations System of National Accounts 1993 (UN SNA 1993) can be found at https://unstats.un.org/unsd/EconStatKB/KnowledgebaseArticle10053.aspx.

input and a column stating household spending as inputs to the production of those labour services.[2]

The second core matrix is formally stated as $[\mathbf{I}\text{-}\mathbf{A}]^{-1}$, the Leontief inverse (**I** is an identity matrix). This is also commonly referred to as the output multiplier matrix, or **B**, with elements b_{ij}, representing the output in each industry i that is (directly or indirectly) required to meet one monetary unit of final demand for commodity output j. The column totals of **B,** $\sum_i b_{ij}$, give us the 'output multipliers' for each industry: that is, the total output required across the economy to support the final demand for any one commodity output, j. The Type II variant of **B** incorporates all direct, indirect and induced interactions between industries.[3]

The focus in this paper is to extend the output multiplier matrix **B** matrix to consider additional economic variables of interest through the introduction of a vector of coefficients stating the value or physical amount of the variable of interest associated with the production of one monetary unit of output, x_i, in each industry, i. We define a 1xN vector, **v**, for value-added, where each element v_i is given by dividing gross value-added (GDP at basic pries, or the sum of payments to labour and other value-added) in industry i by that industry's total output, x_i. We also define a 1xN vector, **e**, for employment, where the numerator of each element is FTE employment in industry i.[4]

It is then possible to consider total output-value-added or output-employment multipliers and their composition by multiplying the rows the output multiplier matrix **B** by the corresponding v_i or e_i coefficients.

Thus, for value-added, the NxN output-value-added multiplier matrix **vB** is represented as:

$$\mathbf{vB} = \begin{bmatrix} v_1b_{11} & v_1b_{12} & \dots & v_1b_{1n} \\ v_2b_{21} & v_2b_{22} & \dots & v_2b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ v_nb_{n1} & v_nb_{n2} & \cdots & v_nb_{nn} \end{bmatrix} \tag{1}$$

The elements v_ib_{ij} in the column for each type of industry output, j, can then be examined to identify the source in each industry, i, of total value-added generated to support that output. This permits consideration of the composition of the total output-value-added multiplier for each industry j, where vector of column totals of **vL** – i.e. $\sum_i v_i b_{ij}$ – give us the total output –value-added multipliers for each industry. Similarly, the NxN output-employment multiplier matrix **eB** is derived as:

$$\mathbf{eB} = \begin{bmatrix} e_1b_{11} & e_1b_{12} & \dots & e_1b_{1n} \\ e_2b_{21} & e_2b_{22} & \dots & e_2b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ e_nb_{n1} & e_nb_{n2} & \cdots & e_nb_{nn} \end{bmatrix} \tag{2}$$

where the vector of column totals of **eB** – i.e. $\sum_i e_i b_{ij}$ – gives us the total output-employment multipliers for each industry.

4. UK input-output data

We use an industry-by-industry analytical input-output table for the UK to generate multiplier values for UK industries, with specific focus on those that supply petrol/diesel, electricity and gas. This allows us to consider the nature of the supply chain and consequent multiplier impacts on output, employment and GDP from spending on petrol and diesel relative to what may be possible if spending shifts to supply chains for electricity and/or gas (where hydrogen for fuel cells is produced from natural gas) in powering electric vehicles. Crucially, we consider the question of whether such a shift may be in line with the UK industrial strategy (HM Government, 2017) focus on developing stronger domestic supply chains.

In terms of availability of suitable data, we note that, due to the complexity of the (economy-wide, multi-sector) IO accounting framework, there is always a time lag in reporting IO data generally and analytical IO tables in particular. The most regular IO data publication by the Office for National Statistics, ONS, is product by industry supply and use tables, with annual tables now available up to and including the reporting year of 2014, which is consistent with the UK National Accounts for 2016.[5] The UK IO tables are reported for N = 103 domestic industries which are classified and categorised using the Standard Industrial Classification, SIC 2007.[6] However, supply and use tables are reported in a product-by-industry and purchaser price format that, while useful for wider national accounting purposes (such as the decomposition of direct GDP generation), is unsuitable for calculating multipliers. Rather, for balancing reasons (where the value of total input must equal total output at the sectoral level) multipliers should be derived using symmetric industry-by-industry or product-by-product tables in basic (producer or factory gate) prices. ONS produced the latter in 2017, relating to the year 2014.[7]

Particularly where there is interest in multiplier impacts in employment and value-added, industry-by-industry tables are preferable given that it is difficult to relate employment and payments to factors of production (capital and labour) to product rather than industry groupings. Therefore, this study uses a 2010 industry-by-industry input-output table derived by the Fraser of Allander Institute at the University of Strathclyde based on the 2010 analytical product-by-product IO table released by the UK Office for National Statistics in 2014.[8]

Corresponding data on direct employment in each of the N = 103 industries – to derive the vector of output-employment coefficients, **e** – are also not made publicly available by ONS. However, the ONS did conduct supplementary analysis linked to the 2010 analytical IO framework for the then Department for Business, Innovation and Skills (BIS), producing a dataset that includes reporting of the vector of output-employment multipliers – column totals $\sum_i e_i b_{ij}$ from **eB** in Eq. (2) – for an industry breakdown that maps to the N = 103 used here. This dataset also provides supplementary multiplier data that allow us to derive the vector **e** for our N = 103 industries. [9]

5. Results and discussion

5.1. Total multiplier impacts for selected UK fuel/energy supply industries

In Table 1 we report total output multiplier values for three selected UK fuel/energy supply industries. The first of these is 'Manufacture of coke and refined petroleum products' (SIC 19), which supplies petrol

[2] We follow the Batey (1985) method where total household income in stating column entries is taken from elsewhere in the national accounts, rather than being limited to the income from employment in the row entries, which is generally insufficient to fund the household expenditures recorded in the IO table.

[3] The row and column for the household sector in matrix **B** are generally ignored given there is no final demand for household 'output', which, in an IO setting, is taken to be labour services.

[4] Both v and e have zero elements for households: where households employ labour (e.g. cleaners, gardeners) this is captured in IO accounting via an additional industry that 'sells' its output to the household sector.

[5] UK IO data in supply and use format are reported on an annual basis by the Office for National Statistics at: https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/inputoutputsupplyandusetables.

[6] The UK guide to the SIC 2007 can be found at https://www.ons.gov.uk/methodology/classificationsandstandards/ukstandardindustrialclassificationofeconomicactivities/uksic2007.

[7] UK IO data in analytical product-by-product format (and an intermediate product-by-industry matrix reported in basic prices) are reported on a periodic basis by the Office for National Statistics at: https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/ukinputoutputanalyticaltablesdetailed.

[8] See instructions for download in Acknowledgements section at the end of the text.

[9] This ONS/BIS dataset (now an archive dataset) can be accessed at http://webarchive.nationalarchives.gov.uk/20150908115359/http://www.ons.gov.uk/ons/about-ons/business-transparency/freedom-of-information/what-can-i-request/published-ad-hoc-data/econ/december-2014/provisional-estimates-of-type-uk-employment-multipliers-and-effects.xls.

Table 1
Multiplier values for selected UK fuel/energy supply industries.

SIC	Sector/industry name	Multiplier (activity per £1million final demand)		
		Output (£million)	Value-added (£million)	Employment (FTE jobs)
19	Manufacture of coke and refined petroleum products	1.47	0.33	2.93
35.1	Electric power generation, transmission and distribution	2.56	0.78	8.05
35.2	Manufacture of gas; distribution of gaseous fuels	2.25	0.81	8.04

and diesel (among other refined fuels). The second is 'Electric power generation, transmission and distribution' (SIC 35.1), which produces and supplies electricity and is the obvious candidate to consider the supply chain required to fuel electric vehicles. We also focus on 'Manufacture of gas; distribution of gaseous fuels' (SIC 35.2), which produces and supplies (but does not extract) gas (see Section 5.3). This permits consideration of hydrogen fuel cells as a potential power source for electric vehicles. Both electricity and gas supply are relevant in this context on the basis that, whilst there are potential bio-sources of hydrogen, it seems most likely that the greatest bulk of hydrogen produced in the UK will be derived from the processing of natural gas or the electrolysis of water. On this basis, the electricity and gas supply industries identified in Table 1 apply to the hydrogen fuel cell case and will supply the majority of the operating economic inputs of a future UK hydrogen supply system. The UK electricity supply industry becomes a clearer candidate when we broaden focus to electric vehicles more generally. Indeed the UK electricity industry is currently playing a role at limited scale in the charging of electric vehicles in the UK.

Selection of the three industries in Table 1 permits a preliminary consideration of whether there is scope to strengthen domestic supply chain activity supported by spending on fuels to run vehicles by changing the nature of the fuel spend required.[10] In considering refuelling of electric vehicles, we focus attention on whether it is possible replicate the strength of domestic linkages currently observed (or, more correctly, in our accounting year of 2010) in the UK gas and/or electricity supply industries. The first step is to compare multiplier values that indicate the strength of upstream supply linkages within the UK per monetary unit (here £1million) of fuel spending.

A note of caution is required at this stage in terms of how multiplier values are perceived and applied. The actual economy-wide impacts of any marginal shift in spending as implied by application of the multipliers depends on the scale and nature of the shift in final demand that may be involved. For example, in switching to electric vehicles, a £1million reduction in UK spending on petrol and/or diesel may not equate to a £1million reallocation of spending to electricity or gas (in the case of hydrogen produced from natural gas). That is, if refuelling an electric vehicles costs less in fuel terms per mile travelled, only part of the £1million would be applied to the electricity supply sector (and its multiplier), with the remainder free to allocate to other types of spending or to savings. Thus, the overall economy-wide impact would depend on the nature of this latter allocation as well as the shift in spending on fuel. Of course, it would also depend on a range of other effects and interdependencies (including but not limited to impacts on Government tax revenues related to fuel purchases) that are not ideally modelled in an IO framework. We return to this point in our conclusions (Section 6); here we focus attention on the multiplier impacts implied per monetary unit of spending to consider the relative strength of supply chain linkages for different types of energy/fuel spending.

In the first numerical column of Table 1, we report the column totals (i.e. $\sum_i b_{ij}$) of deriving matrix **B** from the IO system in Section 3 using the UK IO data for 2010 described in Section 4. That is, for each of the three selected industries, the results in Column 1 of Table 1 relate the total output (in £million) required across the economy to support £1million of final demand for the output of that industry. In the second and third columns we report the results of computing the vectors of output-value-added and output employment multipliers (the column totals of **vB** and **eB** from (1) and (2) respectively) and extracting results for each of the three industries identified. We note that the multiplier results imply average impacts based on based on supply chain relationships and relative prices prevailing in the accounting year of 2010.

First, we consider the results in the first row of Table 1, relating the supply of petrol and diesel (but noting from the SIC 19 descriptor that the UK IO accounts do include the supply of other fuels in this industrial grouping). The output multiplier result suggests that for every £1million spent on petrol or diesel, a total of £1.47million in gross output must be produced across the UK economy. The (output-) value-added and employment multiplier results tell us that this gross output supported is associated with £0.33million in gross value-added (or GDP at basic/producer prices) and 2.93 FTE jobs.

The first important observation that can be made is that the all three of the multiplier values relating to petrol/diesel supply are considerably lower than those reported in the next two rows for the electricity and gas supply industries. The crucial point to note is that the UK 'Manufacture of coke and refined petroleum products' industry has a relatively high import intensity. Examination of the underlying IO tables show that the use of produced goods and services as 'intermediate' inputs (which are the key driver of multiplier values) is high, at almost 83% of the total input requirement of the industry. However, 75% of this is imported from overseas, thereby reducing the extent of multiplier effects in the UK (which are driven only by domestic intermediate and, given the inclusion of induced effects, labour inputs). In fact, the results of the full calculation of the output multiplier matrices **B**, **vB** and **eB**, while not reported here due to space constraints, show that this industry has the lowest ranking of all 103 UK industries in terms of the size of its output, employment *and* value-added multipliers. This implies that any reallocation of spending away from petrol/diesel (or other fuels produced by the industry) towards *any* other UK produced good or service is likely result in a *net* positive impact on goods and services production in the UK economy.

Here our attention is directed to the question of whether a shift from refuelling vehicles run on petrol and diesel towards running electric vehicles may involve development and/or use of stronger domestic supply chains, as promoted in the UK industrial strategy (HM Government, 2017). The focus in this respect is one of 'bang to the buck': how much UK activity is stimulated *per pound* or £m of UK consumption expenditure, without immediate consideration of the absolute or relative scales of spending that may be involved across different time frames and specific scenarios therein.

In considering the multipliers for the electricity and gas supply industries in the second and third rows of Table 1, an important point to return to is import intensity. A key characteristic underlying the higher multiplier values for both these industries relative to the one supplying petrol and diesel is that each has significantly lower dependence on imports. In the gas industry, 75% of intermediate or produced inputs are produced within the UK (compared to only 25% in the case of SIC19, which includes supply of petrol and diesel), while this rises to 85% in the case of the electricity industry. Moreover, both are more

[10] We note that the relevant component of consumer spending 'at the pumps' to focus on the fuel cost, net of taxes and distribution margins.

capital-intensive than refined fuel supply, which boosts the value-added (basic price GDP) multipliers in both cases.

Thus, the ***first key insight that can be drawn from our multiplier analysis is that the low import-intensity of electricity and gas relative to petrol and diesel supply in the UK (combined with relatively high capital intensity) provides a strong foundation for strong domestic supply chain development in the context of a shift towards refuelling electric vehicles.***

This should be set in the context that both the value-added and employment multiplier values for the UK electricity and gas supply industries have large indirect and induced components. It is these that must be examined more carefully if we are to understand the foundations for what may be termed 'strong domestic supply chain development' potential in energy supply to support electric vehicles. This is the focus of the next section.

5.2. Deconstructing headline multiplier impacts

Deconstruction of the headline multipliers in Table 1 involves examination of the columns of the **vB** and **eB** multiplier matrices (Eqs. (1) and (2) in Section 3) for each of the three energy/fuel supply industries. Our second key finding emerges if we focus attention on the indirect and induced components of the multipliers. This involves removing direct own sector effects from each type of multiplier, which are present in the own-sector b_{ij} element where i = j. In the case of the value-added and employment multipliers, the direct effect within this element is given by the direct coefficients, v_i and e_i respectively. Stripping these elements out allows us to consider the distribution of the remaining indirect and induced effects of one monetary unit (£1million) of spending on each of the three energy/fuel supply across all 103 UK industries. For reason of space and conciseness, we do not report the full N = 103 industrial level results of doing so for the UK (Smith et al., 2017, provide more detail in this respect).

One point to note up front is that there is limited cross reliance between the industry that supplies petrol and diesel (SIC 19) and either electricity or gas supply. The maximum share of any multiplier where j = SIC19 located in i = electricity or gas is 2.2% for j = electricity in the SIC output multiplier of 1.47 in Table 1. This enables the type of observations made below to be considered largely independently, as long as we focus on the shift away from SIC 19 to one of the other two: there is more cross reliance between gas and electricity, particularly in terms of the former's reliance on the latter.

In Table 2 we focus attention on the combined importance of UK service sector industries in fuel/energy supply chains (relative to the extraction, construction, utility and manufacturing supply chain support that may be more commonly associated with energy/fuel supply). 45 of our 103 UK IO industries may be classed as service industries (SIC 45–98).[11] Table 2 reports the share of total indirect and induced effects within each type of multiplier (output, value-added and employment) that are located in these service sector industries when we decompose the columns of the **vB** and **eB** matrices for our three energy/fuel supply sectors.

In policy terms, perhaps the crucial point and ***second key insight of this paper is that the importance of energy supply chain reliance on service sector activities increases as we turn attention from gross output to value added and particularly to employment multiplier effects.*** For example, in the UK electricity supply industry, around 30% of indirect and induced multiplier effects contributing to the headline output multiplier of 2.56 (where the direct effect is 1) are located in UK service sector industries. If we turn attention to value-added, domestic

[11] This SIC grouping includes the following broad industry groupings: wholesale and retail, transport and storage, food and accommodation services, real estate services, information and communication, finance and insurance, professional and technical services, along with administrative and other private and public services.

Table 2
Share of indirect and induced multiplier impacts located in service sector industries.

SIC	Sector/industry name	Type of output multiplier		
		Output	Value-added	Employment
19	Manufacture of coke and refined petroleum products	44%	55%	77%
35.1	Electric power generation, transmission and distribution	30%	42%	67%
35.2	Manufacture of gas; distribution of gaseous fuels	34%	40%	71%

service industries such as those providing financial, insurance and distributional services have higher GDP content – represented by their direct value-added intensities in the row multiplication process underlying derivation of the **vB** matrix in Eq. (1) – than industries such as utilities or manufacturing. This leads to the share of indirect and induced output-value-added multiplier impacts for UK electricity supply located in service industries increasing to 42%. However, when we turn attention to employment, this rises to 67% with high-skilled scientific, technical and other professional service type industries being among the main beneficiaries alongside administrative and support sectors. A similar pattern is observed in the case of the UK gas supply industry in the third row. However, it is interesting to note that in the case of SIC 19, the supplier of petrol and diesel, indirect and induced service sector impacts play a more important role *within that industry's supply chain* across all three multipliers.

On the other hand, reflecting the larger scale of the electricity and gas supply industry multipliers, we find that the net impact on all UK service industries (for all three headline multipliers) of reallocating a given value of spending between SIC19 (petrol/diesel supply) to either electricity or gas supply would be positive. For example, if we consider the employment multipliers in the final column of Table 1. The total impact of reallocating £ 1million to electricity or gas is found by simply subtracting the 2.93 multiplier value for SIC19. In either case the net impact is an additional 5 FTE jobs. In the case of a switch to electricity 2.6 of these are service sector jobs; in the case of gas the corresponding result is 2.1. That these results reflect a proportionately smaller share of the shift than of the percentage of the absolute employment multiplier values in Table 3 reflects the change in composition of activity to support fuelling requirements. Nonetheless, almost all UK industries are positively impacted (across all three headline multipliers), with only SIC19 as the supplier of petrol and diesel that would suffer any notable negative impact (0.4 FTE jobs per £1million reallocation).

5.3. Dependence of UK electricity and gas supply on UK off-shore oil and gas extraction industries and the question of green domestic supply chain development

A third key conclusion and crucial result from our decomposition of the output-value-added multipliers for the UK gas and electricity supply industries concerns the role of the UK off-shore oil and gas extraction industry (SIC 6). Our third key conclusion focuses on the finding that the strength of the domestic GDP supply chain multipliers in the UK electricity and gas supply industries is partly dependent on supply chains links to the domestic oil and gas extraction industry.

Inspection of the underlying IO accounts (for the base accounting year of 2010) reveals that 43.5% of goods and services produced in the UK and used in gas supply were directly sourced from the UK off-shore extraction industry. In the case of the UK electricity sector, the direct relationship is less important, with only 20% of the domestic goods and services input requirement to the electricity industry being sourced from the UK extraction sector in the accounting year of 2010. On the

Table 3
Impacts of links to the UK oil and gas extraction industry on output-value-added multiplier values.

	SIC 19 Refined Fuel	SIC 35.1 Electricity Supply	SIC 35.2 Gas supply
Total multiplier effect	0.33	0.78	0.81
Excluding impacts of direct purchases from oil and gas extraction industry (SIC 6)	0.30	0.69	0.64
Excluding all indirect and induced impacts located in oil and gas extraction (SIC 6)	0.29	0.62	0.59

other hand, indirect energy supply relationships are more important in the case of electricity – for example, gas fired power plants purchase inputs from the gas supply sector.

So what does this mean in terms of strong domestic supply chain development overall and the implications of continuing to rely on, and benefit from, the extraction of hydrocarbons? One important issue in the UK context is that the domestic oil and gas extraction industry has experienced decline in recent years, and is almost certainly entering a stage of maturity. Nonetheless, gas is still likely to be used at different stages in electricity and/or hydrogen production. Where this is the case, reduced reliance on the domestic extraction industry would require increased imports from other countries, thereby simply relocating gas extraction processes. Moreover, in economic terms, and specifically consideration of the strong domestic supply chain development aims of the UK industrial strategy (HM Government, 2017), reduced reliance on the UK extraction industry would carry a cost in terms of GDP. It would then present a challenge in terms of how future supply chain development in electricity and/or hydrogen supply may compensate in strict value-added terms (even if fuel demands could still be service potentially with lower financial costs to users and lower emissions resulting).

To begin to develop a basic understanding current (or at least 2010) reliance on the UK off-shore oil and gas industry in energy/fuel supply, Table 3 shows the impacts on the total output-value-added multipliers of our three target industries (with the first row replicating corresponding entries in Table 1) of removing two different elements of linkages to the UK extraction industry (SIC 6).

In the third row, we remove all the indirect and induced multiplier impacts located in the UK extraction industry (SIC 6) that are given by the element where i = SIC 6 in the $\sum_i v_i b_{ij}$ calculation in Eq. (1) for each of our three energy/fuel supply industries. However, as an interim stage, given that these impacts are also driven by the use of UK oil and gas in other industries in these supply chains, in the second row the multipliers are also shown excluding only the impact of each of the three industries' own purchases from the extraction industry. This is calculated by removing only the value-added associated with the direct transaction recorded in the underlying **A** matrix, that is $v_i a_{ij}$, where i = SIC 6 and j is each of our energy/fuel supply industries in turn.

The results in Table 3 show that in both the gas and electricity supply cases, the impact of removing different elements of upstream multiplier linkages to the UK oil and gas extraction industry is relatively large. Nonetheless, other domestic supply chain impacts remain sufficiently strong that the output-value-added multipliers are still markedly larger than that of the industry currently supplying petrol and diesel (whether it uses domestically extracted oil or not). Thus, we can draw our ***third key finding, that the strength of domestic supply chain development to enable refuelling of electric vehicles – particularly in terms of GDP content - will be reduced as we become less dependent on the UK off-shore oil and gas extraction sector. However, it will still deliver a greater multiplier impact per pound of spending than what can be achieved with continued reliance on petrol and diesel.*** We note that we did conduct the same exercise for the output-employment multipliers; however, due to the low labour intensity of the UK extraction industry, the impacts were negligible.

6. Conclusions and policy implications

This paper addresses the fact that more than one strategic policy objective may be relevant in considering low carbon energy solutions and framing policy actions. In the UK, a general shift to low carbon economic development is reflected in a Government commitment (DEFRA, 2017) to ban the sale of petrol and diesel powered vehicles by 2040. Alongside this, the new Industrial Strategy (HM Government, 2017) introduces the importance of strong domestic supply chain development in delivering sustainable economic growth both in general, and specifically in the context of the automotive sector. Here, a special 'Sector Deal' is set out to support the required shift to low emissions vehicles (LEV). The aim of this paper is not to dispute the Strategy's focus on challenges of building high skilled and competitive domestic supply chain activity to support the manufacture of electric powered vehicles and innovation in building UK production of batteries. Rather, our argument is that a more straightforward gain may be realised by extending the framing of policy around LEVs in terms of economic benefits delivered through domestic supply chain activity to support the refuelling of these vehicles relative to their fossil fuelled counterparts.

In the work reported here, we consider how positive economy-wide impacts of shifting from traditional fossil fuel to electric vehicles may be realised if the associated fuel supply could replicate the strength of domestic supply chain linkages currently observed in the UK electricity and/or gas (in the context of hydrogen fuel cells) industries. We do so by using economy-wide input-output multiplier analysis to deconstruct and assess the structure of electricity and gas supply chains relative to that of what is a heavily import-intensive petrol and diesel supply in the UK. Three key results emerge.

First, a combination of low-import and high-capital intensity of electricity and gas relative to petrol and diesel supply in the UK provides a strong foundation for strong domestic supply chain development in the context of a shift towards refuelling electric vehicles. This is reflected in higher headline output, employment and GDP multiplier values that provide insight on the economy-wide supply chain impacts per pound of spending on different types of fuel (though not on the relative scales of spending that may be involved in power electric versus conventional petrol and diesel vehicles).

Second, the economy-wide scope of our input-output analysis reveals the importance of service sector industries relative to the extraction, construction, utility and manufacturing supply chain support often more commonly associated with energy/fuel supply. Moreover, our results suggest that the importance of energy supply chain reliance on service sector activities increases if we focus attention on value added (GDP) and particularly employment rather than simple gross output multiplier effects. This is because service sector activities tend to be more GDP- and/or labour-intensive than many manufacturing and utility industries. Employment is an important variable in political economy terms, while GDP is commonly taken as a key indicator of economic 'health'. This finding is even stronger in the case of petrol/diesel supply, albeit set in the context of lower overall multiplier values or strength of domestic supply chain dependence relative to the UK gas and electricity industries.

Third, we find that the strength of domestic supply chain development to enable refuelling of electric vehicles will be reduced as we become less dependent on the UK offshore oil and gas extraction sector. Nonetheless, our results suggest that the strength of supply chains to support direct electric or hydrogen fuel cell charging is still likely to be greater than what can be achieved (per pound of user spending) with continued reliance on petrol and diesel.

This still raises important policy challenges in terms of planning for the development of energy supply chains that can be considered to be both low carbon and deliver strong domestic returns. A key policy question may be whether investment in and/or support of other low carbon options to generate electricity and/or produce hydrogen fill this gap? That is, could options such nuclear and renewables in electricity supply, production of hydrogen involving gas combined with CCS, and/or energy storage in a range of contexts and scales take the place of our current dependence on oil and gas extraction in underpinning strong domestic supply chains that support GDP and employment across the UK economy?

We close by noting that there is a need to qualify our analysis. First, we note our reliance on input-output data for 2010. Both UK supply chain activity more generally and energy/fuel supply in particular is likely to have changed to some extent since the start of the current decade, perhaps especially in the case of electricity generation with the reduced dependence on coal-powered plants in particular. For this reason, an important recommendation is that the UK's Office for National Statistics should ideally report input-output data in the appropriate industry-by-industry analytical format on a regular and frequent basis.

A second note of caution relates to the simplicity of input-output as an economy-wide modelling framework. While input-output is commonly used and referred to by policymakers, analysts and stakeholders due to its simplicity and transparency, it is subject to restrictive assumptions particularly in terms of price determination and supply responses (see McGregor et al., 1996; Miller and Blair, 2009). It also has a very limited treatment of taxation while concerns have been raised regarding how the shift to lower carbon vehicles may erode fuel duty receipts, as well as requiring significant investment in energy, transport and communications infrastructure (Policy Exchange, 2017). A more flexible economy-wide modelling framework that retains the key structural features of input-output but permits treatment of such a wider range of issues is computable general equilibrium (CGE) modelling (McGregor et al., 1996; Turner et al., 2012), an approach that has been used by the UK Government to analyse a range of issues, including changes in fuel duties (HMRC/HMT, 2014). Nonetheless, we believe that the input-output multiplier analysis conducted in this paper constitutes a useful first step in considering the potential wider economic impacts of the type large scale shift from conventional petrol and diesel to electric vehicles that is anticipated and required over the coming decades.

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This study involved analysis of existing IO data that are publicly available for download at the web-site of the Fraser of Allander Institute, University of Strathclyde. It also draws on archive industrial employment data that can be downloaded via the national archives.

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