Local consumption and territorial based accounting for CO_2 emissions*

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Abstract

We examine the complications involved in attributing emissions at a local level. Specifically, we look at how functional specialisation within a city region can, via trade between sub-regions, create emissions interdependencies; and how this complicates environmental policy implementation in an analogous manner to international trade at the national level. For this purpose we use a 3-region emissions extended input-output model of the Glasgow city region (2 regions: city and wider city-region) and the rest of Scotland. The model utilises data on household consumption to account for consumption flows across sub-regions and plant-level data on emissions from electricity generation to augment the top-down disaggregation of emissions. This enables a carbon attribution at the sub-regional level, which is used to analyse emissions interdependencies within the city-region.

JEL Codes: H73; Q56; R12; R15.
Keywords: CO_2 emissions; environmental accounting; regional interdependency; metropolitan area; city region.

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1 Introduction

Although the greenhouse gas emission problem is inherently global, local level policies could contribute to its solution. In particular, cities are seen to offer potential for reducing greenhouse gas (GHG) emissions. As Dhakal (2010) points out, economic activity is concentrated in cities and therefore they drive a significant share of overall emissions. However, in most cases, per capita emissions from cities are lower than the average for the countries in which they are located. Furthermore, emissions vary significantly between cities and are associated with local planning policies (Glaeser & Kahn 2010). This suggests that there is some potential for reducing emissions through the use of local level emission reduction policies, which are tailored to differences in the functional activities of different sub-regions.

There is increasing interest in analysing GHG emissions and implementing policies for their reduction at the urban level (Dhakal 2010, Dodman 2009, Parshall et al. 2010, Weisz & Steinberger 2010)[1]. Given the important role cities play in emissions generation, and in order to capitalise on the emissions-reduction potential of cities, city-level carbon budgets have been proposed (Salon et al. 2010). Conversely, since much of GHG emissions are embodied in trade across administrative boundaries, it is not clear ex ante how effective or equitable local level emissions policies will prove. This issue has already received significant attention in the context of trade across nations (Munksgaard & Pedersen 2001, Peters & Hertwich 2006) while at the local level, interregional trade, commuting and shopping trips can have similar effects. Therefore, it is important to understand the spatial interdependencies that exist in the composition of the emissions total within regions and nations. Furthermore, the choice of GHG accounting principle that underlies regional, national or local GHG targets can influence the spatial distribution of the required emission reductions.

In order to explore this issue, we use a three region model of Scotland (the regional economy in our case). These are: Glasgow (GLA) (Scotland's largest city), the rest of Strathclyde (RST) (representing Glasgow's wider city region), and a residual sub-region comprised of the rest of Scotland (ROS). The size and location of each of the three sub-regions is shown in the Map in Figure 1, and we provide some background information on the study area in Section 3. Using this model, we seek to explore three issues that are important in understanding the structure of the economy and GHG emissions within a city region and its host regional economy. First, how produced and supported emissions vary across sub-regions; second, to what extent GHG emissions are embodied in intraregional trade (i.e. inter sub-regional trade); and third, what these

[1]This interest is not just academic, but something that is on the agenda for local governments. For example in the UK, Glasgow City Council both measures its 'carbon footprint', and has a Carbon Management Programme to facilitate reduction in line with stated targets. Similar actions have been taken by various sub-regional entities such as West Sussex County Council and the Lake District National Park Authority (Energy and Climate Change Committee 2012, pp. 14-15).

results suggest for the choice of accounting method for local emissions targets and policies.

The next section reviews the relevant environmental, urban, and interregional input-output (IO) literature, and places the analysis in the context of previous work. Section 3 briefly discusses the characteristics of the three sub-regions in the model. Section 4 outlines the empirical framework and approach used in this study. Section 5 presents results and the final section concludes.

2 Greenhouse gas accounting, input output and the urban economy

Two methodologically different accounting principles are frequently used for analysing GHG emissions (Munksgaard & Pedersen 2001, Peters & Hertwich 2008): the territorial accounting principle (TAP) (also known as the production accounting principle) and the consumption accounting principle (CAP). The TAP attributes all emissions to the territorial areas where the emissions are generated, while CAP attributes all emissions to the consumption activity that requires the generation of these emissions; irrespective of the spatial location of the emissions generation.

A limitation of the TAP is that it does not allow for the GHG content of imports, only exports. Which means that countries can reduce emissions by outsourcing polluting activity, but also that countries with significant export production, can be penalised. Munksgaard & Pedersen (2001) demonstrate that in circumstances involving trade between countries (or regions) TAP based emissions can be problematic in practice. They raise the case of Norway and Denmark in the 1990s, when in wet years, surplus quantities of hydropower generated in Norway were sold to Denmark. This had the effect of lowering Denmark's demand for power from traditional (dirty) power plants, which in turn resulted in particularly onerous TAP targets for Denmark. Munksgaard & Pedersen (2001) use this case to illustrate that adopting a consumption accounting principle (CAP) would avoid this difficulty. This debate is important given that some estimates of the emissions embodied in trade can be significant, for instance Andrew et al. (2009) show that around 40% of CAP GHG emissions are typically comprised of emissions embodied in imported goods and services.

A number of studies have argued for the policy relevance of analysing GHG emissions at sub-regional scales, such as cities or metropolitan areas (Dodman 2009, Kates et al. 1998, Larsen & Hertwich 2009, Parshall et al. 2010, Ramaswami et al. 2008, Weisz & Steinberger 2010). There are two main methods for estimating production based inventories (Larsen & Hertwich 2009): top-down attribution, i.e. disaggregating GHG emissions at a national or regional scale down to smaller spatial scales, and bottom up, i.e. by gathering local emissions data. A number of bottom up studies have been conducted for cities (Dodman 2009, Kates et al. 1998). However, this imposes a number of challenges. In particular, the availability of data, completeness of the GHG inventory, comparability across different studies and the definition of boundaries; problems which increase as the area under study gets smaller[2]. In what follows we shall review the top down and bottom up approaches in turn.

Top down approaches using IO methods are common in the empirical literature both for single region (Druckman & Jackson 2009, Turner et al. 2011, Peters & Hertwich 2006, Sánchez-Chóliz & Duarte 2004, Mäenpää & Siikavirta 2007, Ipek Tunc et al. 2007) and inter-regional analyses (Lenzen et al. 2004, Wiedmann 2009, Peters & Hertwich 2009, McGregor et al. 2008). This builds on the early work of Leontief (1970) who extended the demand driven IO economic model to analyse environmental issues. As Larsen & Hertwich (2009) point out, the strength of IO as a top-down approach is that it is comprehensive; capturing annual transactions of the whole economy and avoiding cut-off errors. Its principal weakness is a consequence of assumptions made to overcome data limitations in the construction of the economic-environmental database, such as adopting an average emissions coefficient for each sector when disaggregating into smaller geographical units.

The IO framework is particularly useful for interregional analysis, capturing not only interdependencies between individual sectors within a particular area, but also explicitly identifying trade flows between each of the areas set out in the model. Indeed, as Wiedmann (2009) points out multi region IO has become the norm for CAP type analysis. Relative strengths and limitations of the IO approach are discussed more fully in Wiedmann et al. (2011).

Most multi region IO applications are carried out for international analysis, i.e. examining GHG attribution across two or more national economies. Some are interregional, e.g. McGregor et al. (2008), who examine the carbon interdependency between Scotland and the RUK. However, fewer IO studies have been undertaken at the sub-regional level. There has been some scholarly debate on the attribution and accounting of emissions at the regional level, see for instance Turner et al. (2011), but at the sub-regional level applications are rare. Examples include Larsen & Hertwich (2009) and Wu (2011), which examine the carbon footprints of the municipalities Trondheim in Norway and of Haninge in Sweden, respectively.

Conversely, several bottom up studies of cities have been undertaken. These tend to be either case studies, which are difficult to compare directly, or comparisons based on partial inventories, such as in Glaeser & Kahn (2010). A recurring issue in the environmental economics literature to date, is that studies

[2]For a discussion of these issues see: (Kates et al. 1998, Larsen & Hertwich 2009, Weisz & Steinberger 2010).

for sub-regional areas ignore economic and functional interdependencies between sub-regional areas.

There are a number of reasons to be interested in the interactions occurring at a sub-regional level. Within metropolitan areas differences in population densities and economic activity are often sharply evident between a core and a periphery. This is illustrated in our case by the data (Table 1), but more generally in IO analysis of metropolitan areas (Hewings et al. 2001, Jun 1999, 2004, Madden 1985) and in theoretical models (for an overview see McCann (2001)) - perhaps most prominently in the new economic geography literature (for example (Krugman 1991)). The composition of the metropolitan area becomes particularly relevant when functional and administrative boundaries are not aligned (Hewings & Parr 2007, Hewings et al. 2001). For our study area, both the GLA and RST sub-regions are highly economically interdependent, but different administrative units control GLA and RST; indeed RST is comprised of a number of local authority areas. This raises additional complications in terms of policy coordination. In this sense, we believe our study area is typical for many metropolitan areas[3].

3 Glasgow metropolitan area and the rest of Scotland

The city in our model is Glasgow, which is the largest city in Scotland, with a metropolitan area (comprising Glasgow (GLA) and the rest of Strathclyde (RST)) of approximately 2.13 million inhabitants. We separately identify in our model the Glasgow City Council Area (GLA), which is a single local authority and comprises the central city. Although GLA is a separate political unit and there is significant demand for economic policy analysis based solely on Glasgow[4], it is not a separate economic entity in functional terms. Rather, it is highly interdependent with other local authority areas in Scotland. Therefore, our second sub-region of analysis is Glasgow's wider city-region in the rest of Strathclyde (RST), which has strong links to Glasgow through commuting and shopping trips.

The RST is composed of several local authorities, but we amalgamate these into one sub-region to simplify the analysis[5]. The third sub-region we identify is a residual, the rest of Scotland (ROS). This is useful as

[3]See for instance Hewings et al. (2001) for analysis of economic interdependencies among inner city localities and suburbs within the Chicago metropolitan area.

[4]For example, Glasgow City Council and Scottish Enterprise have joined forces in the Glasgow Economic Commission, specifically charged with developing an economic strategy for the City: `http://www.glasgoweconomicfacts.com/Dept.aspx?dept_id=191`

[5]The boundaries of the Strathclyde sub-region as depicted in this study conform to those of the Strathclyde Regional Council (SRC). This includes the council areas of East Dunbartonshire, West Dunbartonshire, Helensburgh and Lomond, East, North and South Ayrshire mainland, Inverclyde, East Renfrewshire and Renfrewshire, North and South Lanarkshire. The SRC was one of nine regional councils created by the Local Government (Scotland) Act 1973 and came into operation in May 1975. It was responsible for various public services, including education, social work, police, fire services, water sewage and transport. Regional Councils were abolished in 1996 but many public services in the area are still provided by entities operating at the Strathclyde level, such as Strathclyde Police, Strathclyde Fire and Rescue Service, and the Strathclyde Partnership for Transport, which runs public transport in the region.

the database can be constructed by disaggregating the relatively rich economic and environmental datasets available for Scotland, i.e. the official Scottish IO-tables and the environmental accounts. The Strathclyde sub-region is Scotland's largest population and economic centre, containing 41.7% of its population and 41.1% of total employment. At its centre is the City of Glasgow, which is linked via an extensive suburban rail network to the rest of the Strathclyde sub-region. Figure 2 lays out the demarcation of the IO-regions in terms of NUTS 2 and NUTS 3 regions, while Figure 1 provides a map of the three sub-regions. Furthermore, key economic and social indicators for these areas are given in Table 1.

Within Strathclyde the main focus is on the Glasgow City Council jurisdiction, which spans an area of 175 km^2 and included 581 thousand inhabitants in 2006 (the year for which our database is constructed). Roughly 313 thousand full time equivalent jobs are found in Glasgow, which is approximately 17% of total employment in Scotland. This is a much larger share of Scotland-wide employment than Glasgow's population share would suggest. Indeed, as is illustrated in Table 2, four out of every ten jobs in the City are taken by in-commuters, primarily originating from other parts of the Strathclyde sub-region.

The rest of the Strathclyde sub-region (RST) has somewhat different economic characteristics than Glasgow (GLA). In terms of population it is approximately 3 times the size of Glasgow. However, there are only 1.4 times as many jobs in RST as there are in GLA. As is evident from Table 2, the lower job density in the RST sub-region is explained by significant out-commuting to seek employment in Glasgow. Furthermore, households in RST bring significant amounts of consumer spending to GLA (Hermannsson 2013). Therefore, it should be clear that there are strong links within the Strathclyde sub-region, between RST and GLA, through economic activity, transport, and governance.

The third sub-region, the Rest of Scotland (ROS), is determined as a residual that allows the interregional table to conform to the full Scottish IO table for control totals (Hermannsson 2013). This approach of identifying the two regions of main interest for analysis and treating the rest of the country as a residual is similar to that used by Akita & Kataoka (2002) for Japan and Eskelinen (1983) for the study of Finland.

4 Accounting framework and data

To conduct the CO_2 attribution analysis we apply an interregional emissions extended Input-Output accounting framework[6]. We build on the exposition of the interregional emissions extended model provided by Turner et al. (2007) and apply this to 3 regions. A detailed discussion of how a general version of this

[6]See for instance Oosterhaven & Stelder (2007) for an accessible introduction to interregional IO models and multipliers and Miller & Blair (2009) provides a textbook exposition of input-output methods.

accounting framework is derived is provided in Appendix.

$$\begin{bmatrix} f_*^{GG} & f_*^{GW} & f_*^{GS} \\ f_*^{WG} & f_*^{WW} & f_*^{WS} \\ f_*^{SG} & f_*^{SW} & f_*^{SS} \end{bmatrix} = \begin{bmatrix} \omega_x^G & 0 & 0 \\ 0 & \omega_x^W & 0 \\ 0 & 0 & \omega_x^S \end{bmatrix} \begin{bmatrix} \mathbf{M}^{GG} & \mathbf{M}^{GW} & \mathbf{M}^{GS} \\ \mathbf{M}^{WG} & \mathbf{M}^{WW} & \mathbf{M}^{WS} \\ \mathbf{M}^{SG} & \mathbf{M}^{SW} & \mathbf{M}^{SS} \end{bmatrix} \begin{bmatrix} \mathbf{y}^{GG} & \mathbf{y}^{GW} & \mathbf{y}^{GS} \\ \mathbf{y}^{WG} & \mathbf{y}^{WW} & \mathbf{y}^{WS} \\ \mathbf{y}^{SG} & \mathbf{y}^{SW} & \mathbf{y}^{SS} \end{bmatrix} + \begin{bmatrix} f_{hh}^G & 0 & 0 \\ 0 & f_{hh}^W & 0 \\ 0 & 0 & f_{hh}^S \end{bmatrix} \tag{1}$$

The accounting framework set out in equation 1 provides a 3×3 matrix of CO_2 emissions composed of elements f_*^{RS}, where the superscripts denote the producing region R and the consuming region S. A $(1 \times N)$ vector of CO_2 emissions coefficients shows the emissions intensity of output in each production sector, in each region ω_x^R . The Leontief inverse is partitioned into sub-matrices M^{RS} containing the elements α_{ij}^{RS}, the inter-industry multiplier. As before these matrix elements describe the impact of a change in the final demand for sector j upon sector i, but in the interregional variant sector j is located in region S and sector i in region R. Final demand is denoted by a matrix composed of $N \times 1$ vectors y^{RS}, where, as before, R is the region of production and S is the region of consumption. The direct emissions produced by Scottish households are added as a 3×3 matrix containing elements f_{hh}^R. These are determined as the product of households' direct emissions intensities (represented by a diagonal matrix composed of vectors ω_{hh}) and a diagonal matrix of household final demand originating in each region. Since we do not have information on household emission intensities specific to each sub-region $\omega_{hh}^G = \omega_{hh}^W = \omega_{hh}^S$.

$$\begin{bmatrix} f_{hh}^G & 0 & 0 \\ 0 & f_{hh}^W & 0 \\ 0 & 0 & f_{hh}^S \end{bmatrix} = \begin{bmatrix} \omega_{hh}^G & 0 & 0 \\ 0 & \omega_{hh}^W & 0 \\ 0 & 0 & \omega_{hh}^S \end{bmatrix} \begin{bmatrix} \mathbf{y}_{hh}^G & 0 & 0 \\ 0 & \mathbf{y}_{hh}^W & 0 \\ 0 & 0 & \mathbf{y}_{hh}^S \end{bmatrix} \tag{2}$$

In the remainder of this section we briefly summarise how the economic environmental database is constructed [7]. The starting point of this process is the 2006 analytical IO table for Scotland, published by the Scottish Government [8].

The outline of the single region Scottish IO-table is presented in Figure 3. This contains i intermediate sectors, q final demand sectors, and p primary (i.e. value added categories) sectors. Using small bold cases for vectors and capital bold cases for matrices, it is composed of a $\mathbf{x}$ = (i x 1) vector of outputs, $\mathbf{Z}$ = (i x i) matrix-of intermediate demand , $\mathbf{Y}$ = (i x y) matrix-of final demand and $\mathbf{V}$ = (p x i) matrix of primary

[7] Details of the disaggregation process are provided in Hermannsson (2013).
[8] This can be accessed at: `http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Input-Output/Downloads`

inputs.

The table is disaggregated into 3 sub-regions as presented schematically in Figure 4. This process is carried out at a maximum level of disaggregation as allowed by the published IO-table (126 sectors). At a later stage, sectors are aggregated to match environmental data and finally the table is aggregated to 12 sectors to aid in the presentation of results. Again, the superscripts indicate the spatial origin and destination of the matrix elements, with G representing Glasgow, W the rest of the Strathclyde sub-region and S the rest of Scotland. The order follows the familiar row/column convention for matrix elements, for example the matrix $\mathbf{Z^{WG}}$ contains the elements for the intermediate demand rows of the rest of Strathclyde sub-region (W) and the intermediate expenditure column of Glasgow (G).

The flow of intermediate trade between the three sub-regions is determined using employment based location quotients. That is, the input coefficients from the Scottish IO tables are adjusted as the production sectors in the smaller sub-regions will not source all of their intermediate inputs locally and hence some of the required inputs will be imported from the other sub-regions [9]. A weakness of the approach is a tendency to underestimate interregional imports; thereby overestimating local impacts see e.g. Harris & Liu (1998). However, modifications have been developed to counter this bias, such as the FLQ formula (Flegg & Webber 1997), which is used here. This takes into account the relative size of the local purchasing and supplying sectors, as well as the relative size of the region, when determining the adjustment of interregional trade. Empirical testing has revealed that this can recreate, on average, the multipliers obtained from a survey based IO table (Flegg & Tohmo 2013, Kowalewksi 2013, Tohmo 2004). Therefore, in aggregate, we can expect the interregional transactions matrix to give a reasonable approximation of intermediate transactions across regional boundaries. A detailed discussion of the approach and sensitivity analysis of multipliers can be found in Hermannsson (2013).

For final demand $\mathbf{Y}$ and primary inputs $\mathbf{V}$ the table is more complicated. Final demand is comprised of two parts, y_1 and y_2. The household consumption category of final demand (y_1) has a region of origin and a region of destination, and is represented by the interregional matrices $\mathbf{Y^{GG}}$, $\mathbf{Y^{GW}}$, $\mathbf{Y^{GS}}$, $\mathbf{Y^{WG}}$, $\mathbf{Y^{WW}}$, $\mathbf{Y^{WS}}$, $\mathbf{Y^{SG}}$, $\mathbf{Y^{SW}}$, **and** $\mathbf{Y^{SS}}$. The other categories of final demand (y_2), which includes government, export, capital, etc, final demands, are not assigned a spatial origin (from within the interregional IO-accounts), and are denoted as $\mathbf{Y^{G*}}$, $\mathbf{Y^{W*}}$, $\mathbf{Y^{S*}}$.

Most final demand categories are based on employment shares with the exception of exports, which are determined as a residual, and household consumption, for which regional origin and destination is identified.

[9] For a general discussion of the use of location quotients to proxy intermediate transactions in IO tables see Miller & Blair (2009, ch. 8.2)

This approach is consistent with most metropolitan models where it is recognised that household consumption is not necessarily incurred locally, but that people may travel for shopping. In principle this has been solved in metropolitan IO models by specifying an interregional shopping matrix that determines the spatial distribution of household outlays (e.g. Hewings et al. 2001, Madden 1985). However, it is not clear what data are used and how they are constructed. In the absence of sufficiently detailed data we adopt a simple approach that determines net consumption flows across spatial boundaries by estimating separately the origin of demand (based on disposable household income) and the destination of demand (based on capacity of local sector to supply), with the difference determining the net-flow that has to be met outside the region for supply and demand to balance (for details see (Hermannsson 2013, pp.18-21)). The strength of this approach is that with modest data requirements it can determine the net flow of household consumption across the sub-regions in aggregate. This is useful for attributing emissions. However, it ignores cross hauling and therefore multipliers calculated with endogenous households (Type-II) would be biased, overstating the local knock-on impacts of household consumption and understating interregional spill over of knock-on effects. The pattern of household consumption in each of the three sub-regions is the same and is taken from the Scottish IO table. Therefore only the *levels* of consumption varies between households in each sub-region.

For primary inputs, industrial sectors in each sub-region are assumed to have the same need for inputs as the aggregate sector in Scotland. These inputs are not assigned a spatial origin, with the exception of labour, where this is explicitly identified based on the commuting data presented in Table 2.

4.1 Top down v. bottom up emissions estimates

In order to specify the emissions-output coefficients necessary to operationalise the framework there are two important practical issues to consider. The first is the availability of bottom up data on industrial emissions generation in each of the sub-regions and the second is the appropriateness of using top down (regional) estimates of the emissions intensity of industry for each of the sub-regions.

The empirical framework of IO imposes an assumption about the homogeneity of sectoral products; namely that each sector produces a single homogeneous product. This assumption is extended to the sub-regions through the top-down disaggregation. This becomes problematic when extending the model to consider flows of emissions if we think that the product differs between sub-regions to the extent that this has an impact on the embodied emissions.

The electricity sector is an obvious example of this. There are no major electricity production plants located within the boundaries of Glasgow and therefore the output of the sector there must be something other than electricity. This needs to be reflected in the emissions attributed to the electricity sector in the Glasgow sub-region. For this we use on data for the local release of emissions by electricity generation plants to carry out a ‘bottom up’ estimate of these emissions in each of the three sub-regions. Arguably there may be other sectors where a similar approach would be of interest. However, we are confident that this captures the most important source of spatial variation in emissions as electricity generation accounts for 36% of total CO_2 emissions in Scotland. Furthermore, a comparable database, which would permit a bottom-up approach, does not exist for the emissions generation of other sectors.

In terms of the existing literature, McGregor et al. (2008) utilises national emissions-output coefficients for the UK for their model of the emissions flows between Scotland and the rest of the UK (RUK). That is, with the exception of the electricity sector which they argue deserves special attention given the important differences in the electricity generation mix in Scotland and RUK. Their approach is wholly consistent with the approach taken here, it is simply that instead of applying national sectoral emissions coefficients to a regional framework, we are applying regional sectoral emissions coefficients to a sub-regional model.

A more critical view is offered by Turner (2006) which looked at the use of sub-region specific emissions intensities as opposed to national level intensities for the States of Jersey and found important differences between top-down and bottom up derived coefficients. However, in that example UK national coefficients are being scaled down to a small island economy. As Turner (2006) concedes: “...Jersey is a particularly small and idiosyncratic economy...[and so] for other UK regions that are not quite so atypical, a partially region-specific approach that focuses on key areas where polluting technology is expected to deviate signicantly from the UK average may be more appropriate” (Turner 2006, 362).

4.2 Specification of emissions coefficients

Data from the Scottish Government’s Environmental Accounts are used to specify a vector of CO_2 emissions [10]. These separately identify the CO_2 emissions of 93 industrial sectors. For compatibility, both the 126 sector economic (IO) database, and the 93 sector environmental accounts, are aggregated to 67 sectors. Subsequently results are aggregated to 12 sectors for ease of exposition, as is illustrated in Table 3.

As CO_2 emissions are reported on a Scotland-wide basis, a top-down approach is used to assign this to the sectors in each sub-region. The emissions coefficient ω_i^S depicting the average generation of CO_2 emissions per unit of gross output in sector i for Scotland is obtained by diving CO_2 emissions by sectoral

[10] The environmental accounts are published as part of the Scottish National Accounts Project. The database used here, entitled ‘Greenhouse Gas Emissions by 93 Economic Sectors’, is available at: `http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/SNAP/expstats/EnvironmentalAccounts`

gross output so that $\omega_i^S = f_i^S/x_i$. For all sectors except electricity we assume that the emissions intensities for Scotland as a whole hold for the sub-regions, so that $\omega_i^S = \omega_i^G = \omega_i^W = \omega_i^R$.

The same approach is taken for direct household emissions, so that $\omega_{hh}^S = \omega_{hh}^G = \omega_{hh}^W = \omega_{hh}^R$. Attribution of direct household emissions therefore closely follows population across the three sub-regions. Given that household emissions are driven (via consumption) by household income, differences in household emissions between sub-regions, will be driven by differences in sub-regional household income.

Previous work (Glaeser & Kahn 2010, Weisz & Steinberger 2010) suggests that household emissions may be inversely related to population density, with households in more densely populated areas residing in smaller dwellings that require less heating fuels and supporting less transport emissions. It may therefore be the case that our top-down approach to estimating household emissions could be overstating household emissions in Glasgow. Drawing on data from Tables 2 and 5 in Glaeser & Kahn (2010) it is possible to calculate how big the difference is between households in the suburbs and the city centre, relative to the average of the metropolitan area. This reveals that based on 48 metropolitan statistical areas in the US, a suburban household is 6.7% more emissions intensive than the average for the metropolitan area as a whole. Applying this result is problematic as we do not know the composition of the city regions involved. However, this result suggests that the potential bias is of an order of magnitude that is unlikely to change the results qualitatively.

The emissions of the electricity sector in each sub-region are determined using a bottom up process. We draw on data from the Scottish Pollutant Release Inventory, managed by the Scottish Environmental Protection Agency. The dataset contains the CO_2 emissions of all electricity generating plants that emit in excess of a reporting threshold[11]. We use this database to assign the emissions associated with each electricity generation plant to each of the three sub-regions, using the postcode of the plant to identify which sub-region it is located in. The remaining emissions of this sector[12] are attributed to the three sub-regions using employment shares, as employment is likely to be a good indicator of the scale of non-generation activities in each sub-region.

[11] For details see: http://www.sepa.org.uk/air/process_industry_regulation/pollutant_release_inventory/reporting_thresholds.aspx

[12] The emissions attributable to this sector in the Scottish Environmental Accounts are greater than those reported in the Scottish Pollutant Release Inventory. Since we are seeking to disaggregate the Environmental Accounts total, we split out the residual volume of emissions (i.e. the emissions for the electricity sector from the environmental accounts minus the sum of the electricity generation plant emissions from the Scottish Pollutant Release Inventory) between the three sub-regions based on sectoral employment in the three sub-regions.

5 Results

We set out to look at the extent to which production emissions varies between sub-regions, differences in the emissions supported by final demand in each sub-region and the extent of inter-sub-region flows of emissions embodied in trade. This section presents the results of our analysis. In some cases, as noted earlier, data issues suggest these should be interpreted with caution. Nonetheless we believe the analyses highlight heterogeneity at the sub-regional level and underline the importance of understanding sub-regional emissions to inform the design of potential policies for emission reduction at a local level.

5.1 Direct production emissions generation

The emissions generated by each production sector, and directly by households, in each sub-region are detailed in Table 4. The energy sector is the most important emitter, accounting for more than a third (36%) of all emissions in Scotland. In all three sub-regions the four biggest emitters are Manufacturing, Energy, Transport & communication and household emissions. These account for 79%, 83% and 84% of all emissions in GLA, RST and ROS respectively. As is evident the industrial structure differs between the sub-regions and hence also the ranking of the most important emitters. For instance, energy accounts for 46% of ROS emissions, while its 17% in GLA and only 6% in RST. Conversely, households are by far the biggest emitter in RST (38%), while accounting for 26% and 18% of emissions in GLA and ROS, respectively.

Comparing the share of emissions (from Table 4) to the share of employment in each sub-region (from Table 1) suggests that economic activity in RST and GLA, in particular, is cleaner than in ROS. Specifically, Glasgow hosts 17% of Scotland's (FTEs) employment, but generates only 9% of Scottish emissions and RST has 24% of Scottish FTE jobs, and generates 18% of the emissions. Conversely, ROS produces 73% of emissions, but hosts 59% of Scottish FTE jobs. This is even more striking if we calculate the emissions-FTE ratio for each region using data from Table 1 and Table 4. While 15.4 tonnes of CO_2 are emitted per FTE job in GLA, this goes up to 21.9 in RST and 37.0 for ROS.

Given that employment shares were used to construct the disaggregated economic database, this outcome is the result of variation in the composition of economic activity between the sub-regions. Generally, as is evident from Table 4, service sectors are disproportionately represented in GLA and RST. However, more specifically, as a result of the bottom-up approach for disaggregating the emissions from the electricity sector, these are overwhelmingly attributed to ROS. Had this approach not been used, we would have expected greater similarity between employment shares and emissions shares. Indeed, if we leave the emissions from energy aside, the range of emissions per job becomes more concentrated, with 12.8 tonnes of CO_2 per FTE in GLA, 20.6 in RST and 20.0 in ROS.

5.2 Emissions supported by final demand & emissions embodied in trade

Table 5 details the attribution of emissions to final demand in each sub-region. An important result to note is that each of the sub-regions generates a large volume of emissions to meet export demand (either RUK or ROW); 39% of GLA emissions are supported by RUK and ROW demands compared to 49% in RST and 58% in ROS. This is in line with previous findings from work on national and regional emissions and highlights the question whether the abatement of these emissions should be undertaken in Scotland (a territorial view), or by the destination country for these exports (the consumption accounting principle (CAP) view) [13].

The focus here is on the sub-regional corollary, i.e. to what extent emissions spill over the sub-regional boundaries. This occurs in two stages. First, final demand from a particular sub-region can be met by output produced in another. Second, production in one sub-region can support emissions elsewhere indirectly through purchases of intermediate inputs. The accounting framework captures the interregional flows of household demand and therefore permits an analysis of how the demands of households in one sub-region, require the generation of emissions in another[14]. Table 5 details the results from this analysis, and shows that Glasgow based households, through their consumption, support the generation of 412,500 tonnes of CO_2 locally (or 12% of the total production emissions in Glasgow), 70,923 tonnes of CO_2 in the rest of Strathclyde and 816,104 tonnes of CO_2 in the rest of Scotland. The subsequent rows show equivalent results for the rest of Strathclyde and the rest of Scotland.

This interaction can be summarised in terms of a household emissions trade balance. Using data from Table 5 we calculate the emissions embodied in exports (to households) to each of the other two sub-regions minus the emissions embodied in imports (by households) from the other two sub-regions. For Glasgow this shows that it runs a trade surplus in these emissions with the RST on the order of nearly 300,000 tonnes of CO_2[15]. That is, RST household consumption depends on GLA production activity (and hence emissions) more than GLA households depend upon RST production activity, to meet their consumption needs. Conversely GLA runs a significant trade deficit in emissions with the ROS. This is driven by GLA households consumption of electricity, largely produced in ROS. Similarly the RST sub-region runs a large

[13] This is an issue that is relatively well understood in the literature (commencing with Munksgaard & Pedersen (2001)) and obviously needs to be considered when formulating policy.

[14] However, government final demand is attributed to the sub-region where the expenditures take places as set out in the sub-regional government accounts.

[15] The calculation here being: Emissions embodied in GLAs exports to RST households (369,790 T CO_2) minus emissions embodied in RSTs exports to GLA households (70,923 T CO_2).

deficit in emissions with ROS.

It should be cautioned that, as detailed in Section 4, due to assumptions made to overcome data limitations in the construction of the database, the 'basket of goods and services' consumed by households in each sub-region is taken to be the same and only the *level* of household consumption varies. To the extent that we believe that this consumption pattern is similar across sub-regions this is a reasonable approximation. However this becomes more problematic if we think households consume a very different mix of goods and services in different parts of the country. As discussed in Section 4.2, there is evidence to suggest that for a given income level household emissions tend to decrease with population density, as increased reliance on public transport is offset by smaller dwellings and less use of private transport. Whether, in aggregate, this is likely to make a significant difference to the results is something we are unable to assess with available data[16].

6 Conclusions

There is significant academic and policy interest in implementing policies to reduce greenhouse gas emissions at a local level, such as individual cities or council areas. An obvious outlet for this interest is through planning policies, but more radical policies such as for a local level emissions cap have also been proposed. As is well understood in the literature on interregional, and in particular, international greenhouse gas policies, the effectiveness of unilateral action can be elusive due to the significant share of emissions embodied in trade. At a more practical level it is difficult to attribute emissions to individual cities or sub-regions. Bottom up approaches have provided useful insights into how emissions vary between individual cities in aggregate, but suffer from incompleteness and boundary issues. Top down accounting approaches offer a detailed and comprehensive view and have been implemented successfully for regions and nations. However, due to data limitations little attention has been paid to scaling these approaches down to a sub-regional level.

This paper presents a 3-regions emissions extended input-output framework for a central city and its wider city-region nested within a regional economy. A top-down approach is used to disaggregate regional emissions extended input-output accounts for Scotland, to separately identify the City of Glasgow, the rest of the Strathclyde region and the rest of Scotland. This is augmented with bottom-up data on emissions from electricity generation, an activity that produces more than a third of Scotland's emissions. The accounting

[16]However, in qualitative terms, given the urban nature of Glasgow the approach is likely to overstate the emissions of its households. Furthermore given that ROS is the largest sub region (recall that it represents 59% of employment in Scotland) the Scotland wide average is likely to best approximate its households. Therefore, from an accounting point of view, household emissions in RST are likely to be underestimated, in order for the identity to balance.

framework is used to attribute CO_2 emissions to each sub-region and explore emissions interdependencies both within the city region area and between the city region and its host regional economy.

We find that produced emissions vary with the composition of economic activity, which in turn is influenced by the functional specialisation between different sub-regions. For instance, despite its high job density Glasgow's economy is the cleanest of the three sub-regions as business services and the public sector are disproportionately represented. Similarly Glasgow is aided by its relatively small population as a large share of the working population commutes into the city, leaving its direct household emissions outside the city boundaries. However, in terms of emissions, this general economic geography is arguably of a second order importance relative to the location of electricity generation. This is predominantly located outside the Glasgow metropolitan area. As a result each job in the rest of Scotland is about 150% more emissions intensive than those in Glasgow. If the role of electricity is ignored this difference is reduced to 50%.

Of course not all the emissions are produced to satisfy local demand. Taking a consumption accounting perspective reveals that within the city region Glasgow runs a trade surplus in emissions with the rest of the Strathclyde region. However, examining the city region as a whole, it relies on emissions intensive activity in the rest of Scotland and runs a trade deficit in terms of emissions. Therefore it is not surprising that on per capita basis produced emissions vary significantly between the sub-regions, but once a consumption perspective has been adopted this largely evens out. However, we would caution against taking our results as indication that only the level of consumption matters for emissions. Due to data limitations the accounting framework rests on assumptions of uniform technology and consumption patterns across the sub-regions. This inevitably acts to even out potential variation between the sub-regions. In particular with regard to household emissions.

The results of our attribution analysis show that territorially based emissions are skewed by economic structure and composition. This needs to be considered when local level emissions policies are formulated. For example, local carbon targets based on territorial emissions generation would disproportionately impact areas where emissions intensive activity is concentrated. This approach would lead to a spatially unbalanced burden of adjustment towards the targeted level of emissions, i.e. more of the abatement would fall on areas of higher emissions intensities and less on areas of low emissions intensities. A consumption based accounting approach, in contrast, would lead to a more equal attribution of CO_2 emissions between sub-regions; since consumption behaviour between sub-regions is more homogeneous than production activities between sub-regions. In addition, this would address the difficulties created by electricity generation plant being located in one area, but generating electricity which is sold onto, in this case, a national grid.

For future work it would be desirable to revisit the construction of the database in an attempt to relax the assumption of regional homogeneity in terms of the emissions intensity of particular sectors. To this end, data collection efforts should be prioritised towards the relatively few sectors that generate the most emissions. Similarly for households, it would be useful to augment the current database with local consumption data, in particular with regard to home energy use and reliance on public and private transport.

A 3-region interregional emissions augmented IO-model

Our starting point is the standard Leontief model (see Leontief (1970), Miller & Blair (2009)):

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{A.1}$$

The matrix $(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse. For an economy of N sectors, this is used to calculate the $N \times 1$ vector of gross outputs, $\mathbf{x}$, (with elements x_i, where $i = 1, ..., N,$) from the the $N \times 1$ vector of final demands $\mathbf{y}$ with elements y_i. Each element of the Leontief inverse, α_{ij}, measures the direct, indirect (and where appropriate induced) impact on sector i of a unit increase in the final demand for sector j. These are effectively sector-to-sector multipliers. The value of m_j, the output multiplier for sector j, is found as the sum of the elements of the j^{th} column of the Leontief inverse. This is a sector-to-economy multiplier, that relates final demand in sector j to economy-wide output.

$$m_j = \sum_i \alpha_{ij} \tag{A.2}$$

This basic approach can be augmented to link the exogenous elements for demand to the emissions generated in the production of output (see Turner et al. (2007), Miller & Blair (2009, ch. 10)). Total greenhouse gas generation in production is determined as:

$$\mathbf{f}^x = \mathbf{\Omega^x x} \tag{A.3}$$

where $\mathbf{f}^x$ is a $K \times 1$ vector, with elements f_k^x, where $k = 1, \ldots, K$, representing the total greenhouse gases K generated by all production activities in the economy. $\mathbf{\Omega}^x$ is a $K \times N$ matrix where element $\omega_{k,i}$ is the average generation of emissions k per unit of gross output in sector i. Then the standard Leontief model (Leontief, 1970; Miller & Blair, 2009) can be employed so that it is extended to

$$\mathbf{f} = \mathbf{\Omega}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{A.4}$$

where $\mathbf{f}$ is a $K \times 1$ vector, with element f_k, being the total generation of emissions directly or indirectly required to satisfy total final demand, $\mathbf{y}$, in the economy. In our case final demanders (households) also directly generate emissions (for instance by combusting fuels and driving cars) and hence A.4 is extended for final demand as

$$\mathbf{f}^* = \mathbf{\Omega}^x(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} + \mathbf{\Omega}^y\mathbf{y} \tag{A.5}$$

where we distinguish the $K \times N$ matrix of emission coefficients for the N production sectors $\mathbf{\Omega}^x$, from a $K \times 1$ matrix, $\mathbf{\Omega}^y$, where each $K \times 1$ column within has elements ω_k^y as the average direct emissions of type k per unit of final demand.

The single region model is useful for demonstrating the principle of emissions extended IO. However, for our application we want to develop a 3-region emissions extended IO-model to fit our database. This is the emissions extended version of the 3-region model set out in (Hermannsson 2013). For examples of interregional environmentally extended IO-models, see Wiedmann et al. (2007) and Miller & Blair (2009, ch. 10).

In Eq. A.1 we identified the key equation determining the $N \times 1$ vector of output $\mathbf{x}$ in the single region IO framework. We want to extend this to 3-regions, using superscripts to indicate the spatial origin and destination of the matrix elements, with G representing Glasgow, W the rest of the Strathclyde region and S the rest of Scotland. We begin by partitioning the Leontief inverse so as to obtain not only a multiplier pertaining to the Scotland-wide impact of a particular sector, but to decompose the multiplier effect by the region of impact.

$$\left\{ \begin{bmatrix} \mathbf{I} & 0 & 0 \\ 0 & \mathbf{I} & 0 \\ 0 & 0 & \mathbf{I} \end{bmatrix} - \begin{bmatrix} \mathbf{A}^{GG} & \mathbf{A}^{GW} & \mathbf{A}^{GS} \\ \mathbf{A}^{WG} & \mathbf{A}^{WW} & \mathbf{A}^{WS} \\ \mathbf{A}^{SG} & \mathbf{A}^{SW} & \mathbf{A}^{SS} \end{bmatrix} \right\}^{-1} = \begin{bmatrix} \mathbf{M}^{GG} & \mathbf{M}^{GW} & \mathbf{M}^{GS} \\ \mathbf{M}^{WG} & \mathbf{M}^{WW} & \mathbf{M}^{WS} \\ \mathbf{M}^{SG} & \mathbf{M}^{SW} & \mathbf{M}^{SS} \end{bmatrix} \tag{A.6}$$

The sub-matrices $\mathbf{M}$ contain the elements α_{ij}^{RS}, the inter-industry multiplier. As before these matrix elements describe the impact of a change in the final demand for sector j upon sector i, but in the interregional variant sector j is located in region S and sector i in region R. If region R is the same as S, such as in the matrices on the diagonal $\mathbf{M}^{GG}, \mathbf{M}^{GG}$ and $\mathbf{M}^{SS}$, we have an intra-regional effect, where R and S are not the same the multipliers describe interregional effects. For example the sector by sector multipliers contained in the sub-matrix $\mathbf{M}^{GS}$ describe the impact of sector j in the rest of Scotland upon sector i in Glasgow.

Furthermore, we separate the final demand ($\mathbf{y}$) into local final demand for locally produced commodities and export demand from other regions for commodities, so that we obtain vectors of output $\mathbf{x}$, denoting the region where it is incurred and spatial origin of the final demand that supports it.

$$\begin{bmatrix} \mathbf{x}^{GG} & \mathbf{x}^{GW} & \mathbf{x}^{GS} \\ \mathbf{x}^{WG} & \mathbf{x}^{WW} & \mathbf{x}^{WS} \\ \mathbf{x}^{SG} & \mathbf{x}^{SW} & \mathbf{x}^{SS} \end{bmatrix} = \begin{bmatrix} \mathbf{M}^{GG} & \mathbf{M}^{GW} & \mathbf{M}^{GS} \\ \mathbf{M}^{WG} & \mathbf{M}^{WW} & \mathbf{M}^{WS} \\ \mathbf{M}^{SG} & \mathbf{M}^{SW} & \mathbf{M}^{SS} \end{bmatrix} \begin{bmatrix} \mathbf{y}^{GG} & \mathbf{y}^{GW} & \mathbf{y}^{GS} \\ \mathbf{y}^{WG} & \mathbf{y}^{WW} & \mathbf{y}^{WS} \\ \mathbf{y}^{SG} & \mathbf{y}^{SW} & \mathbf{y}^{SS} \end{bmatrix} \tag{A.7}$$

For this application we are interested in the emissions generated by the production of output in each of the 3 regions. Just as we extended the single region framework to include emissions, we can introduce a $(3K \times 3N)$ matrix of coefficients $\mathbf{\Omega}_x^R$ showing the emissions intensity of output in each production sector, in each region.

$$\begin{bmatrix} \mathbf{f}^{GG} & \mathbf{f}^{GW} & \mathbf{f}^{GS} \\ \mathbf{f}^{WG} & \mathbf{f}^{WW} & \mathbf{f}^{WS} \\ \mathbf{f}^{SG} & \mathbf{f}^{SW} & \mathbf{f}^{SS} \end{bmatrix} = \begin{bmatrix} \mathbf{\Omega}_x^G & 0 & 0 \\ 0 & \mathbf{\Omega}_x^W & 0 \\ 0 & 0 & \mathbf{\Omega}_x^S \end{bmatrix} \begin{bmatrix} \mathbf{M}^{GG} & \mathbf{M}^{GW} & \mathbf{M}^{GS} \\ \mathbf{M}^{WG} & \mathbf{M}^{WW} & \mathbf{M}^{WS} \\ \mathbf{M}^{SG} & \mathbf{M}^{SW} & \mathbf{M}^{SS} \end{bmatrix} \begin{bmatrix} \mathbf{y}^{GG} & \mathbf{y}^{GW} & \mathbf{y}^{GS} \\ \mathbf{y}^{WG} & \mathbf{y}^{WW} & \mathbf{y}^{WS} \\ \mathbf{y}^{SG} & \mathbf{y}^{SW} & \mathbf{y}^{SS} \end{bmatrix} \tag{A.8}$$

Similarly, we can calculate the emissions generated directly by final demand:

$$\begin{bmatrix} \mathbf{f}_y^{GG} & \mathbf{f}_y^{GW} & \mathbf{f}_y^{GS} \\ \mathbf{f}_y^{WG} & \mathbf{f}_y^{WW} & \mathbf{f}_y^{WS} \\ \mathbf{f}_y^{SG} & \mathbf{f}_y^{SW} & \mathbf{f}_y^{SS} \end{bmatrix} = \begin{bmatrix} \mathbf{\Omega}_y^G & 0 & 0 \\ 0 & \mathbf{\Omega}_y^W & 0 \\ 0 & 0 & \mathbf{\Omega}_y^S \end{bmatrix} \begin{bmatrix} \mathbf{y}^{G} & 0 & 0 \\ 0 & \mathbf{y}^{W} & 0 \\ 0 & 0 & \mathbf{y}^{S} \end{bmatrix} \tag{A.9}$$

These can then be added up to obtain total emissions, composed of emissions in production sectors and direct emissions by final demand:

$$\begin{bmatrix} \mathbf{f}_*^{GG} & \mathbf{f}_*^{GW} & \mathbf{f}_*^{GS} \\ \mathbf{f}_*^{WG} & \mathbf{f}_*^{WW} & \mathbf{f}_*^{WS} \\ \mathbf{f}_*^{SG} & \mathbf{f}_*^{SW} & \mathbf{f}_*^{SS} \end{bmatrix} = \begin{bmatrix} \mathbf{f}^{GG} & \mathbf{f}^{GW} & \mathbf{f}^{GS} \\ \mathbf{f}^{WG} & \mathbf{f}^{WW} & \mathbf{f}^{WS} \\ \mathbf{f}^{SG} & \mathbf{f}^{SW} & \mathbf{f}^{SS} \end{bmatrix} + \begin{bmatrix} \mathbf{f}_y^{GG} & \mathbf{f}_y^{GW} & \mathbf{f}_y^{GS} \\ \mathbf{f}_y^{WG} & \mathbf{f}_y^{WW} & \mathbf{f}_y^{WS} \\ \mathbf{f}_y^{SG} & \mathbf{f}_y^{SW} & \mathbf{f}_y^{SS} \end{bmatrix} \tag{A.10}$$

Since the analysis only involves one of the K greenhouse gases we adopt a less general version of this model in equations 1 and 2 presented in Section 4.

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Table 1: Key social and economic indicators for each IO-region in 2006.

		GLA	RST	ROS	SCO
Population		580,690	1,555,374	2,980,836	5,116,900
	% of total	11%	30%	58%	100%
Employment	FTEs	313,535	448,296	1,089,529	1,851,360
	% of total	17%	24%	59%	100%
Gross Domestic Household Income Per Head		11,968	12,975	13,319	13,071
	% of average	92%	99%	102%	100%

Table 2: Origins and destinations of people who travel between Scottish addresses for work/study (headcount/column %). Own calculations, based on Fleming (2006, Table 16A, pp. 64-65).

		Place of work							
		GLA		RST		ROS		SCO	
Residence	GLA	184,245	59%	26,823	6%	3,162	0%	214,231	12%
	RST	124,842	40%	417,832	93%	10,839	1%	553,514	30%
	ROS	4,447	1%	3,641	1%	1,075,528	99%	1,083,616	59%
		313,535	100%	448,296	100%	1,089,529	100%	1,851,360	100%

Table 3: Sectoral aggregation scheme

Env Acc Code	123 sector IO code	12 sector	12 Sector name
1-3	1-3	1	Agriculture, forestry & fishing
4-7	4-7	2	Mining
8-50	8-84	3	Manufacturing
51-55	85	4	Energy
56-57	86-87	5	Other utilities
58	88	6	Construction
59-62	89-92	7	Distribution & catering
63-72	93-99	8	Transport & communication
73-80	100-114	9	Finance & business
81-82	115	10	Public administration, etc.
83-84	116-118	11	Education, health & social work
85-91	119-123	12	Other services

Table 4: Directly generated CO_2 emissions by sector, by household, and sub-region totals (Tonnes)

Emitting sector	**GLA**			**RST**			**ROS**			**National total**		
	CO_2 tonnes	% of GLA emissions generation	% of sector	CO_2 tonnes	% of RST emissions generation	% of sector	CO_2 tonnes	% of ROS emissions generation	% of sector	CO_2 tonnes	% of Scotland emissions generation	% of sector
Agriculture, forestry & fishing	47,035	1	5	249,022	3	25	685,732	2	70	981,789	2	100
Mining	30,991	1	1	202,164	2	8	2,288,181	6	91	2,521,336	5	100
Manufacturing	658,400	14	9	2,070,813	21	27	4,931,068	12	64	7,660,282	14	100
Energy	830,537	17	4	587,119	6	3	18,521,774	46	93	19,939,430	36	100
Other utilities	91,820	2	14	38,022	0	6	528,038	1	80	657,880	1	100
Construction	142,116	3	13	320,827	3	29	662,556	2	59	1,125,499	2	100
Distribution & catering	210,132	4	15	341,479	3	25	841,723	2	60	1,393,334	3	100
Transport & communication	1,047,914	22	18	1,741,004	18	30	3,080,100	8	52	5,869,019	11	100
Finance & business	133,490	3	24	91,848	1	17	322,321	1	59	547,660	1	100
Public administration	170,180	4	19	220,258	2	25	486,353	1	55	876,791	2	100
Educ., health & social work	108,142	2	18	146,626	1	24	361,601	1	59	616,369	1	100
Other services	81,136	2	17	117,452	1	24	287,829	1	59	486,418	1	100
Total emissions from production sectors	**3,551,894**	74		**6,126,636**	62		**32,997,277**	82		**42,675,807**	78	
Direct household emissions	1,278,047	26		3,710,925	38		7,310,045	18		12,299,018	22	
Total emissions	**4,829,941**	100		**9,837,561**	100		**40,307,322**	100		**54,974,824**	100	
Share of total Scottish emissions	*9*			*18*			*73*			*100*		

Table 5: CO_2 emissions (Tonnes) from production as supported by Final Demand, by sub-region of generation

	Where the emissions are generated						
	Glasgow	% of total emissions generated	**RST**	% of total emissions generated	**ROS**	% of total emissions generated	**Total**
Households GLA	412,500	11.6%	70,923	1.2%	816,104	2.5%	1,299,527
Households RST	369,790	10.4%	1,035,839	16.9%	2,380,740	7.2%	3,786,369
Households ROS	496,595	14.0%	517,242	8.4%	6,527,099	19.8%	7,540,937
NPISHs[a]	37,899	1.1%	55,423	0.9%	172,889	0.5%	266,211
Non-Resident Household Expenditure[b]	62,017	1.7%	91,363	1.5%	261,820	0.8%	415,201
Central Government	350,394	9.9%	464,532	7.6%	1,313,902	4.0%	2,128,827
Local Government	185,672	5.2%	259,147	4.2%	734,595	2.2%	1,179,414
Capital[c]	259,747	7.3%	597,867	9.8%	1,474,756	4.5%	2,332,370
Rest of UK Exports	991,119	27.9%	1,958,540	32.0%	14,654,369	44.4%	17,604,028
Rest of World Exports	386,160	10.9%	1,075,760	17.6%	4,661,003	14.1%	6,122,923
Total emissions in each sub-region	3,551,894	100%	6,126,636	100%	32,997,277	100%	42,675,807

[a]Non-profit institutions serving households.
[b]This can be thought of as tourist spending, or more generally expenditure by non-residents.
[c]Gross fixed capital formation, Valuables, and Inventory Changes

Figure 1: 3 Sub-Region Map of Scotland

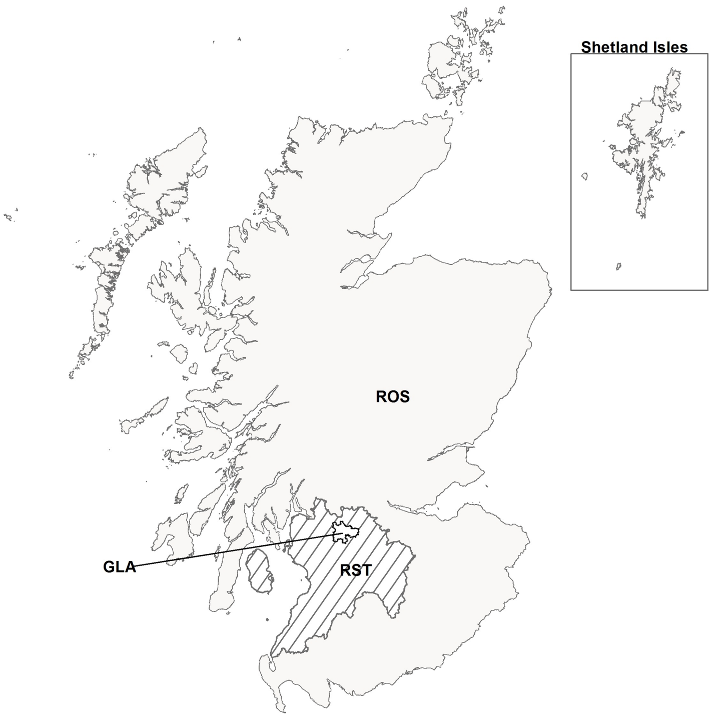

Figure 2: Demarcation of spatial zones in the GLA-RST-ROS IO-tables.

IO region		NUTS 2 Region	NUTS 3 Regions
Scotland (SCO)	GLA	South Western Scotland	Glasgow
	RST		East Dunbartonshire, West Dunbartonshire, and Helensburgh and Lomond; East and North Ayrshire mainland; Inverclyde, East Renfrewshire, and Renfrewshire; North Lanarkshire; South Ayrshire; South Lanarkshire
	ROS		Dumfries and Galloway
		Eastern Scotland	Angus and Dundee; Clackmannanshire and Fife; East Lothian and Midlothian; Scottish Borders; Edinburgh; Falkirk; Perth and Kinross, and Stirling; West Lothian
		North Eastern Scotland	Aberdeen and Aberdeenshire
		Highlands and Islands	Caithness and Sutherland, and Ross and Cromarty; Inverness, Nairn, Moray, and Badenoch and Strathspey; Lochaber, Skye and Lochalsh, Arran and Cumbrae, and Argyll and Bute; Eilean Siar (Western Isles); Orkney Islands; Shetland Islands

Figure 3: Single region IO-table for Scotland

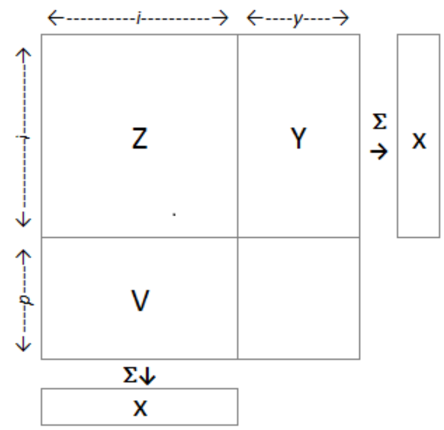

Figure 4: Interregional input-output table for three sub-regions (r = 3)