Responsibility for regional waste generation: A single region extended input-output with uni-directional trade flows

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Abstract. This paper uses a regional input-output framework and data derived on waste generation by industry to examine different aspects of regional waste accountability. In addition to estimating a series of industry output-waste coefficients, the paper considers a series of methods for waste attribution from production and consumption perspectives. In particular, it considers a method that permits a greater focus on regional (private and public) final consumption as the main exogenous driver of waste generation. In doing so, it uses a domestic technology assumption to consider a regional waste footprint where local consumption requirements are assumed to be met using production technologies over which regional authorities are likely to have more control.

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Key words: waste attribution; regional economy; input-output analysis; Wales
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Introduction

This paper uses a regional input-output framework, together with survey data on waste generation by industry, to examine regional waste attribution. In addition to estimating a series of industry direct output-waste coefficients, the paper considers a series of methods for waste attribution and the usefulness of these different methods for policymakers. As interest may lie in the assessment of the total waste burden implied by regional consumption, this paper specifically considers the development of an accounting method that permits a greater focus on regional (private and public) final consumption as the main exogenous driver of domestic waste creation. An accounting technique is considered that involves estimating the waste burden imposed by total use of commodities in the region under a domestic technology assumption. This method gives a hypothetical waste footprint, measuring what domestic waste generation under a consumption accounting principle (MUNKSGAARD and PEDERSEN, 2001) would be if regional consumption demands were met through production methods that employ domestic technology. We argue that this method provides a useful tool for understanding the regional waste attribution problem (with particular focus on the implications of trade), as well as an additional, more consumption-orientated, perspective for regional policymakers. These methods allow regional policymakers to focus on production and consumption behaviours over which they have more control and understanding. Moreover, the tool employs data that are readily available at the regional level.

As a case study, this paper focuses on Wales, a region of the United Kingdom. One focus of the regional environmental strategy and resulting policies in Wales has been the waste generated in the Welsh economy. For example, adopted headline indicators of sustainability include levels of household waste and amounts of waste recycled (see

MUNDAY and ROBERTS, 2006). Moreover, waste indicators link closely to other headline indicators that focus on air and water quality and climate change. The increasing burden that waste places on environmental assets, and the future services from those same assets, has also been acknowledged (see WELSH ASSEMBLY GOVERNMENT, 2009a). Waste strategy for the region is now focused on decreasing the volume of household waste, increasing the volume of waste recycled and composted, and increasing commercial, industrial, and construction waste recycling. Indeed, a recent report for the Welsh Assembly Government noted that "waste generation from consumption-based activities (manifested primarily as household waste) contributes 15% of Wales' ecological footprint" (ARUP, 2008).

There has been progress in the region towards waste reduction. For example, household waste per person fell by nearly 4% between 2004 and 2007, along with increases in reported recycling rates. However, this was not necessarily evidence of any decoupling of growth and waste generation as economic growth faltered in this period. Furthermore, there is evidence of reductions in both commercial and industrial waste generation over the last decade (see FRATER and HINES, 2004; URBAN MINES, 2009). Currently, Wales is moving towards a new waste strategy in 2010 (WELSH ASSEMBLY GOVERNMENT, 2009a). The processes of reflection and extensive consultation undertaken in the region in 2008-09 represented a time to consider the issue of who creates waste in Wales, and how one understands where the ultimate responsibility for this waste generation lies.

The explicit policy concern in Wales appears to be in terms of a production principle approach (MUNKSGAARD and PEDERSEN, 2001), this tying to the Welsh Assembly Government's direct jurisdiction. This is evidenced in part through the indicator set used to monitor progress towards waste-related targets, where the emphasis is on waste generated in Wales, and speaks to quantities of municipal, industrial, and commercial wastes and the proportions recycled and landfilled in the region (see WELSH ASSEMBLY GOVERNMENT, 2009a, 2009b). However, the wider sustainable development duty speaks to more global responsibilities with a vision that "Wales demonstrates the contribution a small, developed nation can make to global sustainable development and environmental improvement" (WELSH ASSEMBLY GOVERNMENT, 2009b, pp.2-3). This wider duty is largely responsible for the uptake of the ecological footprint measure as one headline, overarching sustainable development indicator (MUNDAY and ROBERTS, 2006).

Thus, as well as accounting for waste under production accounting principles (waste generated within the region), there is a need for the region to consider how consumption activity within its borders creates impacts outside the region, i.e. the impacts of trade on waste generation both domestically and abroad. However, this raises the issue of how such analyses can be carried out, particularly where currently available data and analytical tools may only provide an indication of the region's waste footprint.

More generally, this paper addresses issues raised by MUNDAY and ROBERTS (2006) who argued that the strategic drive towards implementation of sustainable development objectives in UK regions have, in some cases, not been matched by the development of approaches to monitor and evaluate progress. Thus, and in the specific context of devolved regional government, it would seem that there is real potential for an economic-environmental accounting and modelling framework to fill this analytical gap (see also McGREGOR et al., 2001, 2008). This is particularly relevant in the case of waste, where at the regional level there are challenges in linking waste generation to different types of industrial activity and to regional consumption.

The remainder of this paper is structured as follows: the second section briefly revisits how industry externalities, such as pollution and waste, are dealt with in an input-output framework and formally describes different attribution approaches. In particular, the section demonstrates the dangers of focusing on simplistic industry output-waste coefficients (direct waste intensities) when exploring waste attribution, and introduces measures that permit a focus on regional (private and public) final consumption as a driver of waste generation. The third section describes the Welsh input-output framework and the nature of the waste data used in conjunction with this framework. The fourth section reports the results of the analysis, focusing on the consumption categories that are highlighted under the selected attribution approaches. The final section concludes by discussing how the analysis provides useful information for regional policy development on waste, its abatement, and how data might be improved to develop the research theme.

Alternative 'treatments' of waste in input-output frameworks

In this section, we highlight different approaches to waste attribution using an input-output framework. It should be noted that input-output frameworks form the basis for many different types of waste analysis. For example, NAKAMURA and KONDO (2009) detail a waste input-output (WIO) framework, which first appears in NAKAMURA (1999) and is applied to the Japanese economy and waste cycles. This WIO framework forms the basis for many different types of analyses: see NAKAMURA and KONDO (2002) for an analysis of different waste management methods and strategies; TAKASE et al. (2005) and KONDO and TAKASE (2007) for analyses related to sustainable consumption; and TSUKUI (2007) for an analysis of waste emissions. There have also been numerous contributions linking the WIO model to other modelling frameworks in attempts to capture additional waste-economy-environment relationships: see KONDO and NAKAMURA (2005) for application of a WIO linear programming model; and NAKAMURA and KONDO (2002) and NAKAMURA et al. (2006) for applications of WIO materials flow analyses.

Where the WIO framework and its extensions aim to incorporate waste and waste management into the input-output framework, our paper adopts a different approach, closer in similarity to a satellite-accounts approach. Our focus is not to follow waste and its associated activities through the economy, but rather to answer questions related to a regional inventory of waste and the ways in which it can be attributed to different industrial sectors and final consumption groups. In what follows, we begin with an explanation of the basic LEONTIEF (1970) environmental input-output model (originally linked to pollution abatement) before moving to consider different means of waste attribution under production and consumption accounting principles.

'Conventional' approaches

In LEONTIEF's (1970) basic demand driven input-output framework, the vector of total output produced in each sector of the economy, **x**, is determined as the product of the Leontief inverse (multiplier) matrix, $[\mathbf{I}-\mathbf{A}]^{-1}$, where **A** is the input-output coefficients matrix and **I** is an identity matrix of corresponding size, and the vector of total final demands for sectoral outputs, **y**. This is extended for waste generation as follows (bold font upper case denotes matrices; bold font lower case denotes vectors, and non-bold lower case implies a scalar):

(1) $\mathbf{w} = \mathbf{\Omega}^{\mathbf{P}}[\mathbf{I}-\mathbf{A}]^{-1}\mathbf{y}$

Where there are i=j=1,…, N industries and commodities (here, N=74), $\mathbf{\Omega}^{\mathbf{P}}$ is a KxN matrix of direct output-waste coefficients with elements $\omega_{ki}=w_{ki}/X_i$, where w_{ki} is the physical amount of waste type k generated by each production sector i in producing its output, X_i. Here, K=1 for one type of waste, so the vector $\boldsymbol{\omega}^{\mathbf{P}}$ replaces $\mathbf{\Omega}^{\mathbf{P}}$ in (1) and the vector $\boldsymbol{\omega}^{\mathbf{P}}[\mathbf{I}-\mathbf{A}]^{-1}$ is a 1xN vector of output-waste multipliers, which represents the total amount of waste generated in production (across all N production sectors) to meet one unit of final demand for sectoral output j.

There are z=1,..., Z final consumption groups (here, in the Type I case, Z=4: Welsh households, government and capital formation, as well as export demands). Where waste is directly generated by final consumers (e.g. households), with a single waste output, one defines $\boldsymbol{\omega}^{\mathbf{C}}$ as a 1xZ vector of direct waste-final expenditure coefficients with elements

$\omega_z = w_z/y_z$, where w_z is the physical amount of waste generated by each final consumption group, z, in consuming goods and services in the process of its total final expenditure, y_z. The Zx1 vector of total final expenditures for each type of final consumption group (transposed row of column totals from the input-output tables) is distinguished from the Nx1 vector, **y**, as **y***. Thus, the total amount of waste generated in the region to meet final consumption demand, w^R, is calculated by extending equation (1) as follows:

(2) $$w^R = \boldsymbol{\omega}^{\mathbf{P}}[\mathbf{I} - \mathbf{A}]^{-1}\mathbf{y} + \boldsymbol{\omega}^{\mathbf{C}}\mathbf{y}^*$$

For a standard Type I input-output analysis, the N industries and Z final consumers are defined as in the input-output accounts. This allows an analysis to capture the direct and also indirect output and waste effects of backward supply linkages between local production sectors.

With no *changes* in final demand, the system in (2) provides the same figure for w^R as one would get from an analysis using the direct waste intensities of each activity:

(3) $$w^R = \boldsymbol{\omega}^{\mathbf{P}}\mathbf{x} + \boldsymbol{\omega}^{\mathbf{C}}\mathbf{y}^*$$

Consequently, (2) simply attributes waste generated in the regional economy (during a single time period) to demand for regional outputs rather than the production of those outputs, as in (3). The approach in (2) is analogous to the attribution of total regional output, **x**, to final consumption demand for this output, **y**, in the basic demand-driven input-output system. This is an important distinction. The approach in (3) is entirely focussed on what MUNKSGAARD and PEDERSEN (2001) term the ‘production accounting principle’ (PAP). However, the approach in (2) takes account of which types of final consumers are driving waste generation activity in the local economy. In a closed economy, (2) equates to an analysis under the consumption accounting principle (CAP) (MUNKSGAARD and PEDERSEN, 2001), or a waste footprint. The issue of economic openness and trade is considered below.

The key features of the standard direct and Type I environmental input-output approaches, which have been applied here to the case of physical waste generation, are identified in Table 1. The conventional Type I attribution technique is useful in considering the structure of pollution/waste problems in the regional economy and allows us to consider the types of final consumption activities that drive waste generation using both the consumption and production driven principles. The Type II attribution technique, which also captures induced consumption and income effects, is less commonly applied in an environmental input-output context. This is most likely due to the fact that Type II involves removing local private consumption (i.e. household demand) as an explicit exogenous driver of pollution generation. This is inconsistent with the commonly held view that human consumption decisions lie at the heart of environmental problems.

However, there are also two key problems with the conventional single region Type I approach in an environmental context. First, in an attribution analysis based on Type I multipliers, responsibility for pollution or waste generation is partly attributed to external sources of final demand (exports). This is especially the case in small open regional economies such as Wales. The second problem concerns imports, the waste implications of which do not enter into the calculation in equation (2) (or the direct calculation in equation (3)).

<Table 1 about here>

Open economy attribution under a domestic technology assumption (DTA)

Input-output methods can also be (and increasingly are being) employed to calculate footprint-type indicators (see TURNER et al., 2007 and WIEDMANN et al., 2007) that consider the pollution content of exports and imports and retain local private and public consumption demands as exogenous drivers of regional pollution.

Two potential alternative methods are identified in Table 1. Taking the last, and perhaps most obvious one, first, if one is concerned with total waste generated around the world to support regional consumption, one ideally requires the estimation of a full regional waste footprint. TURNER et al. (2007) explain how this can be done using an interregional IO framework (as opposed to the single region framework currently available for Wales). They also discuss the considerable data requirements of a full footprint calculation (also see Table 1 above). McGREGOR et al. (2008) attempt a partial application of the approach explained in TURNER et al. (2007). They focus on applying the CAP for the case of interregional trade between Scotland and the rest of the UK, but close the system at the national (UK) level under the PAP.[1]

As noted above, there are also issues relating to jurisdiction when using footprint analyses for policy analysis; Wales, for example, does not have any authority over production technology used or consumption decisions made in other countries. However, there may be a desire to take responsibility for the full waste implications of consumption decisions within Wales, including the waste embodied in imports. Therefore, an alternative approach may be to consider the question: what if the goods and services that Wales chooses to consume were produced using Welsh technology? That is, what would the regional waste footprint be if domestic technology decisions determined the waste content of all the goods and services consumed in the region?

This question can be approached using what is referred to as a 'domestic technology assumption', referred to here as the DTA (see also, DRUCKMAN et al., 2008 and

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[1] McGregor et al. (2008) close their system at the national level using what they refer to as a Trade Endogenised Linear Attribution System (TELAS). This allows examination of the domestic pollution implications of importing goods and services, though not the actual pollution supported in source countries. We consider the contribution of the TELAS approach alongside the DTA approach introduced here in Jensen et al. (2009, 2010).

DRUCKMAN and JACKSON, 2009). This involves assessing the waste (or other pollution) content of the *total* use of commodities (local and imported) according to the domestic production and polluting technologies in Wales (i.e. what regional agencies have some jurisdiction over). That is, the vectors $\boldsymbol{\omega}^{\mathbf{P}}$ and $\boldsymbol{\omega}^{\mathbf{C}}$ of direct output-waste coefficients (direct waste intensities) identified for Wales above and a variant of the **A** matrix that records *total* (combined domestic and imported) use of intermediate inputs to production and thus, a revised $\mathbf{[I\text{-}A]^{-1}}$ matrix showing the hypothetical global multiplier effects if all production to meet Welsh final consumption were carried out using Welsh production technologies. The DTA analysis employs a variant of the Type I model, in that it retains focus on direct and indirect effects but extends this to backward linkages with external production. This involves introducing additional data elements (imports matrices) to the calculation of (4) relative (2), with the implication that the resulting multipliers will be larger (though, as explained below, external demands are removed as a driver of the waste generation of interest).

The Welsh Economy Research Unit at Cardiff Business School provided experimental data in the form of an intermediate imports matrix showing imports (summed across the rest of the UK and the rest of the world) to each of the N=74 Welsh regional production sectors and information on final demand of imports for Z=4 final consumption groups (returning to the standard Type I classification of activities). These data permit an analysis based on the DTA. Using the 74x74 intermediate imports matrix, we derive the import input-output coefficient matrix, **M**. This corresponds to the existing domestic input-output coefficient matrix, **A**, which is now re-labelled **R.** **M** contains entries, m_{ij}, showing the use of the output of external sector i used in the production of one unit of output in Welsh sector j, x_j. In terms of final consumption, there is an additional NxZ (74x4) final consumption matrix, which is labelled $\mathbf{Y^M}$ to distinguish imports to final consumption from the existing **Y** matrix which is re-labelled $\mathbf{Y^R}$ (to distinguish final consumption of regional (Welsh) outputs). Also, in order to focus on the impacts of regional consumption, the vector of export demands from both these matrices is removed so that $\mathbf{Y^R}$ and $\mathbf{Y^M}$ become 74x3 matrices (where Z=3 includes domestic household and government consumption, and capital formation). As before, for the calculation of total supported waste (a scalar), the $\mathbf{Y^R}$ and $\mathbf{Y^M}$ matrices are summed across their rows to give Nx1 vectors $\mathbf{y^R}$ and $\mathbf{y^M}$ of total final demand for sectoral output/commodities.

In consequence, the total waste implications of Welsh final consumption decisions (labelled w^T below), assuming all production abroad shares Welsh technology, can be calculated by restating and extending (2) as follows:

(4) $$w^T = \boldsymbol{\omega}^\mathbf{P}[\mathbf{I} - (\mathbf{R} + \mathbf{M})]^{-1}(\mathbf{y}^\mathbf{R} + \mathbf{y}^\mathbf{M}) + \boldsymbol{\omega}^\mathbf{C}\mathbf{y}^*$$

Note that the entries in the (now 3x1) vector **y*,** used to estimate direct waste generated in final consumption (which, in fact, only applies in the case of households), is unchanged. As in (3), these entries represent *total* final consumption expenditure by each type of consumer (including imports).

The system in (4) incorporates intersectoral feedback effects so that $\mathbf{[I\text{-}(R\text{+}M)]^{-1}}$ can be interpreted as a Leontief multiplier matrix for the portion of the global economy that serves Welsh consumption demand *only* under the assumption that this portion of the global economy employs the Welsh production technology structure. Note that working under this assumption does not mean taking it to be fact; rather it is using the system to consider what would happen if Wales had to meet its own consumption demands using technologies over which Welsh government and agencies have some control/jurisdictional authority. This approach admittedly does not model reality but embodies a useful tool that makes use of available data. Considering the difficulty involved in obtaining country-specific production technologies for each and every trading partner, as well as the jurisdiction issues raised here, we propose that this approach offers a policy relevant alternative. However, it should also be noted that, by only incorporating uni-directional trade flows *into* Wales; the system in (4) does not capture any interregional feedback effects.

It is also important to note that the DTA system in (4), unlike the Type I (partial CAP) attribution framework in (3), *will not* replicate the total amount of waste generated in Wales as accounted under the direct method (the production accounting principle in (3)). Nor would the standard economic variant of (4) replicate the base year output vector of the 2003 Welsh IO table, or Welsh employment in 2003, and so on. This is because imports and exports, and their waste (or other pollutant) content, are unlikely to balance in any regional economy. Thus, the difference between the waste estimated using (4) and that under (2) or (3) may be taken as an estimate of the 'waste trade balance' between Wales and its trading partners.

Data

This section considers the data available for the analysis of waste attribution. The Welsh analytical input-output tables are the bedrock of the analysis undertaken here (see BRYAN et al., 2004 and WERU, 2007). The latest iteration of the input-output tables for 2003 provides information on the sales and purchases of 74 defined sectors (see Appendix 1 for sectoral classifications). Also available are a symmetrical domestic use matrix and an imports matrix, the latter providing information on the make-up of imports going to these same sectors. The Welsh IO framework has had some limited application for economic-environmental modeling (see MUNDAY and ROBERTS, 2006; BRYAN et al., 2004). The framework has also been used to assess the environmental consequences of tourism spending in the region, particularly connected to major events (see JONES and MUNDAY, 2007; COLLINS et al., 2007). However, to date, there has been no detailed analysis of waste or a detailed consideration of waste attribution.

Waste data for this analysis came from the *Commercial and Industrial Waste Survey Wales, 2002-2003*[2] carried out by the Centre for Business Relationships Accountability Sustainability and Society (BRASS) at Cardiff University (see FRATER and HINES, 2004). The results from this survey were primarily used to provide waste arisings (i.e. waste occurring at production sites) and disposal data. The dataset compiled information from 2,122 firms comprised of around 11,000 defined individual waste streams, and 2,200 mixed waste streams. The dataset also provided 5 digit standard industrial classification (SIC) codes for the reference firm, values for employment, a coding of waste stream according to the European waste codes catalogue, and information on tonnage, substance form, initial and final destination, a hazardous waste marker, and summary details of the waste management options being employed in the case of each survey observation.

Figure 1 provides a summary of how the waste covered in the *Commercial and Industrial Waste Survey Wales, 2002-2003* was distributed in terms of management options. The vast majority of the commercial and industrial waste (61%) goes to landfill, with 17% being recycled, and 15% classified as reused. Of the total commercial and industrial waste, an estimated 94.5% was classified as solid waste, 3.3% liquid, and 1.4% as sludge. The remaining 0.8% was mixed waste, powder, and viscous/paste. Of total household waste in 2003, an estimated 82.3% went to landfill (including incineration), with 17.7% being recycled or composted (see NATIONAL ASSEMBLY for WALES, 2005)

<Figure 1 about here>

The survey revealed that the Welsh businesses surveyed produced an estimated 5.3 million tonnes of waste in 2002-2003, of which 79% was industrial waste and 21% was commercial waste; a 14% decrease from the 6.1 million tonnes produced at the time of the previous survey in 1998-1999. This decrease is perhaps due, in part, to the decline of the regional manufacturing sector over this period.

[2] This survey was undertaken during 2003-2004 to gather data ostensibly for the 2002-2003 financial year.

For use in conjunction with the 2003 Welsh IO data, the data on total tonnages of waste was aggregated to the 3-digit SIC code level. There were some gaps in the waste data coverage (and this impacts coverage of our 74 input-output sectors below). For example, the *Commercial and Industrial Waste Survey Wales, 2002-2003* did not collect data from sectors producing waste that was 'not controlled' such as *Construction* and *Mining and Quarrying*. Some details of waste by sector were estimated using data from parallel surveys undertaken in England (including sectors such as *Pulp and Paper*, *Printing*, *Oil Refining*, *Recycling*, *Utilities*, *Wholesale/Retail*, and *Education*). Additional data on waste from the *Construction* and *Other Mining and Quarrying* sectors was subsequently collected from the *Pilot Environmental Satellite Accounts for Wales* (DTZ & WERU, 2007) and linked sources. Moreover, household waste data for 2003 was collected from the *Municipal Waste Management Report for Wales 2007-08*. However, in some cases (specifically primary activities such as coal extraction, oil processing, gas and water supply) no appropriate proxy data were available. In these cases, direct waste is assumed to be zero. While this will impact on both the direct and multiplier analyses in the following section, the assumption is made on the grounds that it is more transparent and less distortive than inserting positive numbers with no actual data content.

This body of data on sectoral waste generation, together with additional economic information, was used to gain a survey-based estimate of tonnes of waste per full time equivalent (FTE) employee in each 3-digit SIC sector. These data provide the basis for grossing-up the waste survey data to an estimate of total tonnes of waste generated by each SIC industry. For the analysis in this paper, total commercial and industrial waste tonnages are used rather than focusing on different waste types or waste destined for specific management options. As discussed later in the conclusions, future work using more disaggregated waste data would permit an examination of the generation and flows of different waste types and management options in Wales.

These data are then aggregated into the 74 industry sectors within the Welsh IO tables, permitting the initial estimation of output-waste coefficients (sectoral direct waste intensities), shown in Appendix 2. Note the zero entries for the output-waste coefficients in the cases of sectors 4, 17, 43 and 44 (for coal extraction, oil processing, gas and water supply activities discussed above). The output-waste coefficients for the other 70 industry sectors are derived by dividing the total tonnage of waste estimated as being generated in each production sector and by households by total sectoral output, x_i, and, in the case of households, total final expenditure, y_z. These direct waste intensities constitute the 1x74 vector $\boldsymbol{\omega}^{\mathbf{P}}$ and the sole entry ω_z (where z=household consumption) of the $\boldsymbol{\omega}^{\mathbf{C}}$ vector introduced in the second section of the paper. Note that this gives us the reverse calculation to that shown in equation (3) for a direct allocation of waste under the production accounting principle. Summing down the first numerical column of Appendix 2 gives us w^R, the total waste generated within the Welsh economy in 2003 (also including uncontrolled waste not accounted for in the survey discussed above), which is 18.6 million tonnes, or the Welsh regional waste account under PAP. Thus, as explained in the second section of the paper, and shown below, with no *changes* in final demand, any attribution exercise using equation (2) returns the same numerical result for w^R.

Waste attribution for Wales 2003

This section reports the results of applying the DTA attribution technique, outlined in the second section of this paper, to the case of Wales in 2003. For comparative purposes, these are reported alongside results for the more conventional single region Type I attribution analysis. Thus, waste is attributed to exogenous final consumption demands in two different ways:

A. Conventional Type I Analysis: attributes direct and indirect waste generation to private and public consumption, capital formation, and exports.

Under conventional Type I, the analysis is allocating total waste generated under the PAP, using equation (2). Thus, A. is a partial CAP account, with attribution of waste generated (within the region only) to final users (including external consumers). The second attribution approach moves towards a full CAP account:

B. DTA Analysis: extending on the conventional Type I analysis to incorporate the consideration of the waste content of imports to support local final consumption demands under the Domestic Technology Assumption. As noted earlier, this means that exports are removed from the attribution exercise. Moreover, the resulting analysis is based on equation (4), where the Leontief inverse, based on a combined rather than domestic use matrix, represents the portion of the global economy that serves Welsh final consumption. This has the implication that output multiplier values are larger (with no import leakage). However, they are applied to reduced final consumption (without external export demands). Generally, given the difference in focus on local consumption demand only and multipliers based on the combined use matrix, total waste implied by Welsh final consumption demands, w^T, need not (and is unlikely to) equal w^R from equations (2) and (3).

Table 2 shows the results of the waste attribution for each of the two cases. The first numerical column shows the results of attributing the total tonnage of waste generated within the Welsh economy– under the PAP in equation (3) - to final consumption demand for the outputs of the 74 Welsh production sectors using equation (2). The Type I output-waste multipliers (tonnes of waste produced throughout the economy per monetary unit of final demand for each production sector's output) are also reported in Appendix 2. Table 2 focuses on the results of using these multipliers to attribute waste generation to the various types of final consumers identified in the Welsh IO tables.

<Table 2 about here>

In moving from the PAP analysis (using equation (3) and with direct waste generation in each Welsh production sector reported in the first numerical column of Appendix 2) to the partial CAP analysis (using equation (2)) we may use the Type I output multipliers (Appendix 2) to examine the waste that is supported by final demand for each sector's output, rather than the direct waste generation associated with the production of that output. That is, waste generated in one sector in the production of output to meet intermediate demand from another production sector is reallocated to the latter, but with the total across the economy remaining unchanged. In terms of domestic (Welsh) consumption demands, this is shown in Appendix 4, which is discussed below in considering the full CAP analysis in terms of the type of sectoral/commodity output consumed.

However, in terms of the results reported in Table 2, the key point about the equality between the PAP results calculated using equation (3) and the partial CAP analysis in attributing waste generation to end user using (2) is reflected in the results shown in Appendix 3. This breaks down the distribution of waste generation in production shown in Appendix 2 according to the geographical source of demand in terms of whether this is internal or external and allows us to take the first step in considering the question of responsibility under the consumption accounting principle. From a full CAP perspective, waste generated within Wales to meet final consumption demand in another jurisdiction should be allocated to the 'waste footprint' of the latter.

The key thing to note from the Type I partial CAP results in Table 2 is that while the bulk of domestic waste generation, 10.9m tonnes (58%), is attributable to Welsh consumers, a large share, 7.6m tonnes (42%) is attributable to external (export) consumption. Thus, under the CAP, the latter would not be included in the Welsh waste account. However, this is the point at which the conventional Type I analysis falls short in the open economy case, because the results do not give any consideration to the pollution content of imports.

In the second numerical column of Table 2, we offer the alternative attribution analysis. Here, using equation (4), an attribution analysis is conducted where imports are incorporated into both the Leontief matrix and final demand, while exports are removed from the latter. In Table 2, we report the key results in terms of what is attributed and to whom. In the first four rows – domestic (Welsh) waste generation – we take the results of the standard Type I analysis using equation (2). These are the results given when we limit attention to the domestic transactions in the **R** matrix and the $\mathbf{y^R}$ and **y*** vectors – i.e. (4) would collapse to (2) with export demand excluded from the **y** vector. For the hypothetical external waste generation embodied in imports – i.e. the additional information from introducing the **M** matrix and the $\mathbf{y^M}$ vector – we take the difference between the calculations under (4) and (2) for each domestic consumer.

A crucial point to bear in mind here is that the system in (4) produces a *hypothetical* CAP measure under a domestic technology assumption. As explained in the second section, this involves assessing the pollution content of the combined (total) use of commodities (regional and imported) according to the domestic waste generation technology reflected in the direct output-waste coefficient vector reported in Appendix 2. In previous studies, the DTA has been regarded as a necessary assumption to fill data gaps regarding the pollution profile of production in other regions/countries (e.g. DRUCKMAN et al., 2008 and DRUCKMAN and JACKSON, 2009). However, we propose that it may be a useful assumption in the context of the issue of production being located outside of the jurisdictional authority of policymakers in the consuming region. We may think of the approach in terms of the waste implications if the region of study (here, Wales) were to produce the commodities it chooses to consume itself. The adjustments to the attribution method that (a.) remove waste generated domestically to meet external consumption demand but (b.) introduce the waste generation that would be required to produce intermediate and final imports using Welsh technology, mean that the total waste generated, w^T, need not be the same as actual waste generated under the PAP, w^R (equation (3)), and attributed to all final consumers (including export demands) in the partial CAP attribution in equation (2). Indeed, given that Wales ran a trade deficit in 2003 (with imports of goods and services exceeding exports), it is expected that the estimation of (4) will provide increased output requirements, and this is reflected in larger output multiplier effects through the variant of the Leontief matrix therein. However, whether this also equates to increased waste requirements depends on the mix of imports and exports and their relative waste intensities. Indeed, in Turner et al (2010), using the same IO framework but focussing on carbon emissions instead of waste (in a CGE analysis of the economic and carbon impacts of an export-led expansion in steel production), we find that Wales's trade deficit in goods and services is accompanied by a 'carbon trade surplus'. That is, carbon attributed using the DTA method in equation (4) is *less* than actual carbon generated within Wales from (2) and attributed to final consumption in (3). Despite carbon embodied in exports being measured under (3) using smaller output multiplier values in the standard domestic use Leontief (as is appropriate given the focus on Welsh domestic production and polluting activity only), the carbon intensity and scale of export demand for some key polluting sectors in the Welsh economy (e.g. *Iron and Steel* production) is sufficient to outweigh the carbon embodied in total imports).

The importance of identifying and examining key waste generation activities is illustrated by considering how Welsh production and waste generation would have to change if it were to meet all its consumption requirements domestically. For example, in 2003, Welsh industry imported half of its *Other Mining and Quarrying* inputs, production of which (as shown in Appendix 2) has a very high direct waste intensity (28,438 tonnes per £1 million output). If Wales were to produce these inputs domestically, the rise in total domestic waste generation would be almost 33%, an additional 6.1 million tonnes. This required increase (from just one type of commodity consumption) equates to 79% of the tonnage attributable to external (export) demand in the standard Type I analysis reported in Table 2.

In the context of the CAP analysis, Appendix 4, decomposes the Welsh 'waste footprint' estimated using the DTA method in (4) in terms of what types of sectoral/commodity outputs are consumed (instead of who consumes them in Table 2). That is it takes the DTA output-waste multiplier matrix, $\omega^P[1\text{-}(R+M)]^{-1}$ and multiplies through by final demands for each commodity/sectoral output, the sum of y^R* and y^M* (the asterix indicating the transpose of the vectors in (4)). The results are shown in the third numeric column of Appendix 4. The results for the corresponding calculation for the Type I case, using $\omega^P[1\text{-}A]^{-1}$ and y^R*, are shown in the first column, and the difference between these two – the implied waste embodied in imports – is shown in the second. These results can be further decomposed by examining the underlying matrices of total waste supported in the internal or external production sectors.

The results in Appendix 4 show that final demand for *Other Mining and Quarrying* outputs accounts for just over 9% of the total, despite only accounting for less than 0.2% of final expenditure. Again, this is due to the very high direct waste intensity and waste multipliers for this sector (see Appendix 2). Similarly, Appendix 4 shows that final demand for highly waste-intensive *Construction* production accounts for 27% of the total Welsh DTA CAP measure (though also accounting for a higher share of final expenditure, just over 4%). Almost 98% of the 7.3million tonne 'footprint' of this sectoral/commodity output is accounted for by embodied own-sector and by *Other Mining and Quarrying* waste.

One issue in the waste accounting exercise conducted here relative to that for carbon in Turner et al (2010) is that that these two highly waste intensive activities (accounting for just under 65% of the total waste generated within Wales in Appendix 2, and for 36% of the total waste requirement in Appendix 4) are relatively less export-orientated than key carbon intensive activities. This is particularly the case with Welsh *Construction*, which only exports 14% of its output. *Other Mining and Quarrying* exports a higher share of its output (44%), but this is significantly less than, for example, the highly carbon intensive *Iron and Steel* sector (which exports 80% of its output), and is offset by a greater quantity of direct and indirect outputs from the corresponding external sector embodied in imports throughout the Welsh economy.

Generally, the input-output framework facilitates detailed examination of what drives waste allocated under the various PAP and CAP analysis. However, while export demand for the outputs of the two highly waste intensive sectors discussed above dominate in the PAP analysis using equation (3) and the Type I CAP analysis in (2) (where *Construction* and *Other mining and quarrying* together account for almost 65% of direct waste generation in Appendix 2, and 60% of the 7.75million tonnes embodied in export demand in Table 2), decomposition of the DTA analysis presents a more varied picture.

At the aggregate level, Appendix 4 decomposes the total CAP DTA waste footprint by the type of sectoral/commodity outputs consumed, breaking this into domestic and imported waste.[3] Figure 2 analyses the underlying sources of embodied waste making up this measure (excluding waste directly generated in the household sector: 25.7million tonnes from Appendix 4), though these are aggregated from the 74 sectors in Appendix 1 for presentation purposes. The results presented in Figures 2 (and 3 below) are generated by decomposing the production attribution matrices on the right-hand side of (2) and (4) – i.e. $\boldsymbol{\omega}^{\mathbf{P}}[\mathbf{1}\text{-}\mathbf{A}]^{\mathbf{-1}}\mathbf{y}$ and $\boldsymbol{\omega}^{\mathbf{P}}[\mathbf{1}\text{-}(\mathbf{R}+\mathbf{M})]^{\mathbf{-1}}(\mathbf{y}^{\mathbf{R}}+\mathbf{y}^{\mathbf{M}})$ respectively. Figure 2 shows that waste directly generated in the 'Primary and Utilities' sectors (an aggregation of sectors 1-4, dominated in waste terms by the *Other Mining and Quarrying* sector) and in *Construction* dominate at the aggregate level.

[3] Note that negative entries are reported in the first numerical column of Appendix 3 for several sectors. These (for example, sector 19, Pharmaceutical) are highly export-intensive sectors where net domestic demand is negative by reductions in stocks (as an element of capital formation) in the underlying input-output accounts for 2003.

However, the comparison with direct final expenditures and the outputs supported by these expenditures in Figure 2 reflects the fact that this is driven by the waste intensity of these indirect linkages, rather than their scale. Figure 2 reveals that the largest expenditures and supported outputs underlying the DTA results are in the aggregate 'Manufacturing' sector (sectors 5-41) and 'Public Services' (sectors 69-73). However, particularly in the case of the latter, it is the scale of activity supported by final consumption rather than its waste intensity that is most important.

The case of public sector activities is a particularly policy relevant one, with governments increasingly using their own resource and pollution 'footprints' as a focus for both reducing the impacts of their own behaviours and as an example to both industry and households. For example, in Wales there is a public sector waste minimisation campaign designed to assist the public sector in Wales develop practices that will help it meet set targets for waste minimisation, and with the vision that elements of the private sector will match the public sector example. Volume targets are central to the campaign. For example in 2010 the target was for the public sector in Wales to reduce waste volumes by 10% compared to 1998 figures. The *Wales Public Sector Waste Production Survey* (2009) revealed that the public sector produced an estimated 190,674 tonnes in 2007, a decrease of 24 per cent on 1998 figures (see Welsh Assembly Government, 2011).

The results in Appendix 4 show that the combined contribution of provision of output to meet Welsh final demand in the five 'Public Services' sectors is 14% of the total 'waste footprint' calculated using the DTA method. While these public sectors are relatively import intensive (together directly importing 41% of their intermediate inputs), together they export less than 6% of their output, with the main final consumer being Government (accounting for 84% of final demand, and with almost 100% of Government direct final expenditure in 'Public Services'). These features have two key implications. First, the waste tonnage attributed to Government in DTA attribution in Table 2, is almost entirely explained by the tonnage attributed to final demand for 'Public Services' output in Appendix 4 (though the latter is larger because of non-government final demands for the outputs of these sectors). Second, the implication that the impact of public service activities will be much greater on CAP than PAP measures, as well as the associated 'waste deficit' in Table 2.

<*Figure 2 about here*>

The composition of the 'Public Services' provision waste footprint is summarised in Figure 3. The first point to note is that, given the importance of intermediate linkages between the five component sectors, own-sector waste is an important component of the domestic waste footprint (determined by equation (2)). However, as in the overall DTA footprint calculation illustrated in Figure 2, *Construction* waste generation within Wales is particularly dominant. Again, this is driven by the waste intensity of *Construction* activity: the 'Public Services' sectors only source around 4% of their direct inputs from this sector, with a multiplier impact of around 1.2 taking indirect effects into account. However, in the case of waste embodied in imports, the pattern of commodities imported is quite different to that of domestic purchases (particularly with less own-sector reliance, with less than 3% of Welsh 'Public Sector' imports from the corresponding external sectors, compared to 53% of domestic intermediate purchases). This has the implication that the waste content of imported goods and services relies on quite different indirect linkages and corresponding output multiplier effects than domestic intermediate purchases in the 'Public Services' sectors. Figure 3 demonstrates that indirect supply linkages to the 'Primary and Utilities sectors', particularly *Other Mining and Quarrying* (which accounts for just over 61% of the waste embodied in imports to meet Welsh final demand for 'Public Services' outputs) are the dominant driver of this component of the 'Public Services' waste footprint. It is also important to note (not shown in Figure 3) that while imports account for less than half of the intermediate input requirement in the 'Public Services' sector, waste embodied in imports accounts for just over 70% of the total DTA footprint of final consumption of the combined output. Again, this is due to the different pattern of goods and services imported, and their associated (direct and indirect) waste intensities.

<Figure 3 about here>

In summary, the results in Table 2 show that taking the difference between the conventional Type I and DTA CAP attribution exercises in the first and third columns, with the former mapping directly to the PAP account, means that our analysis suggests that Wales ran a trade deficit in waste of 8.6 million tonnes in 2003. This equates to 46% of the domestic waste generation that is the focus of current policy initiatives in Wales. Underlying this result is the finding that the amount of waste embodied in exports in the standard Type I analysis in the first column, almost 7.8million tonnes, is considerably less than that embodied in imports in the DTA Type I analysis in the third, 16.3million tonnes.

Discussion and conclusions

This paper has focused on different methods of waste attribution within a regional input-output accounting framework. In the Welsh case examined in this paper there is a strong interest in developing plans to better manage waste and reduce volumes of absolute waste. The Welsh Assembly Government (2009a) *Towards Zero Waste* plan focuses on a significant reduction in volumes of waste (to around 27% of 2007 levels by 2025) and with tools encouraging more closed loop recycling, changing consumer lifestyles, minimisation of non-recyclable waste, encouragement of sustainable construction practices and reduced amounts to landfill. Current strategy is also adopting much more of a sectoral focus, for example, with focus on construction wastes, and wastes connected to food manufacturing, service and the retail supply. However, we would argue that it is these very sectors where different waste accounting principles might give policymakers useful guidance i.e. not just on the volumes of waste generated by local production but also in the amounts of waste outside Wales levered by regional consumption. One issue is that the achievement of regional 'volume' targets might be accompanied by greater levels of waste embodied in imported goods and services. An improved accounting of volumes also speaks directly to Welsh Assembly Government concerns about their waste footprint and a set of 'global' sustainability responsilities instituted as part of the Government of Wales Act (see Munday and Roberts, 2006).

Fundamentally too strong a focus on monitoring waste within geographical boundaries (the domestic production of waste), rather than considering how domestic consumption creates a waste footprint further afield, would seem to be at odds with wider regional sustainability aspirations. Clearly, the focus on the production accounting principle and 'territorial' responsibility has value in terms of examining policy-relevant waste quantities. However, this paper suggests that, depending on the policy question at hand, greater attention might be given to both the consumption accounting principle and the production accounting principle with respect to waste. The relatively open nature of the regional economy means that monitoring methods which specifically exclude trade provide only a partial perspective. Similar conclusions have been made with respect to climate change indicators (greenhouse gas indicators) where monitoring under the production principle provides only a partial understanding of regional 'responsibilities' (TURNER et al., 2007).

However, while a CAP measure for regional monitoring may be desirable, there are problems in obtaining all of the necessary information. In this paper, it has been suggested that the single region input-output framework is a useful starting point for a detailed attribution analysis and an important adjunct for regional policymakers exploring industries and consumptive behaviours that create waste both directly and indirectly.

This paper illustrates that a DTA method may provide particularly useful insights for policymakers by explicitly addressing the waste embodied in imports, while focusing on the consumption and production technology decisions that fall under the jurisdiction of regional policymakers. This approach provides some insight into the nature of the regional waste footprint using data that are more likely to be available at the regional level (the DTA method proposed here only requires data on the regional economy and not the large amounts of economic, trade, and waste generation data from regional and national economies that are linked to Wales through trade). It also focuses attention on the pollution savings a region gains by importing goods and services, rather than the actual costs in other regions, the nature of which local consumers may have little influence over.

Of course, there are issues involved in the use of such a measure. It may be that after considering waste and other pollution problems from the DTA perspective, there would be a desire to examine the actual pollution content of imports. Clearly, the DTA approach proposed here is only something of a 'half-way house' towards a full consumption accounting principle. However, provided that the underlying assumptions, and their implications, are understood, such a measure is a cost effective and transparent means of gaining waste attribution insights. Moreover, once the approach is clearly understood, assumptions may be relaxed, for example, by introducing direct waste intensity data from countries that Wales imports from through a weighted vector of waste coefficients in the DTA calculation in equation (4), or should resources and expertise be available to allow such a development, by investing in data that allows for estimation using a full interregional accounting system. The authors are currently working, with the assistance of colleagues at Organisation for Economic Co-Operation and Development (OECD), to attempt such an extension for the case of carbon accounting (Jensen et al., 2010). Moreover, the methods used here permit connections to be made in terms of the final consumption groups that can be linked to waste streams and it is this type of information that allows for policies to be focused not only on industry groups, but the underlying consumption behaviours that drive different types of waste generation. This has been one focus of recent strategic documents in Wales (including One Planet Wales), which stress the importance of changing the behaviour of individuals and institutions (see Ravetz et al., 2007).

Finally, care is obviously required in drawing too much inference from modeled results in an input-output framework. The general limitations of the input-output approach are well known and are not repeated here (see HEWINGS, 1985: 38-41, 86-89 for a concise review or MILLER, 1998: 42). Moreover, at this time, few UK regions have published input-output tables available, but many have access to tables which have been mechanically derived from the UK input-output framework, meaning the type of analysis undertaken here could be repeated for other UK regions.

Going forward, there are a series of possibilities. This paper has concentrated on total waste generated. However, an analysis which focuses on particular types of waste or waste destined for specific waste management methods may also be of interest. For example, hazardous wastes can be separated out from the dataset and an analysis undertaken which may reveal, for example, industries and respective supply chains that give rise to particularly dangerous and expensive to handle wastes. As shown by LEONTIEF (1970), the input-output approach can also be extended to consider the resource implications of disposing of waste generated in the economy (see also ALLAN et al., 2007). Furthermore, there is the possibility, within the underlying regional input-output framework, of deriving scenarios based on changes in consumer behaviour and industry structure. As previously mentioned, this analysis can also be adapted for examining other environmental externalities, such as the generation of greenhouse gases.

This framework can also be considered a starting point to moving to more intricate models of waste-economic relationships such as the WIO model and its extensions (see NAKAMURA and KONDO, 2009). Such possibilities are of particular interest as the structure of the regional economy changes over time. These types of extended analyses may help planners and policymakers alike in understanding what these changes mean for waste generation. Such a framework would also allow policymakers to investigate changing demands for different waste management options and expected changes in the regulatory pressures placed on regional industries and consumers. However, the particular limitations of input-output techniques in analyzing the impacts of *changes* in activity, which centre on the conventional input-output model's silence on prices and assumption of inelastic supply, must not be ignored. For this reason, another priority for future research may be to relax these assumptions in a more flexible computable general equilibrium framework (where the environmental input-output framework constructed here would serve as the core database).

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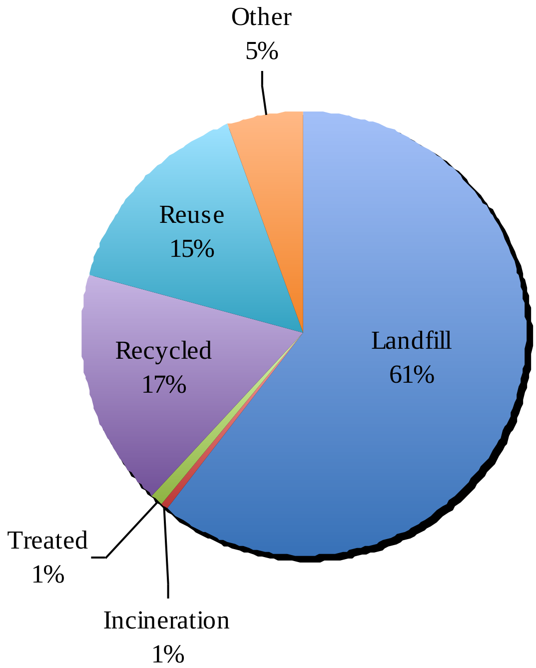
Figure 1: Waste Management Method by Type



Note: Other (5%) includes, for example, waste composted, digested, disposed to sewer, discharged to controlled waters, soakaway, waste derived fuel, pyrolysis, gasifier, waste placed in deep injection boreholes, and lagoon disposal.

Source: Derived from the *Commercial and Industrial Waste Survey Wales, 2002-2003.*

Figure 2: Decomposition analysis of the Welsh DTA waste footprint and related expenditures/supported outputs

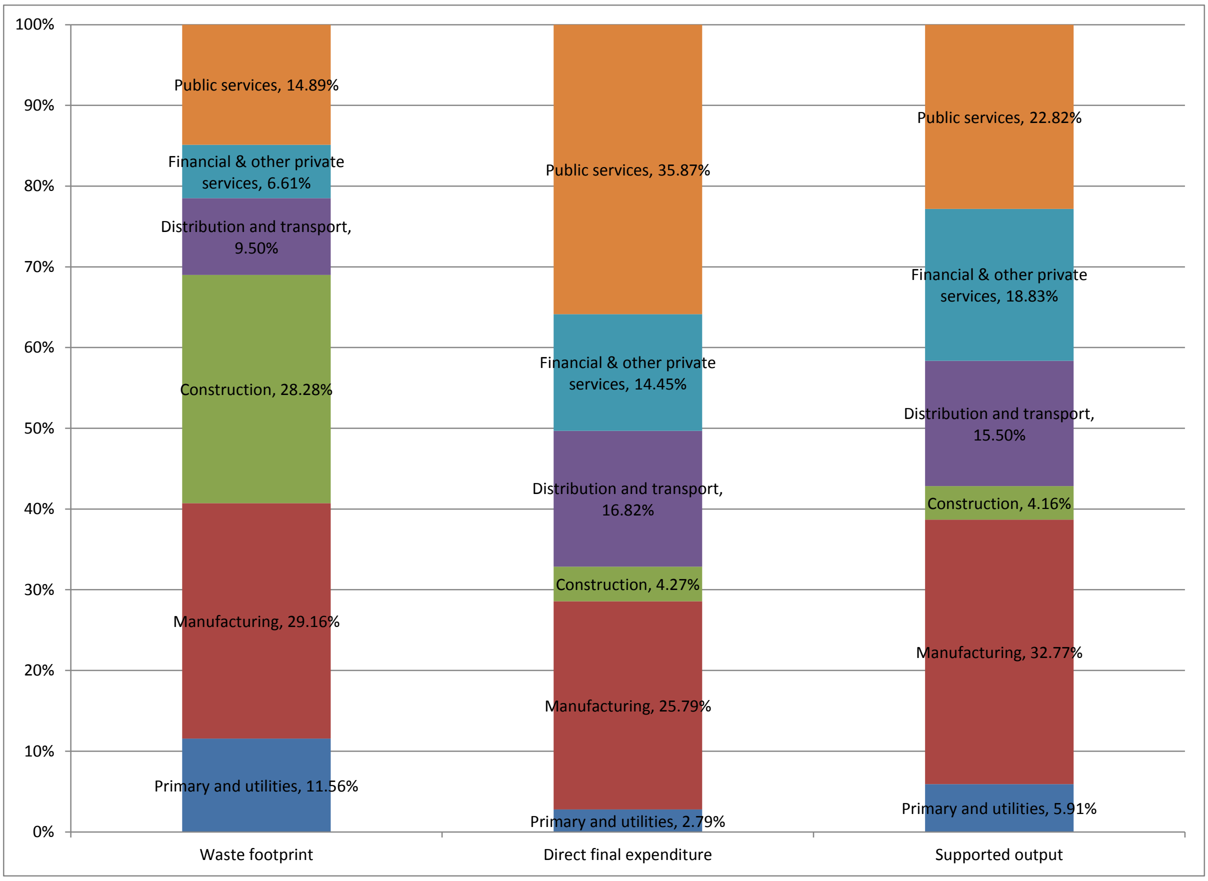


Figure 3: Decomposition of the Welsh 'Public Services' DTA waste footprint

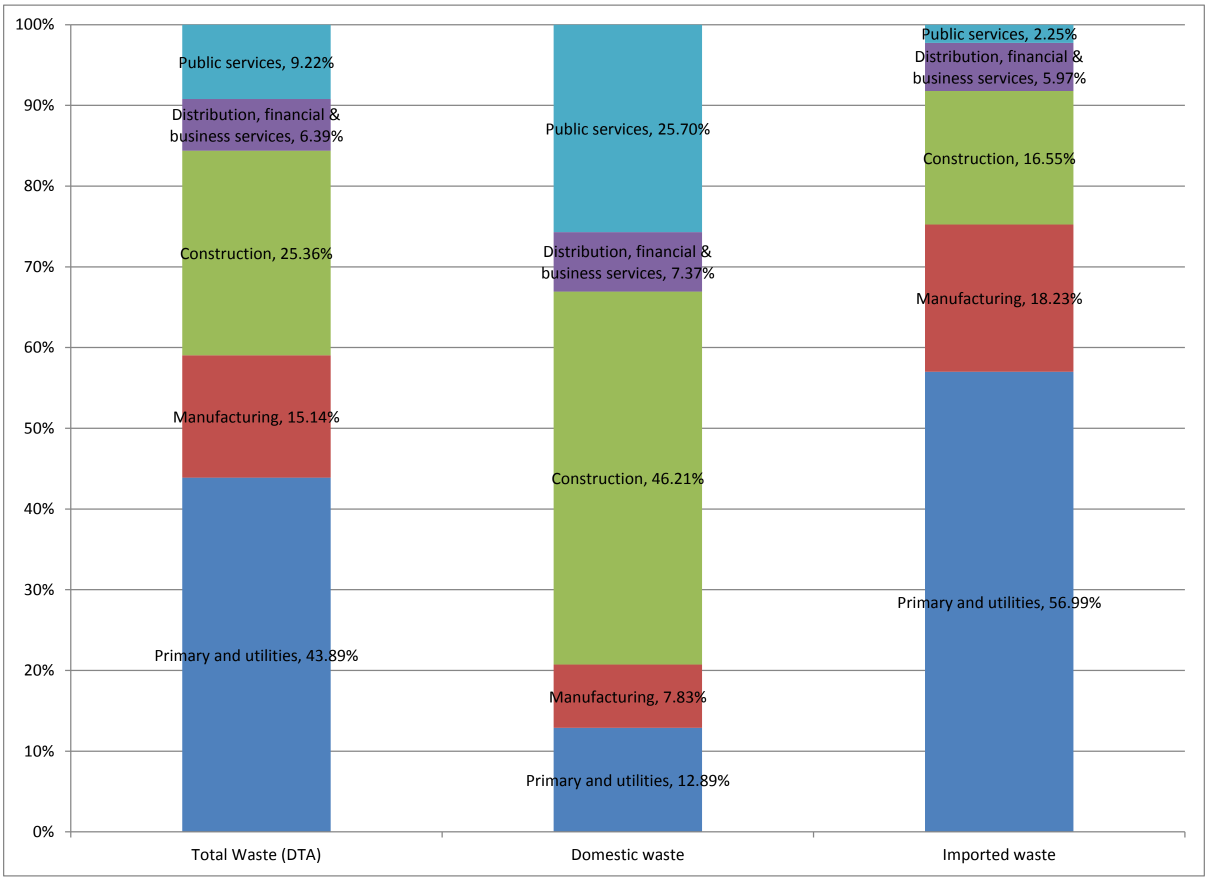


Table 1: Key aspects of different IO approaches for regional environmental/waste analysis

	Factors included in analysis	Issues for environmental analysis
Direct	* Domestic waste generation in target region (Wales)	* Analysis entirely from a production perspective
Type I	* Domestic waste generation in target region (Wales) * Direct and indirect (backward linkage/inter-industry) effects	* Attribution of some waste generation to external (export) demand but no account of impacts of imports
Domestic Technology Assumption	* Global waste generation supported by target region (Wales) consumption, under assumption that Welsh production/polluting technology applies universally *Attributed entirely to Welsh consumption demands (households, government and capital) * Allows focus on choices Welsh policymakers have jurisdiction over	* Capacity and capability issues if taken as actual footprint * Method permits relaxation of DTA assumption, but with uni-directional trade (no interregional feedback effects)
Interregional footprint analysis	* Actual (estimated) global waste generated supported by target region (Wales) consumption (including interregional feedback effects) * Potential full application of Consumption Accounting Principle	* Waste attributed to local consumption demands dependent on production/polluting technology decisions that are not under the jurisdiction of regional policymakers (or consumers) * Extensive data requirements (depending on focus, potential world interregional IO tables with economic and environmental data in IO format for all direct and indirect trade partners)

Table 2: Input-Output Accounting of the Welsh Waste Trade Balance (2003)

	Actual generation (Type 1)	Hypothetical generation (DTA)
Total waste attributed (tonnes)	**18,612,628**	**27,179,036**
Waste supported by Welsh final demands		
Domestic (Welsh) waste generation:		
Directly generated (households):	1,522,000	1,522,000
Indirect - generated in Welsh production sectors supported by:		
Households	2,338,721	2,338,721
Government	1,028,998	1,028,998
Capital	5,971,294	5,971,294
	10,861,012	**10,861,012**
Hypothetcial external waste generation (imports)		
Households		8,323,432
Government		2,368,840
Capital		5,625,752
		16,318,024
Waste supported by external demands for Welsh production	7,751,616	
Implied Waste Trade Balance (Deficit):		
Actual waste generation minus DTA waste generation	-8,566,408	
Waste embodied in exports minus waste embodied in imports)		

Appendix 1: Sectoral Aggregation Scheme

Sector #	Sector Description	SIC
1	Agriculture & Fish	1, 5
2	Forestry	2
3	Coal Extraction	10, 11, 12
4	Other Mining & Quarrying	13, 14
5	Meat	15.1, 15.4
6	Dairy	15.5
7	Fish Products, Vegetables, Grain Mill Products	15.2, 15.3, 15.6
8	Bread & Biscuits	15.81, 15.82
9	Misc Foods	15.7, 15.85 to 15.89
10	Confectionery	15.83, 15.84
11	Drinks and Tobacco	15.91 to 15.98, 16
12	Textiles	17.1 to 17.7
13	Clothing	18, 19.1 to 19.3
14	Wood Products	20
15	Paper and Pulps	21.1, 21.2
16	Publishing	22
17	Oil Processing	23
18	Chemicals	24.1 to 24.3, 24.6, 24.7
19	Pharmaceutical	24.4
20	Soaps	24.5
21	Rubber Products	25.1
22	Plastics	25.2
23	Glass and Ceramics	26.1 to 26.3
24	Cement/Plaster	26.4 to 26.8
25	Iron and Steel	27.1 to 27.3
26	Aluminium & Non-Ferrous Metals	27.41, 27.43, 27.45
27	Forging/Pressing	27.5, 28.4, to 28.7.
28	Structural Metals	28.1, 28.2, 28.3
29	Machinery	29.1 to 29.6
30	Domestic Appliances	29.7
31	Office Machinery	30
32	Electrical Motors and Transformers	31.1, 31.2
33	Wires and Cables	31.3
34	Industrial Electrical Equipment	31.4 to 31.6
35	Electronic Components	32.1, 32.2
36	TVs	32.3
37	Control Equipment	33
38	Motor Vehicles	34
39	Other Vehicles	35
40	Furniture	36.1
41	Other Manufacturing	36.2 to 36.6, 37
42	Electricity	40.1
43	Gas	40.2, 40.3
44	Water	41
45	Construction	45
46	Distribution and Repairs	50
47	Wholesale	51
48	Retail	52
49	Hotels, Restaurants, and Catering	55
50	Railways	60.1
51	Road Transport	60.2, 60.3
52	Sea and Air Transport	61, 62
53	Transport Services and Travel	63
54	Postal Services	64.1
55	Telecomms	64.2
56	Banking and Finance	65.1
57	Insurance	66, 67
58	Other Financial Services	65.2
59	Real Estate	70.1, 70.3
60	Ownership of Dwellings	70.2
61	Renting of Moveables	71
62	Legal Services	74.11
63	Accountancy Services	74.12
64	Computer and Related Activities	72
65	R&D	73
66	Market Research & Advertising	74.13 - 74.15, 74.4
67	Other Business Services	74.5 - 74.8
68	Other Professional Services	74.2, 74.3
69	Public Administration	75
70	Education	80
71	Health	85.1, 85.2
72	Recreation Services	85.3, 91, 92
73	Sanitary Services	90
74	Other Services	93, 95

Appendix 2: Direct Waste Distribution (tonnes), Output-Waste Coefficients and Output-Waste Multipliers (tonnes per £1 million output)

Sector/ Commodity #	Sector/Commodity Description	Direct Waste Distribution	Output-Waste Coefficients	Type 1 Output-Waste Multipliers	DTA Type I Output-Waste Multipliers
1	Agriculture & Fish	175,042.10	159.90	223.58	451.69
2	Forestry	2,208.51	27.52	96.39	227.83
3	Coal Extraction	0.00	0.00	54.33	358.86
4	Other Mining & Quarrying	6,100,000.00	28,438.14	29,314.88	33,039.92
5	Meat	178,263.67	208.44	295.95	610.33
6	Dairy	89,000.51	234.13	347.93	648.79
7	Fish Products, Vegetables, Grain Mill Products	39,305.36	128.62	196.95	466.30
8	Bread & Biscuits	31,895.08	78.33	118.12	355.92
9	Misc Foods	18,265.66	78.34	135.42	398.63
10	Confectionery	5,641.69	78.11	127.01	353.45
11	Drinks and Tobacco	9,994.43	20.25	56.14	316.05
12	Textiles	15,664.28	40.46	67.29	296.50
13	Clothing	3,368.71	19.54	56.83	242.02
14	Wood Products	210,800.98	533.29	580.88	985.22
15	Paper and Pulps	65,771.54	79.49	135.36	610.42
16	Publishing	92,128.38	138.54	163.23	370.91
17	Oil Processing	0.00	0.00	26.03	359.36
18	Chemicals	56,057.48	26.43	72.80	834.18
19	Pharmaceutical	5,682.19	23.02	49.75	238.99
20	Soaps	29,519.27	80.62	124.45	406.20
21	Rubber Products	8,684.26	100.70	142.93	466.27
22	Plastics	101,164.78	96.50	133.10	496.20
23	Glass and Ceramics	36,627.99	116.60	242.91	2,054.45
24	Cement/Plaster	40,358.24	105.90	418.99	2,850.23
25	Iron and Steel	304,174.93	147.15	281.82	2,841.39
26	Aluminium & Non-Ferrous Metals	990.24	1.11	96.33	3,734.43
27	Forging/Pressing	119,953.04	113.47	154.76	1,001.32
28	Structural Metals	47,190.40	106.92	166.50	956.92
29	Machinery	51,822.24	54.21	85.58	648.50
30	Domestic Appliances	13,906.67	44.12	72.62	590.06
31	Office Machinery	1,802.25	18.41	55.94	480.41
32	Electrical Motors and Transformers	13,508.42	38.67	72.48	435.18
33	Wires and Cables	30,377.99	214.67	245.77	1,139.65
34	Industrial Electrical Equipment	39,734.23	82.14	113.55	498.97
35	Electronic Components	12,264.24	26.37	65.46	425.82
36	TVs	4,048.88	6.27	41.40	349.59
37	Control Equipment	332,807.45	425.57	464.54	777.13
38	Motor Vehicles	75,113.04	39.49	110.34	858.88
39	Other Vehicles	32,003.36	21.86	56.25	434.34
40	Furniture	325,265.72	494.51	566.94	980.76
41	Other Manufacturing	505,989.07	983.43	1,019.99	1,613.62
42	Electricity	19,867.60	7.47	33.62	232.94
43	Gas	0.00	0.00	35.43	307.58
44	Water	0.00	0.00	71.93	233.20
45	Construction	5,952,000.00	1,765.37	2,320.94	3,779.21
46	Distribution and Repairs	280,837.63	290.15	319.80	501.15
47	Wholesale	66,510.85	37.43	90.43	299.05
48	Retail	602,862.45	155.53	192.09	349.81
49	Hotels, Restaurants, and Catering	267,114.86	107.77	150.21	308.04
50	Railways	1,931.88	4.10	64.16	301.98
51	Road Transport	38,870.76	32.85	59.48	190.43
52	Sea and Air Transport	5,147.81	23.28	43.38	188.98
53	Transport Services and Travel	20,680.63	17.44	76.34	308.49
54	Postal Services	42,492.14	97.44	121.38	217.18
55	Telecomms	1,769.36	1.68	49.48	236.46
56	Banking and Finance	2,912.62	1.24	46.69	187.74
57	Insurance	8,128.20	15.96	79.63	270.51
58	Other Financial Services	1,550.47	2.79	29.43	133.38
59	Real Estate	1,787.26	3.60	119.20	328.02
60	Ownership of Dwellings	3,882.75	1.10	121.01	296.66
61	Renting of Moveables	26,016.15	82.80	112.95	225.07
62	Legal Services	3,681.50	5.98	24.07	87.22
63	Accountancy Services	2,189.52	5.99	23.79	83.83
64	Computer and Related Activities	5,656.45	10.85	26.76	119.29
65	R&D	7,685.19	81.70	100.85	189.83
66	Market Research & Advertising	4,007.99	5.55	29.24	139.62
67	Other Business Services	89,403.69	71.45	98.45	211.31
68	Other Professional Services	26,992.06	42.39	69.85	155.06
69	Public Administration	55,526.65	10.26	117.08	371.21
70	Education	36,666.84	9.86	44.13	140.35
71	Health	73,245.00	11.02	38.87	170.49
72	Recreation Services	138,463.13	39.50	74.51	180.43
73	Sanitary Services	42,559.04	51.74	107.94	309.55
74	Other Services	33,790.69	67.96	85.54	166.18
	HH	1,522,000.00	56.18		
	Total	18,612,628.43	-	-	-

Appendix 3: Attribution of waste generation in Welsh production (tonnes) to end users

Sector/ Commodity #	Sector/Commodity Description	Domestic (Welsh) waste generation: Supported by external demand	Supported by Welsh final demand
1	Agriculture & Fish	129,856	45,186
2	Forestry	1,824	385
3	Coal Extraction	0	0
4	Other Mining & Quarrying	3,273,181	2,826,819
5	Meat	117,520	60,743
6	Dairy	61,251	27,750
7	Fish Products, Vegetables, Grain Mill Products	24,730	14,575
8	Bread & Biscuits	19,264	12,631
9	Misc Foods	8,961	9,304
10	Confectionery	3,904	1,738
11	Drinks and Tobacco	3,200	6,794
12	Textiles	14,689	975
13	Clothing	2,346	1,023
14	Wood Products	127,814	82,987
15	Paper and Pulps	58,170	7,602
16	Publishing	62,189	29,940
17	Oil Processing	0	0
18	Chemicals	53,682	2,376
19	Pharmaceutical	4,427	1,255
20	Soaps	18,185	11,335
21	Rubber Products	7,229	1,455
22	Plastics	83,568	17,597
23	Glass and Ceramics	31,842	4,786
24	Cement/Plaster	28,433	11,925
25	Iron and Steel	297,846	6,329
26	Aluminium & Non-Ferrous Metals	961	30
27	Forging/Pressing	99,311	20,642
28	Structural Metals	38,291	8,899
29	Machinery	39,630	12,193
30	Domestic Appliances	13,231	676
31	Office Machinery	1,276	526
32	Electrical Motors and Transformers	11,735	1,773
33	Wires and Cables	29,129	1,249
34	Industrial Electrical Equipment	37,209	2,525
35	Electronic Components	10,378	1,886
36	TVs	2,923	1,125
37	Control Equipment	272,510	60,297
38	Motor Vehicles	69,472	5,641
39	Other Vehicles	27,804	4,199
40	Furniture	202,888	122,378
41	Other Manufacturing	463,060	42,929
42	Electricity	15,642	4,225
43	Gas	0	0
44	Water	0	0
45	Construction	1,359,874	4,592,126
46	Distribution and Repairs	110,502	170,336
47	Wholesale	45,324	21,187
48	Retail	84,694	518,169
49	Hotels, Restaurants, and Catering	149,968	117,147
50	Railways	752	1,180
51	Road Transport	24,493	14,378
52	Sea and Air Transport	2,589	2,559
53	Transport Services and Travel	14,957	5,723
54	Postal Services	23,924	18,568
55	Telecomms	1,038	732
56	Banking and Finance	2,030	883
57	Insurance	4,487	3,641
58	Other Financial Services	1,138	412
59	Real Estate	442	1,345
60	Ownership of Dwellings	27	3,856
61	Renting of Moveables	12,865	13,151
62	Legal Services	2,371	1,311
63	Accountancy Services	1,306	884
64	Computer and Related Activities	3,223	2,434
65	R&D	4,053	3,632
66	Market Research & Advertising	1,522	2,486
67	Other Business Services	58,157	31,247
68	Other Professional Services	17,687	9,305
69	Public Administration	160	55,367
70	Education	5,402	31,265
71	Health	2,308	70,937
72	Recreation Services	22,215	116,248
73	Sanitary Services	19,934	22,625
74	Other Services	4,618	29,172
	TOTAL	7,751,616	9,339,012

Appendix 4: Breakdown of waste generation (tonnes) under the consumption accounting principle (CAP)

Sector/ Commodity #	Sector/Commodity Description	Welsh waste generation attributable to Welsh demands for Welsh sectoral/commodity outputs	External waste generation attributable to Welsh demands for imported sectoral/commodity outputs	DTA Waste 'Footprint' by type of sectoral output/commodity produced to meet Welsh final consumption	Share of total
1	Agriculture & Fish	25,263	225,523	250,786	0.92%
2	Forestry	474	1,332	1,807	0.01%
3	Coal Extraction	-33	1,830	1,798	0.01%
4	Other Mining & Quarrying	2,229,313	332,066	2,561,380	9.42%
5	Meat	62,830	272,957	335,787	1.24%
6	Dairy	33,253	162,081	195,334	0.72%
7	Fish Products, Vegetables, Grain Mill Products	13,867	146,222	160,088	0.59%
8	Bread & Biscuits	13,023	102,396	115,419	0.42%
9	Misc Foods	9,273	72,058	81,331	0.30%
10	Confectionery	1,675	52,310	53,985	0.20%
11	Drinks and Tobacco	17,776	273,299	291,075	1.07%
12	Textiles	1,188	107,399	108,587	0.40%
13	Clothing	1,790	162,375	164,166	0.60%
14	Wood Products	68,345	144,075	212,419	0.78%
15	Paper and Pulps	3,758	92,358	96,117	0.35%
16	Publishing	5,879	151,289	157,168	0.58%
17	Oil Processing	1,449	66,855	68,304	0.25%
18	Chemicals	1,936	138,011	139,947	0.51%
19	Pharmaceutical	-55	14,812	14,758	0.05%
20	Soaps	13,483	92,720	106,203	0.39%
21	Rubber Products	1,217	21,523	22,740	0.08%
22	Plastics	5,382	48,006	53,388	0.20%
23	Glass and Ceramics	3,122	58,079	61,201	0.23%
24	Cement/Plaster	6,142	56,844	62,986	0.23%
25	Iron and Steel	3,231	57,516	60,747	0.22%
26	Aluminium & Non-Ferrous Metals	1,156	61,914	63,070	0.23%
27	Forging/Pressing	16,067	263,968	280,035	1.03%
28	Structural Metals	7,313	149,204	156,517	0.58%
29	Machinery	12,198	296,946	309,144	1.14%
30	Domestic Appliances	701	110,380	111,081	0.41%
31	Office Machinery	804	35,429	36,233	0.13%
32	Electrical Motors and Transformers	2,459	60,954	63,413	0.23%
33	Wires and Cables	222	62,470	62,692	0.23%
34	Industrial Electrical Equipment	1,187	40,958	42,146	0.16%
35	Electronic Components	3,334	85,175	88,509	0.33%
36	TVs	5,973	179,950	185,923	0.68%
37	Control Equipment	44,506	246,582	291,088	1.07%
38	Motor Vehicles	9,861	1,530,106	1,539,967	5.67%
39	Other Vehicles	4,131	254,295	258,426	0.95%
40	Furniture	105,414	312,240	417,654	1.54%
41	Other Manufacturing	29,665	983,648	1,013,313	3.73%
42	Electricity	9,696	75,921	85,617	0.32%
43	Gas	996	35,351	36,346	0.13%
44	Water	8,748	20,086	28,834	0.11%
45	Construction	3,920,692	3,335,971	7,256,664	26.70%
46	Distribution and Repairs	133,428	122,448	255,876	0.94%
47	Wholesale	25,330	59,174	84,504	0.31%
48	Retail	624,493	534,995	1,159,488	4.27%
49	Hotels, Restaurants, and Catering	140,813	416,863	557,676	2.05%
50	Railways	13,662	71,804	85,466	0.31%
51	Road Transport	10,350	39,431	49,781	0.18%
52	Sea and Air Transport	4,003	77,366	81,369	0.30%
53	Transport Services and Travel	5,767	23,164	28,932	0.11%
54	Postal Services	4,017	5,624	9,641	0.04%
55	Telecomms	12,252	112,860	125,112	0.46%
56	Banking and Finance	9,179	59,522	68,702	0.25%
57	Insurance	3,834	302,127	305,962	1.13%
58	Other Financial Services	1,913	7,086	8,999	0.03%
59	Real Estate	28,326	49,626	77,952	0.29%
60	Ownership of Dwellings	423,424	627,667	1,051,090	3.87%
61	Renting of Moveables	6,580	16,588	23,168	0.09%
62	Legal Services	1,632	6,328	7,960	0.03%
63	Accountancy Services	32	153	185	0.00%
64	Computer and Related Activities	-247	7,202	6,955	0.03%
65	R&D	4	86	89	0.00%
66	Market Research & Advertising	7,799	33,447	41,246	0.15%
67	Other Business Services	3,327	16,411	19,738	0.07%
68	Other Professional Services	2,827	8,614	11,442	0.04%
69	Public Administration	628,845	1,383,428	2,012,273	7.40%
70	Education	127,910	285,026	412,936	1.52%
71	Health	179,506	611,694	791,201	2.91%
72	Recreation Services	167,568	336,315	503,884	1.85%
73	Sanitary Services	31,249	68,107	99,357	0.37%
74	Other Services	32,482	39,382	71,864	0.26%
	TOTAL INDIRECT WASTE	**9,339,012**	**16,318,024**	**25,657,036**	**94.40%**
	Direct waste generation by households			1,522,000	5.60%
	Total hypothetical waste generation (DTA)			**27,179,036**	**100.00%**