Beyond Carbon Leakage: Off-Shoring of Employment and GDP in Decarbonizing International Supply Chains

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Abstract

Industrial decarbonisation is a major challenge in terms of both emissions reduction and the 'just transition' element of the 2015 Paris agreement. It raises issues in terms of potential carbon leakage and associated off-shoring of jobs and GDP where carbon reduction impacts the location decisions of production. We propose that economic multiplier metrics can help quantify the extent of these potential displacement effects. Focussing on cement production as a particular decarbonisation challenge, we demonstrate that displacement of currently EU-based production activity could potentially lead to reductions in domestic jobs and GDP, combined with a net increase in world CO_2 emissions.

Keywords: industrial decarbonisation; just transition; carbon leakage; input-output multiplier

JEL classifications: C67, D57, L61, Q52

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1. Introduction

There has been significant policy effort and attention in decarbonising the EU economy, seeking to achieve the Paris 2015 targets. To date, much attention and success has been focussed on decarbonising electricity generation via the reduction of fossil fuel use and introduction of an increased role of renewable energy sources. More recently there has been increased attention on decarbonising heat and transportation. However, decarbonisation of industry remains a challenge, perhaps for two key reasons.

First, CO_2 is not produced just as a by-product of energy use. A number of important industries within Europe, such as steel and cement manufacturing, generate significant amounts of CO_2 through industrial processes rather than the actual *use* of energy. These industries will need to be decarbonised if the EU is to achieve its Paris 2015 emissions reduction goals. Moreover, this is in a context where the introduction of renewable technologies and energy sources may not be straightforward or even feasible.

Second, considering potential changes in industrial activity brings into sharp focus the 'just transition' element of the Paris agreement. United Nations Framework Convention on Climate Change (UNFCCC, 2015, p.4) states that the agreement is subject to '[T]aking into account the imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities.' Thus, as argued by Zero Emissions Platform (ZEP, 2018, p.4) it would seem to follow that 'there is a need to retain and ultimately grow jobs and production activity, rather than risk displacing emissions to other countries where global climate impacts may outweigh any economic gain.' The crucial point is that displacement of emissions must be taken in a context of potentially off-shoring production and, thus, jobs, GDP and other determinants of economic well-being within the countries/EU member states where emissions occur.

Currently, management of industry emissions in EU countries is largely conducted via a combination of regulations and regulated market-based measures, including, but not limited to, the EU ETS. A concern, as the need to decarbonise industry becomes more pressing in the context of Paris 2015 targets, is that further adjustment to existing and/or introduction of new regulations and other policy instruments could drive the industries to relocate production outside the EU territory. There is already a fairly extensive literature (see Section 2) on the phenomenon and modelling of carbon leakage associated with the off-shoring of industrial activity from developed to developing economies.

Here we focus attention on how consideration of the full chain of upstream CO_2 emissions, jobs and GDP linked to industrial activities in different spatial contexts may provide a fundamental knowledge base for policy makers in considering the 'just transition' element of the Paris 2015 agreement. We propose that this involves consideration of spatially extended inter-regional variants of the economic multiplier metrics using input-output methods. Focussing on the case of German cement production, we demonstrate that key insights emerge in terms of not only a spatial reallocation of both direct and supply chain emissions, jobs and GDP, but whether or not there is potential for a net increase in CO_2 generated at world level. Identifying and analysing this interdependence is crucial for designing effective industrial decarbonisation policies and strategies that are likely to be perceived as 'just' at both national and international levels.

The remainder of the paper is structured as follows. In Section 2 we provide an overview of the main contributions on carbon and economic leakage. In Section 3 we set out the inter-regional input-output (IRIO) method that is then applied in Section 4 to demonstrate the use of multiplier metrics to consider issues around the spatial location of production and the potential multiple sources of leakage via upstream supply chain linkages. We compare alternative locations and supply chain requirements for an industry grouping that includes cement production. Cement production is of particular interest as a high emitting industry that commonly attracts significant attention in the industrial decarbonisation debate given the process rather than energy use nature of emissions generated (see ZEP, 2018). However, the multiplier methods demonstrated are generic across industries. In Section 5 our conclusions are drawn in terms of more fundamental insights in developing the evidence and knowledge base to better inform both policy consideration of the 'just transition' issue and future spatial economic analysis to inform and support policy development.

2. Existing literature on carbon and economic leakage issues

The issue of carbon leakage has already received fairly extensive attention in the literature, particularly since the seminal contribution by Arrow et al. (1995). Authors such as Sheldon (2006) have shown that environmental policy measures such as carbon taxes applied in one country might result in increased emissions in other countries through changing incentives for the location of 'dirty' industries where products and/or production processes are mobile across international borders. In recognition of the fact that leakage does not only result from relocation of direct emissions sources, but also from the location of emissions embedded in upstream supply chains, analyses have commonly been undertaken using multi-sector economy-wide computable general equilibrium (CGE) methods. For example, Babiker (2005), Bruvoll & Fæhn (2006), and Elliott et al. (2010) all analyse pollution leakage in response to specific carbon taxes or emission caps.

Recently, Schenker, Koesler, & Löschel (2018) apply CGE methods to consider the impacts of the use of EU ETS both as the sole means to achieve a reduction in EU CO_2 emissions and in conjunction with other instruments such as border taxes on carbon embodied in imports. They show that attempting to control territorial emissions through carbon pricing can lead to significant losses in domestic GDP and welfare, while leading to substantial carbon leakage. They find that the introduction of border taxes has the potential to mitigate negative impacts on both GDP and carbon leakage. However, their analysis suggests that this is likely to be at the expense of significantly higher reductions in exports and imports, as compared to a standalone unilateral emission pricing approach.

More generally, the extent to which carbon (or other pollutant) leakage is associated with leakage in jobs and GDP, particularly in terms of the industrial emissions where policy action can prove problematic (both in political economy and technological terms), is less clear. That is, no clear relationship between economic growth and pollution leakage has been proven. For example, in a study using both historical data and CGE modelling, Bruvoll & Fæhn (2006) find that economic growth in 'rich' countries has not been associated with leakage impacts in the form of net imports of 'dirty' goods. However, this is in the context of a 'growth-induced unilateral carbon tax policy in a rich open economy' (Bruvoll & Fæhn, 2006, p.499), rather than any sector-specific instrument. They also find evidence of rise in a range of economic costs (alongside a reduction in environmental benefits) when a global rather than national perspective is adopted. In turn, this may suggest that economic leakage is a factor that must be addressed in making climate policy decisions at national (and sub-national/regional) level. Indeed, this may be reflected in the wording of the 'just transition' element of the Paris 2015 agreement that we quote above, alongside the clear recognition of national sovereignty in setting priorities for economic welfare.

There is a growing body of microeconomic work considering issues around carbon leakage and potential spatial relocation of production activity. For example, in considering the mitigation of carbon leakages risk, Martin, Muûls, De Preux, & Wagner (2014) focus on how industry compensation may prevent relocation decisions by polluting firms in the manufacturing sector of six European countries that are subject to EU ETS regulation. Highlighting the current inefficiency in compensating firms for the regulatory burden via freely allocated permits, they design a rule tailored towards preventing both carbon and employment leakage in view of industry relocation decisions. The authors show that a differentiated compensation scheme based on polluting firms' marginal improvement in the government's objective function significantly reduces both forms of leakage. Thus, their rule would involve a 'win-win' in terms of less risk of both carbon and employment leakage.

Utilising firm-level micro data, Commins, Lyons, Schiffbauer, & Tol (2011) assess the impact of environmental regulation – in the form of energy taxes and emissions trading – on the performance of various sectors in the EU economy. Although these authors consider an array of performance metrics, in the case of employment they obtain an adverse effect of energy taxes but find no effect of employment leakage under phase I of the EU ETS. In contrast, Abrell, Faye, & Zachmann (2011) find that the EU ETS had a negative (albeit small) effect on employment, but, on the other hand, shows no effect on the sectors' value-added.

Demailly & Quirion (2008) look at the possibility of employment losses that may be channelled through a reduction in domestic output occurring as a consequence of industry relocation driven by emissions trading under the EU ETS. Based on simulations for the iron and steel sector, their results do not find any basis for a loss of competitiveness. If their results are robust, this finding might imply that the risk of job loss could be minimal in this sector.

While these micro-focussed studies do provide valuable insight at industry case study level, here we argue that, given the importance of supply chain activity in determining emissions, jobs, GDP (and ultimately a range of determinants of performance, including competitiveness), a multi-sector approach is necessary to consider issues impacting carbon leakage and the 'just transition'. Mapping to the more sophisticated CGE approaches identified above, which incorporate IO data to simulate specific scenarios, Perrier & Quirion (2018) study the relationship between employment and investment targeted at low carbon sectors. Their analysis, based on IO tables for France, reveals a positive effect of such investment on employment (i.e., less employment leakage) 'if it targets sectors with a higher share of labour in value-added, lower wages or lower import rates' (p. 472).

However, where concern is on inherently spatial economy issues such as carbon leakage and off-shoring, the information content of IO approaches (in their own right and/or as a foundation for more sophisticated analyses using methods such as CGE) can be more fully exploited. This is reflected in the extensive literature using inter- or multi-region IO methods to consider carbon (and other environmental) ‘footprints’; via ‘production’ vs. ‘consumption’ accounting of carbon emissions (see Turner, Lenzen, Wiedmann, & Barrett, 2007, for method and Wiedmann, 2009, for a review of applications) but arguably not fully exploited in terms of links between these headline indicators and underpinning economic activity in different industries and spatial areas. On the other hand, interesting work has involved extending on the fundamental economic IO methods to consider the impacts of production, technology and trade patterns on emissions levels. A key study in this regard is Levinson (2009), who shows that input-output decomposition methods can be used to examine whether reductions in emissions can be linked to technology changes or to the changes in trade, including the transfer of polluting industries overseas.

Here we build on these foundations in conducting a sectorally and spatially detailed IO analysis of the structure of potential carbon, jobs and GDP leakage/off-shoring associated with different production locations for polluting industries (with applied focus on an industry grouping that includes cement production). Our policy motivation and framing is to consider whether refining and reporting of underpinning economic ‘multiplier’ metrics may provide a useful element of the knowledge base informing policy analysis of industrial decarbonisation issues. Our proposition is that IRIO multiplier methods may offer particularly useful insight where carbon leakage concerns are closely linked to the potential off-shoring of jobs and GDP leakage, a crucial issue in the context of the ‘just transition’ framing of the Paris 2015 agreement. We do emphasise that our current contribution aims to set an insightful foundation, rather than a substitute, for further work extending the more sophisticated bottom-up micro and top-down economy-wide approaches reviewed above.

3. Methodology and data

3.1 Inter-regional input-output (IRIO) methodology

The methodology used in this paper develops the IRIO approach specified by Turner & Katris (2017) to consider physical energy-use multiplier effects of changes in direct household energy demand for industry outputs. That paper proposed ‘energy saving multipliers’ as an alternative indicator to study the effectiveness of energy efficiency improvement policies. Here we focus on utilising IRIO multipliers to analyse structural supply chain issues that could drive unanticipated responses to policy action, but with focus on carbon emissions, jobs and GDP leakage/off-shoring that may occur in response to actions aimed at industrial decarbonisation. Generally, our approach draws on that specified by Turner et al. (2007) to calculate ‘ecological footprints’, which, in turn, is based on conventional IRIO methods set out by Miller & Blair (2009). In terms of employment and value-added content of upstream supply chain activity, we build on conventional IO methods detailed by Miller & Blair (2009), adding spatial as well as industry-level focus to the Turner, Alabi, Smith, Irvine, & Dodds (2018) propositions regarding the insight of multiplier analysis in informing and framing energy and climate policy development.

The core element of any IO multiplier analysis is the Leontief inverse matrix, ***L***, which, through column entries for any industry *j* that serves final demand, reports the total output required across all sectors to service one monetary unit of that final demand. The core element of the IRIO framework is the $(T \cdot N)$x$(T \cdot N)$ matrix, where *T* is the number of regions considered and *N* the number of sectors in each region. Here, the Leontief inverse has the following general form:

$$\boldsymbol{L} = \begin{bmatrix} l_{11}^{11} & \cdots & l_{1j}^{1s} & \cdots & l_{1N}^{1T} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ l_{i1}^{r1} & \cdots & l_{ij}^{rs} & \cdots & l_{iN}^{rT} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ l_{N1}^{T1} & \cdots & l_{Nj}^{Ts} & \cdots & l_{NN}^{TT} \end{bmatrix} \quad [1]$$

The elements of matrix ***L*** indicate the output required by sector *i* in region *r* to support one monetary unit worth of final demand for the output of sector *j* in region *s*, for *i,j*=1,2,…,*N* and *r,s*= 1,2,…,*T*. We can extend to consider multiplier impacts in variables reported elsewhere in the IO accounts (for example, value-added, or combined payments to labour and gross operating surplus from the primary inputs quadrant) or others related to sector outputs via satellite accounts (for example, employment and/or emissions). To consider these, the Leontief inverse is adjusted through the introduction of output coefficients, which report the number of employees required, or value-added generated, or the emissions directly generated in the production of each sector *i* in region *r*. This allows the calculation of multipliers that report the total requirement for each variable across the wider IRIO system (via upstream supply chain linkages) required to support the production of output by sector *j* in region *s* to meet one monetary unit worth of final demand for its output, and to examine the composition of this requirement at the level of each producing sector within each producing region.

Formally, the process requires the introduction of a *(T·N)*x*(T·N)* diagonal matrix ***K***:

$$\boldsymbol{K} = \begin{bmatrix} k_1^1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & k_N^T \end{bmatrix} \quad [2]$$

Each element k_i^r is derived from the appropriate IO or satellite account and reports the amount of the variable of interest (here, value-added, employment, emissions) directly employed or generated in sector *i* per monetary unit of production. In the case of value-added, this will be in the same monetary units as the IO tables are reported (here, $million). Employment will ideally be reported in terms of full-time equivalent (FTE) employees, but is often (as with the IO database used here – see Section 3.2) reported in terms of 'head count' number of employees. Emissions are reported in appropriate physical units (e.g., kilotonnes of carbon or CO_2 equivalent). In the case of employment, k_i^r reflects the number of sector *i* in region *r* employees[1] required to produce one monetary unit worth of output.

Pre-multiplying matrix ***K*** with matrix ***L*** results in the matrix:

$$\boldsymbol{KL} = \begin{bmatrix} k_1^1 l_{11}^{11} & \cdots & k_1^1 l_{1j}^{1s} & \cdots & k_1^1 l_{1N}^{1T} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ k_i^r l_{i1}^{r1} & \cdots & k_i^r l_{ij}^{rs} & \cdots & k_i^r l_{iN}^{rT} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ k_N^T l_{N1}^{T1} & \cdots & k_N^T l_{Nj}^{Ts} & \cdots & k_N^T l_{NN}^{TT} \end{bmatrix} \quad [3]$$

The ***KL*** matrix is also a multiplier matrix but with column totals reporting the total amount of the satellite variable required throughout the economic area being studied per monetary unit of final demand for the output of sector *j* in region *s*. For the case of employment, each element $k_i^r l_{ij}^{rs}$ refers to the number of employees used in sector *i* in region *r* to produce the necessary output to support one monetary unit worth of final demand for the output of sector *j* in region *s*. The column total for each industry *j* in each region *s*, $\sum_{r=1}^{T}\sum_{i=1}^{N} k_i^r l_{ij}^{rs}$ is the total multiplier, in this example total employment across the entire economic area required to support one monetary unit of final demand for industry *j* (region *s*) output. The vector of column totals – the multipliers – may be referred to generally as ***kl****.*

In this paper, we focus on CO_2 emissions, employment and value-added (GDP). With the use of the appropriate satellite accounts and/or data drawn from within the IO accounts, we can quantify matrices such as ***CL***, to consider CO_2 emissions, ***EL*** for employment, and ***VL*** for value-added:

$$\boldsymbol{CL} = \begin{bmatrix} c_1^1 l_{11}^{11} & \cdots & c_1^1 l_{1j}^{1s} & \cdots & c_1^1 l_{1N}^{1T} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ c_i^r l_{i1}^{r1} & \cdots & c_i^r l_{ij}^{rs} & \cdots & c_i^r l_{iN}^{rT} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ c_N^T l_{N1}^{T1} & \cdots & c_N^T l_{Nj}^{Ts} & \cdots & c_N^T l_{NN}^{TT} \end{bmatrix} \quad [3a]$$

$$\boldsymbol{EL} = \begin{bmatrix} e_1^1 l_{11}^{11} & \cdots & e_1^1 l_{1j}^{1s} & \cdots & e_1^1 l_{1N}^{1T} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ e_i^r l_{i1}^{r1} & \cdots & e_i^r l_{ij}^{rs} & \cdots & e_i^r l_{iN}^{rT} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ e_N^T l_{N1}^{T1} & \cdots & e_N^T l_{Nj}^{Ts} & \cdots & e_N^T l_{NN}^{TT} \end{bmatrix} \quad [3b]$$

$$\boldsymbol{VL} = \begin{bmatrix} v_1^1 l_{11}^{11} & \cdots & v_1^1 l_{1j}^{1s} & \cdots & v_1^1 l_{1N}^{1T} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ v_i^r l_{i1}^{r1} & \cdots & v_i^r l_{ij}^{rs} & \cdots & v_i^r l_{iN}^{rT} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ v_N^T l_{N1}^{T1} & \cdots & v_N^T l_{Nj}^{Ts} & \cdots & v_N^T l_{NN}^{TT} \end{bmatrix} \quad [3c]$$

Where the new elements c_i^r e_i^r and v_i^r are specific variants of the ‘output coefficients’ k_i^r, the column totals in each corresponding vector ***cl***, ***el*** and ***vl*** give us the total output multiplier values.

One of the key benefits of the IO framework proposed here is that it allows us to analytically identify different components of upstream supply chains for all the different industry sectors/grouping within nations/regions in the economic area under examination (where IRIO databases, such as the WIOD one used here, often have global coverage). In the current context, this permits consideration of how emissions, jobs and value-added embedded in supply chain activity supporting demand for any one activity in any one region (in our case, cement production in Germany) is spatially distributed in terms of industry groupings and their geographical locations.

The multipliers in the system above allow for consideration of intensity, i.e., per monetary unit of final demand served by the industry being directly considered. However, the demand driven accounting framework outlined here also allows us to consider how the level of final demand for the output of any industry *j* in any region *s* (in the accounting year the IO accounts are reported for) impacts at scale across the wider supply chain. This involves arranging total final demand (or some sub-set thereof) for each producing industry in each region in a diagonal matrix:

$$\boldsymbol{Y} = \begin{bmatrix} y_1^1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & y_N^T \end{bmatrix} \quad [4]$$

Post-multiplying [4] with [1] and/or [3] provides us with the scaled impacts, across the wider economic area, of the final demand represented in [4]. For the generic version with output coefficients represented by k_i^r, this gives us the following activity matrix:

$$\boldsymbol{KLY} = \begin{bmatrix} k_1^1 l_{11}^{11} y_1^1 & \cdots & k_1^1 l_{1j}^{1s} y_j^s & \cdots & k_1^1 l_{1N}^{1T} y_N^T \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ k l_{i1}^{r1} y_1^1 & \cdots & k_i^r l_{ij}^{rs} y_j^s & \cdots & k_i^r l_{iN}^{rT} y_N^T \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ k_N^T l_{N1}^{T1} y_1^1 & \cdots & k_N^T l_{Nj}^{Ts} y_j^s & \cdots & k_N^T l_{NN}^{TT} y_N^T \end{bmatrix} \quad [5]$$

The row total of [5] for each industry *i* in each region r, $\sum_{s=1}^{T} \sum_{j=1}^{N} k_i^r l_{ij}^{rs} y_j^s$ gives the same total as would be computed using the direct emissions intensity, k_i^r, and sectoral output, x_i^r. That is, it is direct emissions, employment or value-added as recorded in the base year IO and satellite accounts and the sum of all row totals provides the accounting year totals for each variable across the entire economic area (where the IRIO may apply to the full global economy). The vector of column totals, ***kly***, with elements $\sum_{r=1}^{T}\sum_{i=1}^{N} k_i^r l_{ij}^{rs} y_j^s$ for each industry *j* in each region *s*, redistributes these totals in terms of the outputs of different industries in different countries/regions that directly service final rather than intermediate demands. Note that it is also possible to arrive at each element of the vector ***kly*** by simply multiplying the corresponding element of the multiplier vector ***kl*** for sector *j* in region *s* by the final demand for that industry's output, y_j^s.

3.2 Data

We use IRIO data published by the World Input-Output Database (WIOD). For the main part of the analytical work we are using the WIOD 2016 release (Timmer, Dietzenbacher, Los, Stehrer, & Vries, 2015; Timmer, Los, Stehrer, & De Vries, 2016). We select the latest year included in the 2016 release, 2014, but note that this only includes the core economic tables that inform matrix ***L***. We note that there are two key further deficiencies. First, ideally IO multiplier analysis will use full-time equivalent rather than 'head count' jobs data to ensure consistency across accounting units. However, the IRIO satellite data are reported in terms of the latter.

The second is that the 2016 WIOD release does not include any emissions accounts. Therefore, we use the data from the 2013 release (Genty, Arto, & Neuwahl, 2012). This creates a compatibility issue as in the 2016 release the industries are aggregated into 56 sectors using ISIC rev. 4, compared to the 35 sectors using ISIC rev. 3 used in the 2013 release. This problem has been resolved by linking the sectors of the 2016 release to the ones in the 2013 release (see Appendix 1). Moreover, in the 2016 release a number of additional countries is included, which were not in the 2013. The additional countries are Croatia, Norway and Switzerland, all members of the EU or EEA. We have assumed then that the emissions generated by the sectors in those countries are near the average emissions generated by the sectors in the rest of the EU. Moreover, the emissions data issue is further complicated by the CO_2 emissions accounts only provide data up to 2009. Thus, we have used the 2009 CO_2 emissions intensities as the basis for every country, adjusting them to current prices for each of the following years using the World Bank GDP deflators[2].

We make one final note of caution relating to the trade-off between spatial and sectoral detail in the data. One of the key benefits of IRIO accounting frameworks such as the WIOD used here is the fact that the data originally published at national level are harmonised and presented in a uniform way, thereby allowing for meaningful comparison and analysis of interactions between different nations. On the other hand, this is set against a cost of a higher level of aggregation both in terms of reporting primary inputs (value-added is reported at gross level rather than breaking out income from employment) and grouping of industrial sectors than typically possible in national level IO accounting. In terms of the latter, the key implication is a constraint on analytical capacity in conducting IO multiplier analyses based on quite large and not necessarily uniform industrial sectors. As noted, the WIOD data used here group all the industries in each nation/region and the global economy into 56 sectors. A specific implication is that, in considering cement production as a key polluting activity, we need to do this in the context of the sector named 'Manufacture of non-metallic mineral products', which also includes production of lime and glass, and some other activities.

This has implications and demands caution in interpreting multiplier results for the industry across different countries. This is because the composition of any one aggregate sector is likely to differ in different countries. Differences in composition will impact the nature of emissions, employment and generation of value-added for production in different countries. These are the three variables that we focus on below in considering potential leakage/off-shoring implications of industrial location. Nonetheless, we believe that our IRIO multiplier analyses still provide valuable insight in considering these issues at the stage of planning and policy formulation with respect to industrial decarbonisation, and ensuring a 'just transition' without counterproductive carbon and associated economic leakage.

4. Key results

In this section we apply the system in equations [1]-[5] using the WIOD data for the most recent year reported, 2014. The aim is to illustrate how IRIO multiplier metrics may be used to consider potential implications in terms of off-shoring of emissions, jobs and value-added (GDP) if policy and/or other responses to climate change targets induces a relocation of production. We do not attempt to model any scenarios in this regard, where a more flexible and theoretically consistent general equilibrium framework would be better suited. Rather we focus on how economic input-output analysis may help initial consideration of where policy planning (and further research/modelling to inform the process) needs to be targeted if carbon leakage and other potentially unanticipated outcomes – here with focus on the national level 'just transition' element embedded in the Paris agreement – are to be avoided.

For our illustrative analysis, we focus attention on the case example of the industrial grouping that contains cement production, and on Germany in particular (the EU member state with the largest volume of production in this activity). We demonstrate how comparative multiplier analysis across key cement producing nations, and consideration of the spatial distribution of domestic and international upstream supply chain linkages, may aid identification of potential negative displacement effects of shifting production locations. Cement production provides an interesting example, given the process nature of CO_2 emissions within the industry itself, and increasing industry and policy debate and discussion around the role of cement sector in delivering a low carbon economy.[3] However, the demonstration of our proposed method could be applied to other industries, with focus on any other EU member state (or, indeed any country identified in the WIOD database) where the selected industry is important in terms of both reducing emissions and sustaining jobs/economic value.

In section 4.1 we begin by using multipliers to consider the extent to which emissions, jobs and value-added both within existing national EU-based industry and upstream supply chains may be displaced across space and potentially increase if production relocates. In Section 4.2 we focus on the nature of potential supply chain losses within the domestic economy that national policymakers must give priority to, not least in terms of the 'just transition' element of the Paris 2015 agreement.

4.1 Multiplier analysis of potential off-shoring and carbon leakage impacts of production location decisions

Table 1 summarises key results of computing the core multiplier matrix ***KL*** using equation [3]. Table 1a reports for the output-CO_2 multiplier variant, ***CL*** (equation [3a]). Along the row for each country, we sum the key elements of the total global multiplier, that is the column total of the matrix ***CL*** for industry *j* = 'Manufacture of non-metallic mineral products', in each of 12 countries, *s*. This is reported in the fifth numerical column of Table 1, with the previous four columns breaking this value down. In the first column, we report the direct emissions intensity, c_i^r, where *i=j* and *r=s*. The second column reports the full own-sector entry, $c_i^r l_{ij}^{rs}$, again where *i=j* and *r=s*; that is, including both direct emissions in producing \$1m of output to meet final demand requirements plus emissions associated with any own-sector (indirect) supply chain requirements (e.g. use of lime in producing cement). The third column reports the summation of own country entries (input purchases from all other sectors of the domestic economy (e.g. Germany), $\sum_{i=1}^{N} c_i^r l_{ij}^{rs} y_j^s$, where *r=s*. The fourth column reports the summation of EU entries, $\sum_{r=1}^{T} \sum_{i=1}^{N} c_i^r l_{ij}^{rs} y_j^s$, where only entries for *r = an EU member state* are included (for EU member states this includes the domestic entries in the previous three columns). Tables 1b and 1c report corresponding information for jobs/employment and value-added/GDP respectively.

We select 12 countries (6 EU member states and 6 non-EU countries) for inclusion in Table 1 based on their being the ones with the largest levels of output in the 'Manufacture of non-metallic mineral products' in the accounting year of 2014. The value of output in 2014 is reported in sixth numerical column of Table 1a only, with the same values applying in Tables 1b and 1c also. The product of the value of output and the direct intensity in the first column gives total direct industry emissions/employment/GDP in that accounting year. The seventh column (again, reported in Table 1a only) reports the value of total final demand. As explained at the end of Section 3.1, this figure can be applied to each multiplier value in columns 2-5 to determine the scale of total direct plus indirect supply chain emissions/employment/GDP required to meet final demand for sectoral output in the accounting year. This calculation can be used if we wish to summarise at high level, rather than compute the full ***KLY*** (or ***CLY*** for CO_2) total industry production emissions/employment/GDP set against the total global amounts required to service final demand for industry output. However, our focus here is mainly on the underlying multiplier values as indicative of impacts of marginal shifts in production location.

Table 1. High level spatial composition of key IRIO output multipliers associated with the output of industry grouping 'Manufacture of Non-Metallic Minteral Products' in selected countries

Table 1a. Output-CO2 multipliers (kilotonnes of CO2 per $1m of final demand for industry output)

	Direct	**Direct plus indirect**					
		Own sector	**Own country**	**EU**	**Global**	**Total output ($m)**	**Final demand ($m)**
EU member states							
Germany	0.63	0.69	0.81	0.86	0.91	59,766	10,971
Italy	0.64	0.72	0.84	0.89	0.94	40,601	4,848
France	0.49	0.54	0.59	0.65	0.70	31,782	2,507
UK	0.46	0.50	0.78	0.82	0.89	27,808	2,266
Spain	0.91	1.05	1.27	1.31	1.37	20,533	1,006
Poland	0.90	1.01	1.37	1.43	1.49	16,311	2,701
Non-EU							
China	0.82	1.00	1.74	0.01	1.79	892,413	14,244
USA	0.94	1.02	1.26	0.01	1.33	116,433	13,675
Japan	1.12	1.18	1.34	0.01	1.43	60,841	1,875
India	0.79	0.86	1.18	0.01	1.26	55,001	7,611
Russia	0.42	0.45	0.64	0.01	0.68	34,245	2,531
Turkey	0.72	0.80	0.89	0.03	1.00	22,706	1,193

Table 1b. Output-employment multipliers (number of jobs per $1m of final demand for industry output)

	Direct	Direct plus indirect			
		Own sector	Own country	EU	Global
EU member states					
Germany	4.08	4.45	8.29	9.74	13.26
Italy	4.70	5.31	9.22	10.40	15.86
France	3.30	3.66	7.14	8.69	13.17
UK	2.91	3.21	6.79	8.00	12.53
Spain	4.54	5.20	9.71	10.96	16.40
Poland	11.02	12.34	20.34	21.90	26.43
Non-EU					
China	13.01	15.90	47.97	0.18	53.04
USA	3.46	3.79	6.82	0.26	10.89
Japan	5.55	5.87	9.82	0.18	18.40
India	111.53	121.14	196.64	0.20	204.89
Russia	20.01	21.58	37.95	0.51	41.14
Turkey	16.22	18.15	27.98	0.81	34.55

Table 1c. Output-GDP multipliers ($m value-added per $1m of final demand for industry output)

	Direct	Direct plus indirect			
		Own sector	Own country	EU	Global
EU member states					
Germany	0.37	0.40	0.74	0.86	0.97
Italy	0.31	0.35	0.71	0.81	0.95
France	0.32	0.35	0.71	0.83	0.95
UK	0.29	0.32	0.70	0.80	0.95
Spain	0.32	0.36	0.72	0.82	0.96
Poland	0.33	0.36	0.68	0.80	0.94
Non-EU					
China	0.25	0.31	0.85	0.02	0.99
USA	0.40	0.44	0.86	0.02	0.99
Japan	0.41	0.43	0.73	0.02	0.97
India	0.29	0.32	0.67	0.02	0.90
Russia	0.35	0.37	0.84	0.04	0.93
Turkey	0.36	0.40	0.75	0.07	0.95

In considering the results reported in Table 1, we note that those countries with lower direct CO_2 intensities (first column of Table 1a) are likely to be ones where activities other than cement production dominate the composition of the ‘Manufacture of non-metallic mineral products’ industry grouping (hereafter referred to as ‘Cement etc.’). This problem is a function of the sectoral aggregation issue with the WIOD data (see Section 3.2 above).

With this caution in mind, the results in the first part of Table 1a show that the two biggest ‘Cement etc.’ producing EU nations, Germany and Italy, have very similar ‘global carbon footprints’ per $1m of output produced to meeting final demand (0.91 and 0.94 kilotonnes per $1m respectively). The largest share of this is own-sector direct (first column), and just under 90% in each case is own-country (third column). On the other hand, if we consider non-EU nations like the USA and China (the largest global producers) and Turkey (the biggest non-EU exporter in Europe), the results in Table 1a show that the global emissions multipliers tend to be higher: 1.33 kilotonnes per $1m final demand for output in US, 1.79 for China, with Turkey more in line with Germany and Italy at 1.0 (and lower than other EU nations such as Spain and Poland). On the other hand, the ‘imported CO_2’ element tends to be lower in larger nations, with 95% of the USA multiplier being own-country, and 97% in the case of China.

Figure 1. Output-CO_2 multipliers by location of required direct and supply chain emissions (kilotonnes of CO_2) required per $1m of final demand for 'Cement etc.' industry output

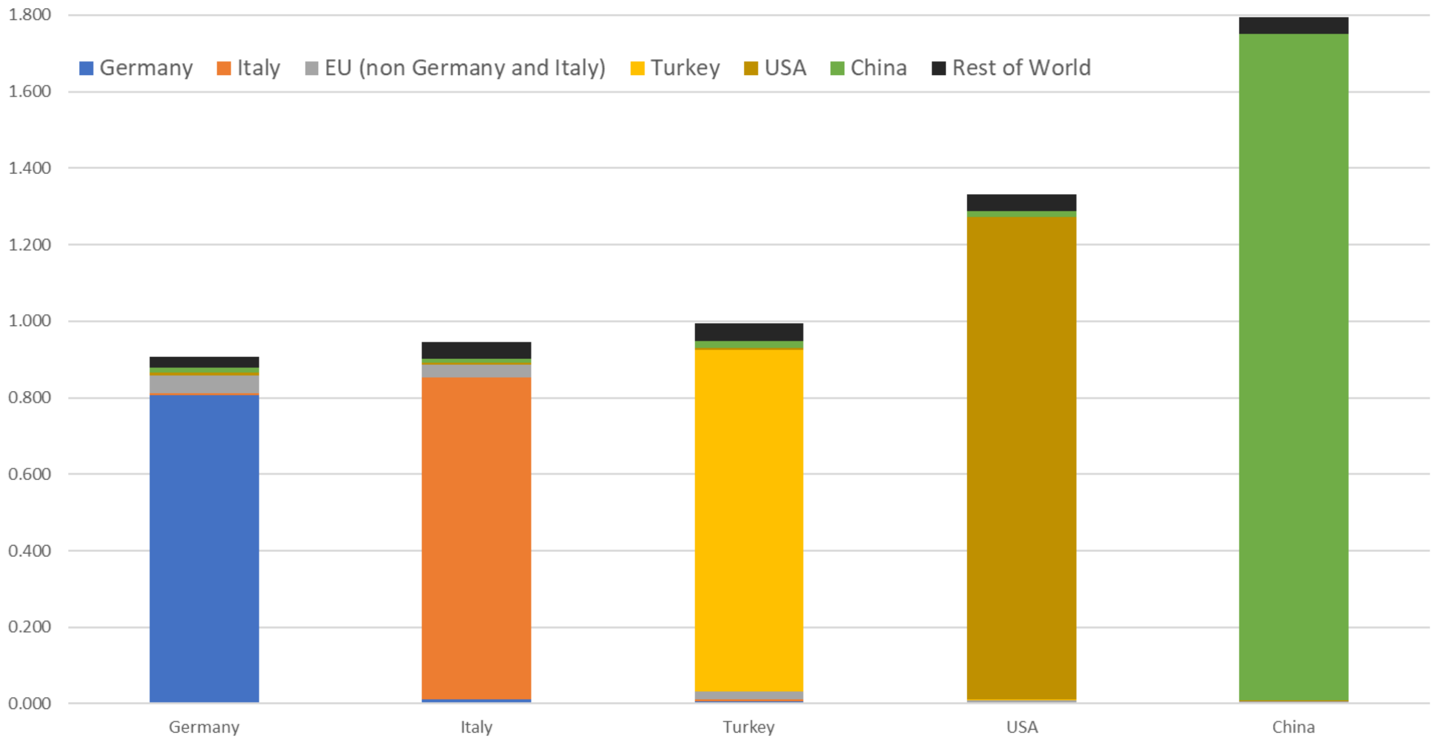


Figure 1 then demonstrates the consequent comparative impact on global emissions of $1million of final demand requirement for 'Cement etc..' being met by the production sector location in each of Germany, Italy, Turkey, the USA and China. The bars in Figure 1 equate to the total global output-CO_2 multipliers in the fifth column of Table 1a; however, their composition is shown in terms of the location of production across emitting regions (entries where *r* represents each of the five countries identified plus an EU/rest of EU aggregation and a 'rest of world', ROW, one for all other countries/regions not identified in the chart or within the EU block).

A first key result thus emerges in that (in the absence of any additional policy action) the IRIO multiplier analysis suggests that cement production located outside of the EU is likely to generate a spatial displacement of CO_2 generation (largely own-country and direct therein), but with the likelihood of an overall increase in global CO_2 emissions.

On the other hand, when we consider the output-employment and output-GDP multipliers reported in Tables 1b and 1c respectively, economic activity in external supply chains tend to be more important for each of the countries we focus on. For example, in the case of German 'Cement etc.', only 60% (8.3) of the 16.4 jobs required per $1m of output produced to meet final demand are located in Germany, and almost 30% (3.5) are located outside of the EU. The domestic concentration of global GDP supported by final demand for German 'Cement etc.' is higher (76%), with almost 90% generated within the EU as a whole.

However, perhaps the main thing to note from Table 1b in particular, is the relatively high direct labour/employment intensity of the non-EU nations (with the exception of the USA). This leads to two further and inter-linked main results that are key in terms of the economic/emissions and 'just transition' trade-offs in consideration of alternative locations of production. These are reflected in the alternative, spatial communication of the total global employment and GDP multipliers in Figures 2 and 3 (again defined by the location of required employment and GDP generation in producing regions, *r*). Figure 2 demonstrates that production of 'Cement etc.' in locations like Turkey or China (but not the USA, where ‘Cement etc.’ production is less labour intensive) has a higher direct and supply chain labour requirement to accompany higher global CO_2 emissions. On the other hand, Figure 3 demonstrates that the jobs involved are less productive in terms of GDP generation, with the five alternative production locations producing broadly similar levels of GDP with the variation being in the spatial locations where this value-added accrues.

Figure 2. Output-employment multipliers by location of required direct and supply chain jobs (numbers employed) per $1m of final demand for 'Cement etc.' industry output

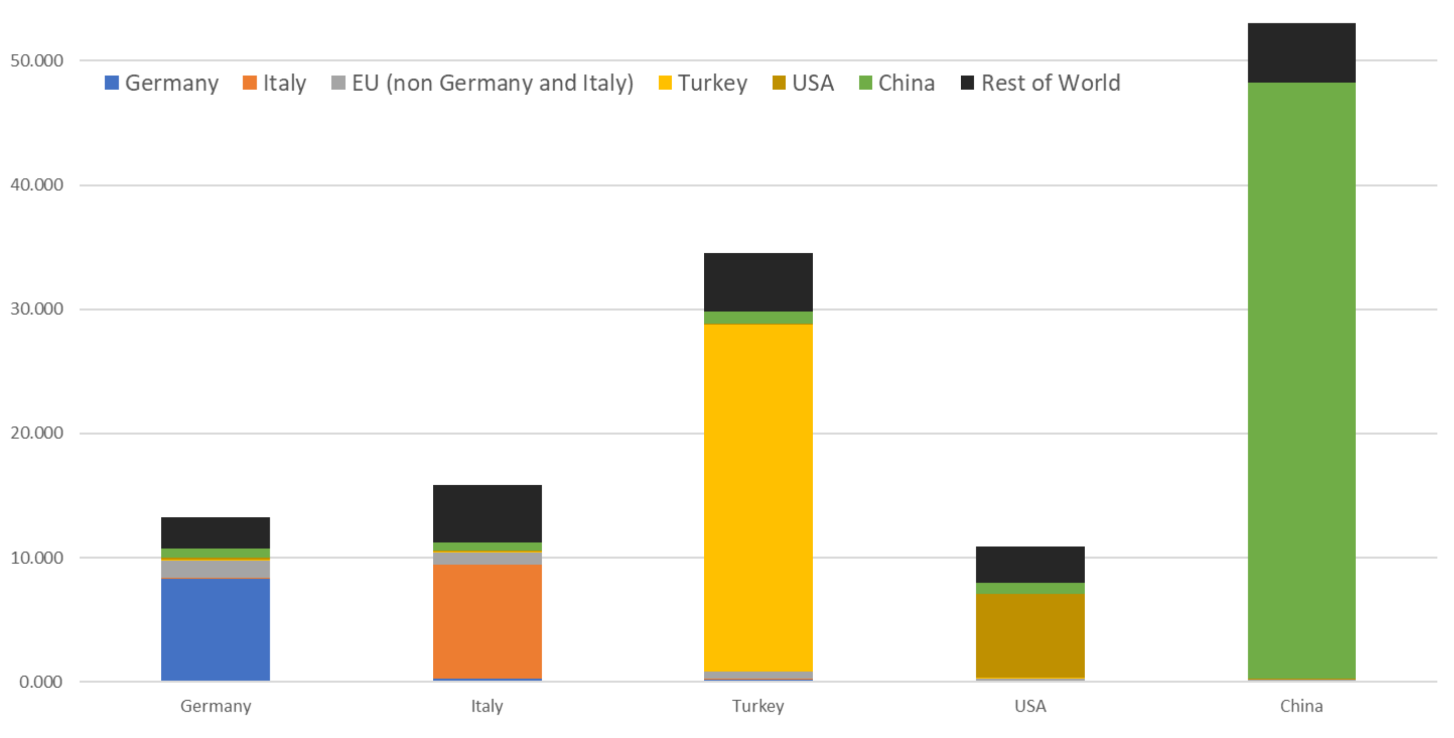
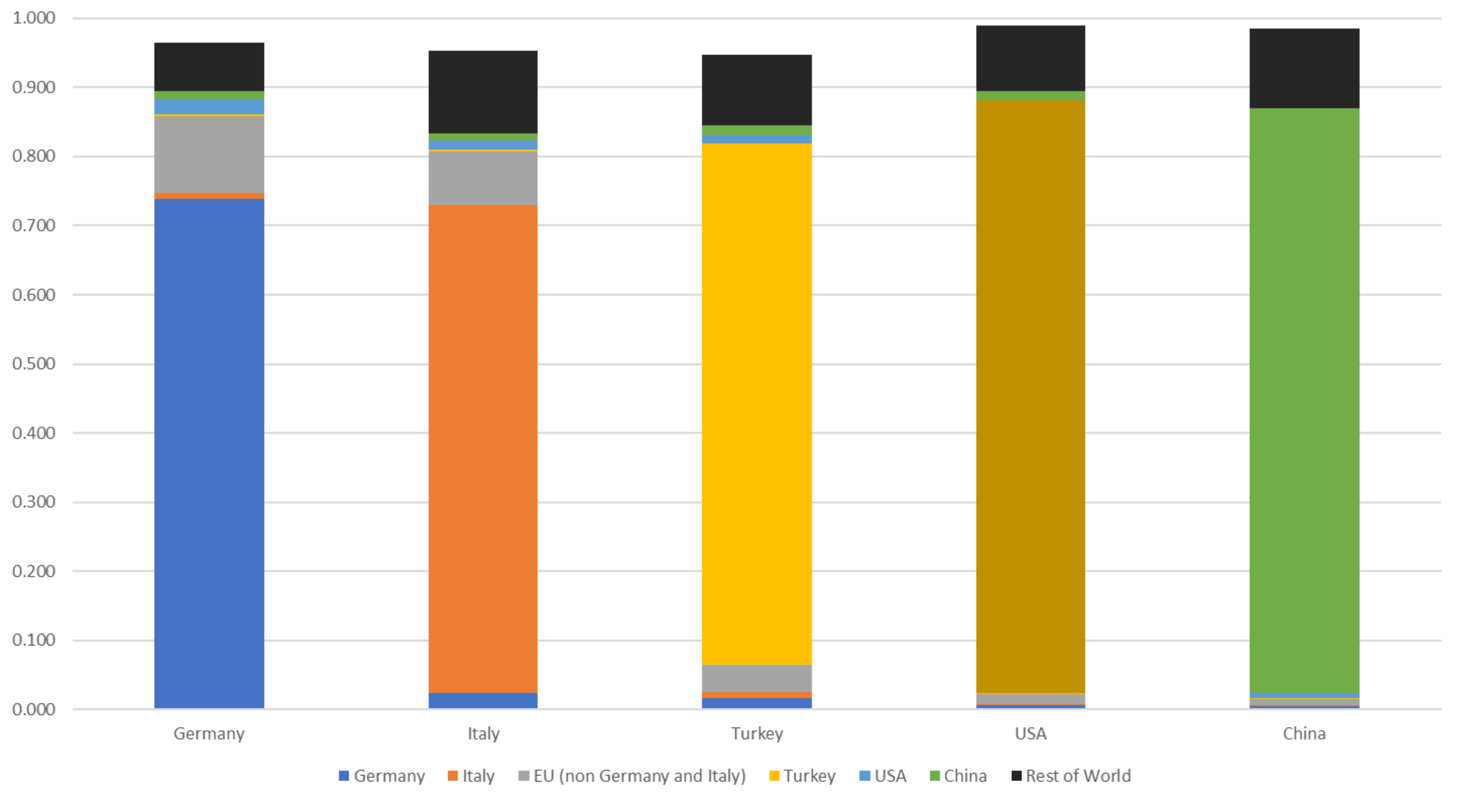


Figure 3. Output-GDP multipliers by location of required direct and supply chain value-added ($million) per $1m of final demand for 'Cement etc.' industry output



A second key result thus emerges in that (again, in the absence of any policy action) the IRIO multiplier analysis suggests that cement production located outside of the EU is likely to generate a spatial displacement of GDP generation that is associated with a net increase in global employment. That GDP does not increase in line with employment reflects a less productive employment of labour in servicing demand for cement (and other non-metallic mineral products) in particularly the emerging nations that production and supply chain activity may be displaced to. That this is likely to be accompanied by a net increase in global CO_2 emissions raises political questions in terms of the justness of the transition both at a global level and within nations where cement production and related supply chain activity may reduce. The latter can be considered using the IRIO multiplier framework and is the focus of our attention in the next section.

4.2 Decomposing the extent of own sector indirect supply chain displacement within nations

The scientific literature and policy discourse (at both national and international levels) have given much attention to issues around action to reduce domestic carbon emissions vs. risk of carbon leakage, and increasingly linking the latter to issues around spatial relocation of production activity (see Section 2 above). However, it is only more recently that the policy debate in the EU has shifted to focus specifically on the 'just transition' element of the Paris agreement, and in particular what the implications of industrial decarbonisation in EU nations may be in terms of the level and quality of employment at a domestic level (e.g. see ZEP, 2018). The previous section demonstrates that IRIO multiplier analysis may prove useful in highlighting potential patterns of spatial displacement of value-added and jobs at different geographical levels. In this section we consider how further decomposition of the type of multiplier results derived using the system in equations [1] to [5] may provide further insight in to potential domestic patterns of impacts if an industry like cement production is even partially displaced. Focussing again on the case of cement production in Germany, we extend this focus to consider wider supply chain impacts on GDP in other EU member states. This is motivated by the result reflected in Figure 3 above, where, of the five nations we report for, the biggest external supply chain content of the 'Cement etc.' GDP multipliers is observed in the case of value-added content across the EU for the German industry.

In the first instance, the results reflected in Figure 4 for the distribution of the German 'Cement etc.' output-employment multiplier are akin to what could be generated using a national IO framework rather than the full IRIO. At this stage we note that a more local level account could provide more sectoral detail, and link directly to income from employment rather than the sole focus on gross value-added (GDP at basic prices) that is the focus of this paper. Nonetheless, we propose that it is useful to continue with the IRIO framework in order to link both to the results in Section 4.1 and the analysis for GDP below (which extends to consider impacts in other EU nations). The results in Figure

4 are generated by decomposing the *j* = ‘Cement etc.’ own-country employment multiplier in the third column of Table 1b (8.29 jobs per $1m final demand) in order to focus on the distribution across individual elements $e_i^r l_{ij}^{rs}$ (equation [3b] where *r*=*s*). The pie chart reports results for each German industry grouping, *i*. Note that the percentage results shown may be applied to any level of final demand for the German ‘Cement etc.’ industry’s output. We highlight the per $1m employment level of the multiplier itself (8.29) and the total 90,915 jobs supported by the 2014 base year final demand for the sector’s output (reported as $10,971 in Table 1). We exert caution in considering any scenarios regarding potential changes in production levels given the restrictive assumptions involved in IO modelling (see Miller & Blair, 2009).

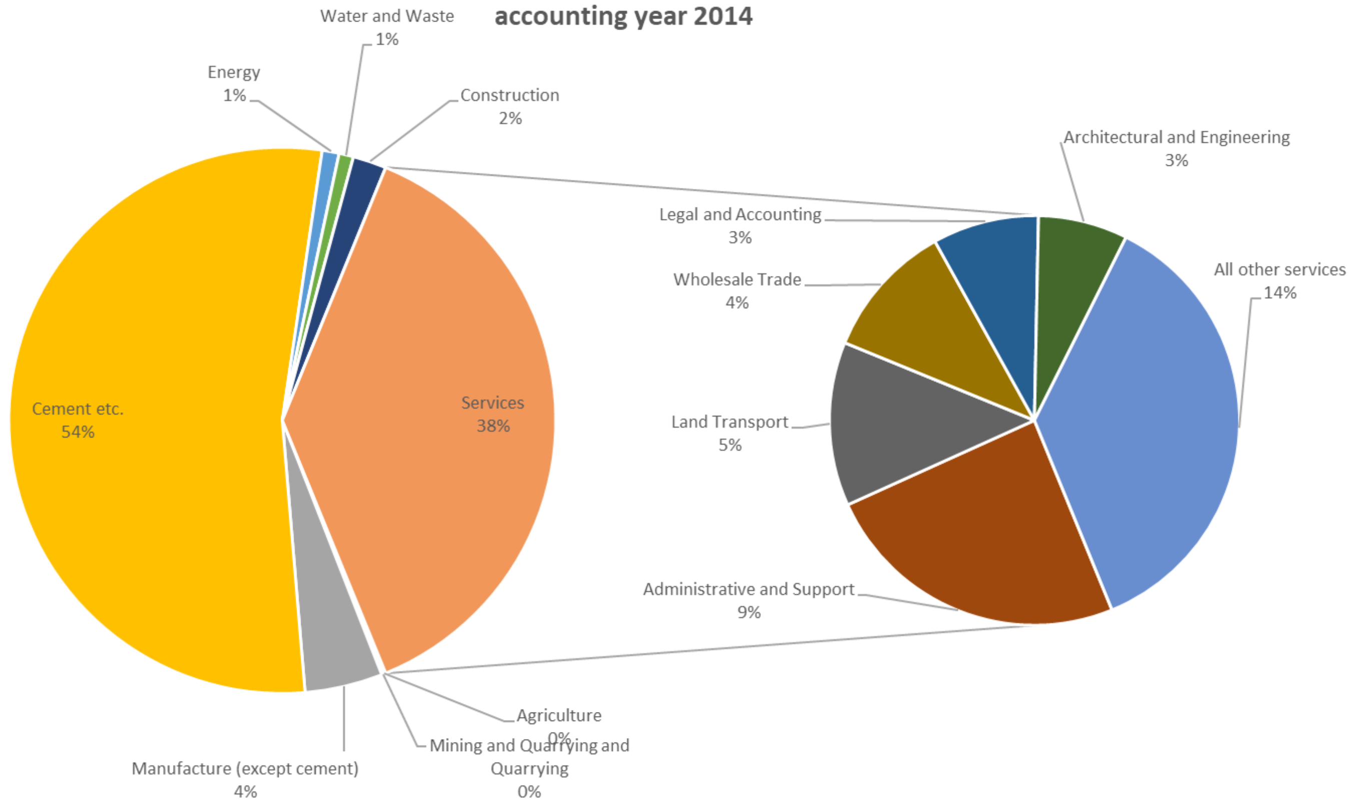


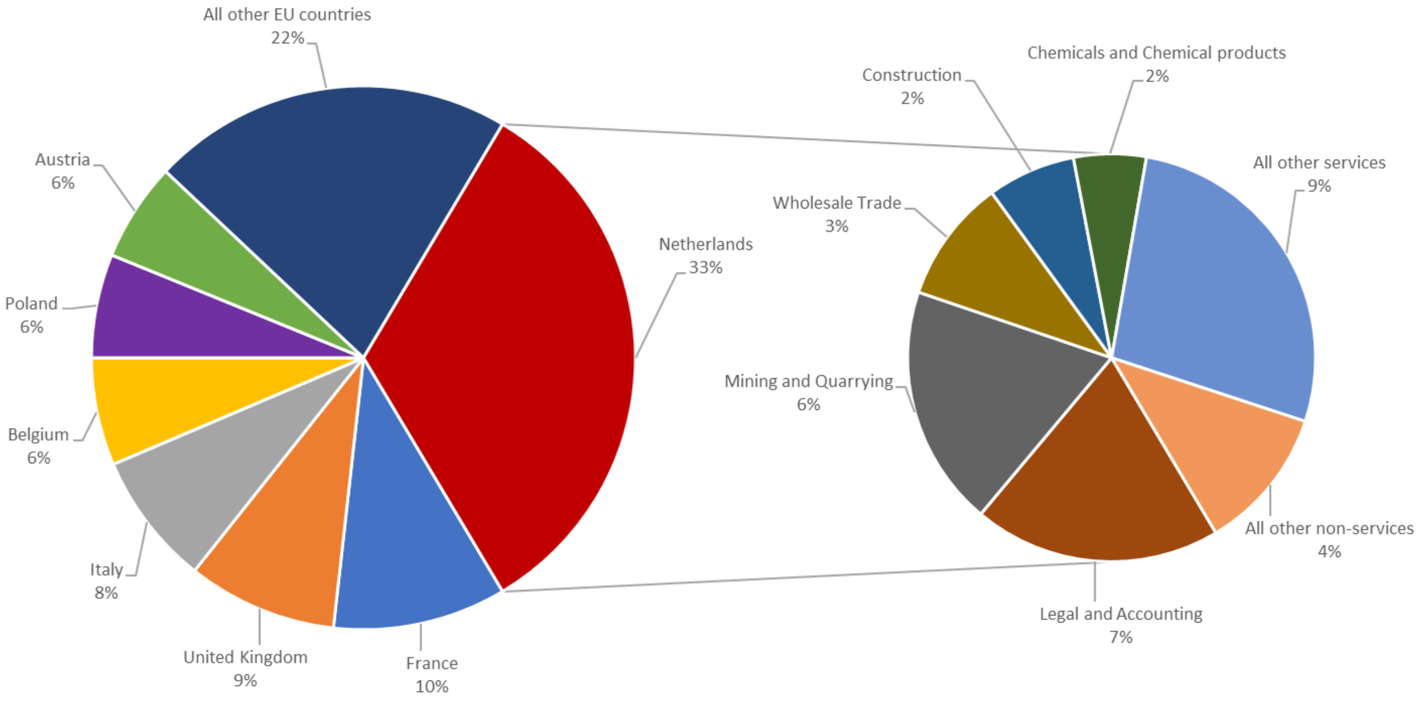
Figure 4. Distribution of German employment multiplier effects by sector required to support final demand for German 'Cement etc.' industry output: 8.29 jobs per $1m or 90,915 jobs in accounting year 2014

The key result emerging from Figure 4 is the importance of supply chain employment supporting German ‘Cement etc.’ production located in domestic service sectors. The crucial message is that concern over any loss of German jobs if the domestic industry were to decline should not be limited to direct industry and technical supply chain jobs. Specifically, Figure 4 shows that 35% of the 90,915 German jobs involved in supporting 'Cement etc.' production via indirect supply chain links are located in various service sectors. Now, at this point it is important to remind ourselves that the WIOD data used report jobs in terms of 'head count' rather than the full-time equivalents often reported alongside national level IO accounts. However, when we repeat the analysis underpinning Figure 4 for GDP (i.e. referring to $v_i^r l_{ij}^{rs}$(equation [3c] where *r*=*s*= Germany and *j* = 'Cement Etc.') we find a very similar distribution with only very marginal shifts in the distribution across sectors. The largest is in favour of 'Administrative and Support' which accounts for 6% of the output-GDP multiplier compared to 9% of the output-employment one.

However, in considering value-added/GDP generated in supply chain activity supporting production of the German 'Cement etc.' sector, the importance of other EU impacts reflected in the results reported in Table 1c and Figure 3, is further considered in Figure 5. The results here are also computed with focus on specific $v_i^r l_{ij}^{rs}$in the computation of equation [3c], but now extending focus to producing industries, *i*, and regions, *r*, in the wider EU.

The key result emerging in Figure 5 is the importance of the German 'Cement etc.' industry's upstream impact on value-added generation across a range of EU nations, and particularly in Germany's direct geographical neighbour, the Netherlands (33% of the total other/non-Germany EU output-GDP multiplier). In the smaller pie chart on the right of Figure 5 we decompose that 33% (i.e. considering all elements of the *j*='Cement etc.' and *r*=Netherlands elements of the German column of the matrix in equation [3c]). The further key result emerging there is that the importance of the German 'Cement etc.' industry in supporting GDP generation in service sector activities is not limited to the domestic supply chain: it extends to impact a number of service industries (including 'Legal and Accounting') located in the Netherlands.

Figure 5. Spatial distribution of supply chain GDP generated to support production of output to service German 'Cement etc.' final demand (with industry level detail for the Netherlands)



This type of result may help underpin and focus policy analysis and research going forward in specific contexts. For example, the strength of German-Dutch supply chain relationships identified in Figure 5 may be crucially important in considering potential domestic industrial decarbonisation actions. For example, existing direct and indirect supply chain linkages to the Port of Rotterdam and legal services may help enable carbon capture and storage solutions (see ZEP, 2018, on key industrial activity in the German North Rhine-Westphalia region and links to the Port of Rotterdam Authority CCS project). A fuller analysis would require more spatial and industry detail in IO accounting, ideally to inform micro-focussed industry and project studies.

5. Summary and conclusions

The aim of this paper has been to demonstrate how IRIO multiplier analysis, involving focussed decomposition of sectoral and spatial impacts, provides useful information and insight on the direct and indirect structure of supply chain activity supported by industries faced with the challenge of decarbonisation. We have focussed attention on CO_2 emissions, where the nature of carbon leakage risks must be understood in considering the Paris 2015 climate change reduction targets, and on employment and value-added/GDP, where an understanding of supply chain dependencies is necessary in considering the 'just transition' element of that agreement.

We propose exploiting the full capabilities of the spatially and sectorally decomposed IRIO multiplier accounting framework to consider the CO_2, jobs and value-added/GDP content of domestic and international supply chains supporting any given industry currently producing in different national locations. The aim is to develop an information base to inform policy consideration of the impacts of potential decarbonisation solutions in terms of actions that may induce retention or relocation of industry activity. We demonstrate the nature of the information set that emerges for the case of an industry grouping containing cement production, with a focus on the German industry in particular. A number of key findings emerge for this case example that are likely to have more general relevance.

Our first key finding is that, in the absence of any additional policy action, locating cement production outside of the EU is likely to generate a spatial displacement of CO_2 emissions and a potential overall increase in global CO_2 emissions. Our second is that this is likely to be accompanied by spatial displacement of GDP generation, albeit possibly associated with a net increase in global employment. In our example focussing on potential off-shoring of Germany cement production (and associated supply chain activity), that GDP does not increase in line with employment reflects a less productive employment of labour. Such an outcome may raise questions in terms of the justness of the transition both at a global level (where CO_2 emissions increase along with employment) and within nations loss of production in one industry will trigger a series of impacts in employment and GDP generation in a wide range of economic activities.

Our third finding relates to the importance of service sector activity underpinning supply chain employment supported by industrial production. Focussing on value-added, our fourth is that GDP generation in a number of EU nations is impacted by supply chain requirements to support German cement production, and this is particularly the case for Germany's direct neighbour, the Netherlands, and, again, service sectors play an important role.

More generally, our analysis highlights the importance of considering how shifting locations for manufacturing processes (such as cement production) from their current locations to ones with less strict environmental regulations may lead to an increase of global CO_2 emissions. The results demonstrate how this will be accompanied by a displacement of jobs and GDP not only in the original host region but throughout the upstream supply chain. This has implications for the 'just transition' element of the Paris 2015 agreement, which emphasises the importance of national priorities regarding employment (and the quality of jobs). This focuses attention on the need to decarbonise industrial activities in their current locations, by means that do not negatively impact key performance indicators for both industry and the wider economy, such as competitiveness. In this respect, our analysis shows how the type of multiplier metrics reported here provide first step in considering the both potential costs of relocation and the benefits of retaining activity. We note that there has been recent attention to this type of use of multiplier metrics in two non-academic studies (ZEP, 2018; Stiftelsen for Industriell og Teknisk Forskning [SINTEF], 2018) considering the role of hydrogen and/or carbon capture, utilisation and storage (CCUS) in industrial decarbonisation This paper then also serves the purpose of setting out a more formal grounding for future development of a body of evidence in this area.

Thus, the results reported here should be seen as a first attempt and building block towards providing a quantitative assessment of the potential impacts due to off-shoring of cement production currently located in the EU. Such a scenario analysis would require a number of developments in data and methods. For example, if CGE analyses of the type reviewed in Section 2 were to be attempted, this would ideally require more up-to-date IRIO data. We have used the most recent WIOD data, for 2014, but with emissions data relating only to output intensities (where CGE applications require a link to input use where appropriate) and adjusting intensities that applied in 2009. In addition, where focus is on specific industrial production activities like cement, greater sectoral disaggregation would ideally also be required. Similarly, improved analyses would exploit full-time equivalent (FTE) job data rather than 'head count' jobs data. Both may be more likely with national level IO data. Where IO multiplier analyses are intended to be more illustrative and generally informative on the complexity of supply chain activity, these issues may be less of a problem.

On the other hand, the main issue for considering different decarbonisation scenarios in whole (global, international or national) economy context is that the demand-driven IO model is restrictive in its assumptions regarding, in particular, supply side response and price/market behaviour. Where scenario analyses are required, the role of IO accounting frameworks shifts to the provision of a structural database that allows for of a more flexible and theoretically consistent CGE framework. Nonetheless, we argue that the type of structural multiplier analysis presented constitutes a valuable first step in considering the type of production and supply chain interactions that should be captured in any modelling of scenarios in a whole economy or general equilibrium context.

Data statement

This study involves analysis using existing data that are publicly available from the WIOD database (http://www.wiod.org/release16); the 2014 IRIO table (http://www.wiod.org/database/wiots16); associated Socio-Economic Accounts (http://www.wiod.org/database/seas16) and corresponding

'CO_2 emissions' data (limited to CO_2 emissions from energy use) for each country (http://www.wiod.org/database/eas13). No new data were created during this study.

Endnotes

[1] Whether the number of employees refers to the absolute number of people employed or full time equivalent employees depends on type of data reported in the socio-economic account used. As already indicated in our analysis the employment data report the absolute number of people employed.

[2] The GDP deflators used can be found in this link: https://data.worldbank.org/indicator/NY.GDP.DEFL.ZS?end=2017&start=2009

[3] The EU cement association, Cembureau, has published a document detailing its vision to reduce the footprint of the EU cement sector by 32% compared to 1990 level and provides discussion of how different policy tools and emerging technologies could be used to achieve this goal. The document is available at https://cembureau.eu/media/1500/cembureau_2050roadmap_lowcarboneconomy_2013-09-01.pdf.

More recently, the UK Government published an action plan, jointly with the UK cement sector, focussing on delivery of the UK 2050 CO_2 targets. This action plan is available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651222/cement-decarbonisation-action-plan.pdf

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Appendices

Appendix 1. Link of WIOD sectors in 2016 release to WIOD sectors in 2013 release

Sectors in 2016 WIOD release		Sectors in 2013 WIOD release
Crop and animal production, hunting and related service activities		Agriculture, Hunting, Forestry and Fishing
Forestry and logging		Agriculture, Hunting, Forestry and Fishing
Fishing and aquaculture		Agriculture, Hunting, Forestry and Fishing
Mining and quarrying		Mining and Quarrying
Manufacture of food products, beverages and tobacco products		Food, Beverages and Tobacco
Manufacture of textiles, wearing apparel and leather products		Textiles and Textile Products; Leather, Leather and Footwear
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials		Wood and Products of Wood and Cork
Manufacture of paper and paper products		Pulp, Paper, Paper , Printing and Publishing
Printing and reproduction of recorded media		Pulp, Paper, Paper , Printing and Publishing
Manufacture of coke and refined petroleum products		Coke, Refined Petroleum and Nuclear Fuel
Manufacture of chemicals and chemical products		Chemicals and Chemical Products
Manufacture of basic pharmaceutical products and pharmaceutical preparations		Chemicals and Chemical Products
Manufacture of rubber and plastic products		Rubber and Plastics
Manufacture of other non-metallic mineral products		Other Non-Metallic Mineral
Manufacture of basic metals		Basic Metals and Fabricated Metal
Manufacture of fabricated metal products, except machinery and equipment		Basic Metals and Fabricated Metal
Manufacture of computer, electronic and optical products		Electrical and Optical Equipment
Manufacture of electrical equipment		Electrical and Optical Equipment
Manufacture of machinery and equipment n.e.c.		Machinery, Nec
Manufacture of motor vehicles, trailers and semi-trailers		Transport Equipment
Manufacture of other transport equipment		Transport Equipment
Manufacture of furniture; other manufacturing		Manufacturing, Nec; Recycling
Repair and installation of machinery and equipment		Basic Metals and Fabricated Metal; Machinery, Nec; Electrical and Optical Equipment
Electricity, gas, steam and air conditioning supply		Electricity, Gas and Water Supply
Water collection, treatment and supply		Electricity, Gas and Water Supply
Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services		Other Community, Social and Personal Services
Construction		Construction
Wholesale and retail trade and repair of motor vehicles and motorcycles		Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
Wholesale trade, except of motor vehicles and motorcycles		Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
Retail trade, except of motor vehicles and motorcycles		Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
Land transport and transport via pipelines		Inland Transport
Water transport		Water Transport
Air transport		Air Transport
Warehousing and support activities for transportation		Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies

Postal and courier activities		Post and Telecommunications
Accommodation and food service activities		Hotels and Restaurants
Publishing activities		Pulp, Paper, Paper , Printing and Publishing; Renting of M&Eq and Other Business Activities
Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities		Other Community, Social and Personal Services
Telecommunications		Post and Telecommunications
Computer programming, consultancy and related activities; information service activities		Renting of M&Eq and Other Business Activities
Financial service activities, except insurance and pension funding		Financial Intermediation
Insurance, reinsurance and pension funding, except compulsory social security		Financial Intermediation
Activities auxiliary to financial services and insurance activities		Financial Intermediation
Real estate activities		Real Estate Activities
Legal and accounting activities; activities of head offices; management consultancy activities		Renting of M&Eq and Other Business Activities
Architectural and engineering activities; technical testing and analysis		Renting of M&Eq and Other Business Activities
Scientific research and development		Renting of M&Eq and Other Business Activities
Advertising and market research		Renting of M&Eq and Other Business Activities
Other professional, scientific and technical activities; veterinary activities		Renting of M&Eq and Other Business Activities
Administrative and support service activities		Renting of M&Eq and Other Business Activities
Public administration and defence; compulsory social security		Public Admin and Defence; Compulsory Social Security
Education		Education
Human health and social work activities		Health and Social Work
Other service activities		Other Community, Social and Personal Services
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use		Private Households with Employed Persons
Activities of extraterritorial organizations and bodies		Extra-territorial organizations and bodies

Appendix 2. WIOD 2016 release sectors and corresponding names used within paper and figures

Sectors in 2016 WIOD release	**Name used in paper and figures**
Mining and quarrying	Mining and Quarrying
Manufacture of other non-metallic mineral products	Cement etc.
Manufacture of chemicals and chemical products	Chemicals and Chemical products; also part of Manufacture (except cement) in Figure 4
Electricity, gas, steam and air conditioning supply	Energy
Water collection, treatment and supply	Water and Waste
Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	
Construction	Construction
Wholesale trade, except of motor vehicles and motorcycles	Wholesale Trade
Land transport and transport via pipelines	Land Transport; Also part of All other service in Figure 5
Legal and accounting activities; activities of head offices; management consultancy activities	Legal and Accounting
Architectural and engineering activities; technical testing and analysis	Architectural and Engineering; Also part of All other services in Figure 5
Administrative and support service activities	Administrative and Support; Also part of All other services in Figure 5
Crop and animal production, hunting and related service activities	Grouped as Agriculture in Figure 4. Also part of All other non-services in Figure 5
Forestry and logging	
Fishing and aquaculture	
Manufacture of food products, beverages and tobacco products	Grouped as Manufacture (except cement) in Figure 4. Also part of All other non-services in Figure 5
Manufacture of textiles, wearing apparel and leather products	
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	
Manufacture of paper and paper products	
Printing and reproduction of recorded media	
Manufacture of coke and refined petroleum products	
Manufacture of basic pharmaceutical products and pharmaceutical preparations	
Manufacture of rubber and plastic products	
Manufacture of basic metals	
Manufacture of fabricated metal products, except machinery and equipment	
Manufacture of computer, electronic and optical products	
Manufacture of electrical equipment	
Manufacture of machinery and equipment n.e.c.	
Manufacture of motor vehicles, trailers and semi-trailers	
Manufacture of other transport equipment	
Manufacture of furniture; other manufacturing	
Repair and installation of machinery and equipment	

Wholesale and retail trade and repair of motor vehicles and motorcycles	Grouped as All other services
Retail trade, except of motor vehicles and motorcycles	
Water transport	
Air transport	
Warehousing and support activities for transportation	
Postal and courier activities	
Accommodation and food service activities	
Publishing activities	
Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities	
Telecommunications	
Computer programming, consultancy and related activities; information service activities	
Financial service activities, except insurance and pension funding	
Insurance, reinsurance and pension funding, except compulsory social security	
Activities auxiliary to financial services and insurance activities	
Real estate activities	
Scientific research and development	
Advertising and market research	
Other professional, scientific and technical activities; veterinary activities	
Public administration and defence; compulsory social security	
Education	
Human health and social work activities	
Other service activities	
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	
Activities of extraterritorial organizations and bodies	