Who pollutes in Scotland?

A prelude to an analysis of sustainability policies in a devolved context

by Peter G McGregor, Iain H McNicoll, J Kim Swales and Karen R Turner, University of Strathclyde*

Introduction

Sustainable development is a key objective of UK government policies (Department of Environment, 1996) and is receiving increasing emphasis in a regional development context. For example, the Scottish Parliament has responsibility for the protection of the environment, sustainable development is one of the outcome objectives of the Scottish Executive's Framework for Economic Development (Scottish Executive, 2001), and the Scottish Executive is about to host a conference on environmental accounting.[1] Furthermore, the National Assembly for Wales is unique among European governments in having a constitutional duty to promote sustainable development. Given the nature of devolution and the dependence of the success of national sustainability programmes on policies delivered at the regional level, the region has become the natural level on which to focus the evaluation of policies directed at sustainability and formulated within the UK.

We consider that this policy emphasis on sustainable development renders investigation of the economy-environment nexus in Scotland (and in a wider regional context) a matter of some urgency for a number of reasons. First, it is clear that changes in economic policies under the control of the Scottish Parliament may, and typically will, have environmental impacts. Secondly, the economic policies of the Westminster Parliament may also have consequences for the environment in Scotland, and the Scottish Parliament would again presumably wish to know what these are likely to be. Thirdly, in part because of its openness, the Scottish economy is subject to many non-policy shocks that are outwith the Parliament's control, and these too will impact on the environment of Scotland.

Additionally, the Scottish Parliament has the power, within the limits implied by the fact that important taxation powers are reserved to the Westminster Parliament, and by the latter's commitment to key international agreements on environmental improvement, to formulate its own environmental policies. Again, presumably the Scottish Parliament would ideally want to know the economic cost associated with the pursuit of particular environmental policies. Finally, there will undoubtedly be some environmental policies formulated at Westminster that impact on the Scottish environment and economy, and it would be useful to have some means of estimating the direction and scale of such effects.

Overall, there seems little doubt that environmental issues will figure large in the Scottish Parliament. (See e.g. Advisory Group on Education for Sustainable Development, 1999.) Furthermore, credible devolved decision making on environmental issues would appear to necessitate the development of an appropriate database and framework for analysis. Accordingly, we believe that there is now a compelling case for developing an empirical framework for Scotland that will ultimately prove capable of tracking both the economic effects of environmental policies and other environmental disturbances, as well as the environmental effects of economic policies and other economic disturbances.

In this paper we take a modest, but nonetheless important, first step towards providing an appropriate framework for the analysis of economic and environmental policies in a devolved Scotland. Our objective is to generate a database and descriptive analysis that together constitute a prelude to the fuller analysis of sustainability policies.

A Scottish environmental input-output (IO) table for 1998

While there are alternative interpretations of sustainability, there is unanimity that pollution is a critically important element in sustainability and that analysis of the economy-pollution nexus necessitates a multi-sectoral approach because pollution intensities are known to vary dramatically across sectors/industries. IO tables are invaluable sources of data in this context, since they provide a multi-sectoral snapshot of an economy. The tables clearly identify: the destination of each sector's output, in terms of intermediate sales (to other Scottish sectors) and to final demands;

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the pattern of each sector's intermediate purchases and its expenditure on labour and capital inputs. Furthermore, Scotland is in the uniquely favourable position among UK regions of being provided with a regular series of officially compiled IO tables, the latest of which is for 1998 (Scottish Executive, 2001). We proceed, therefore, by augmenting the Scottish IO tables to incorporate key information on pollution by sector.

The original idea for an IO database and model to examine the generation of pollution is attributable to Leontief (1970). Pilot studies exist for Scotland for the year 1989 (McNicoll and Blackmore, 1993)[2], and for the UK for the year 1993 (Vaze, 1997). The present paper is in large part an attempted up-dating of the earlier Scottish study, drawing on the best quality and most recent data available. The up-date seems timely, if not overdue, in view of the new emphasis afforded Scottish environmental issues by the developments identified in the introduction to this paper.

In environmental IO systems the central environmental component is a set of fixed *output-pollution coefficients* that identify the amount of each pollutant associated on average with the production of one unit (normally £1 million worth) of a sector's gross output. In our full empirical analysis, we identify 11 pollutants (including one composite indicator) and 75 sectors. In all there are therefore a total of 825 output-pollution coefficients. Some final demand activities, such as household and tourist expenditures, are responsible for the direct generation of emissions through, for example, the combustion of fossil fuels during heating or transport activities. For these activities we also construct coefficients linking the emission of each pollutant to expenditure by these groups. In fact, in our empirical analysis, data limitations allow us only to treat households in this way. Accordingly we also require 11 household expenditure-pollution coefficients.

How then do we determine the values of each of the 836 output/expenditure-pollutant coefficients? At first sight the measurement of any individual output-pollution coefficient would appear straightforward. We simply divide the amount of each pollutant (normally in kilograms or tonnes) accompanying the production of a sector's output by the sector's gross output (value of sales). However, while the IO tables provide the required estimate of each sector's output in Scotland, there is generally no systematic measurement of the pollutant levels associated with this production.[3] Accordingly, we are compelled to consider indirect methods of measurement of the pollution generated by each sector.

The method employed in the pilot UK environmental IO tables and in the UK Environmental Accounts time series of air emissions is complex (Vaze, 1997). It employs three critical variables to estimate the total amount of a pollutant produced by a sector: its *fuel use* in production; the *emissions factors* associated with the various ways in which the sector uses (combusts) fuels; and the sector's *non-combustion-related emissions*. In Scotland, the absence of much of this required information precludes the adoption of this approach to the estimation of sectoral pollution levels. While there is some information on fuel use by sector available in the IO accounts it is insufficient for present purposes, and we have no information on either emission factors for fuels used in Scottish sectors' production processes or on non-combustion-related emissions for these sectors. Accordingly, we have to consider alternative methods of estimating sectoral pollution in Scotland.

We have attempted to get around this problem by "borrowing" the corresponding UK output- and expenditure-pollution coefficients. This implies assuming that the Scottish output-pollution and consumption expenditure-pollution coefficients are identical to those for the UK. In these circumstances it is important to get as close a match as possible between Scottish and UK sectors and so we conduct the analysis at the maximum level of sectoral disaggregation that the data permit. In fact, using the UK coefficients is not quite as straightforward as it may seem, since we have to estimate these from information that effectively limits the numbers of separate sectors that we can employ in our subsequent analysis.

The United Kingdom Environmental Accounts (UKENA) provide time series accounts of air pollutants (1991-1998) for the 91 sectors used in Vaze's (1997) pilot study. While these are not entirely consistent with the SIC classification used in standard IO, the Environmental Accounts Branch of National Statistics (formerly ONS) has compiled a trial 76-sector economy-environment database that attempts a reconciliation of the IO (123-sector) and UKENA (91-sector) accounts. This uses the same type of framework employed in the Dutch "National Accounting Matrix including Environmental Accounts". This trial NAMEA database is the source of the UK sectoral gross outputs and pollutant levels that we use to calculate output-pollution coefficients for the 75 sectors that are relevant to Scotland. The NAMEA database also allows us to compute a set of household expenditure-pollution coefficients, but does not report the levels of pollutants directly associated with any of the other elements of final demand.[4]

While the use of some national coefficients in regional IO analyses is not at all unusual, it is recognised to be a potential weakness. Specifically, here our use of UK output/ expenditure-pollution coefficients implies that we are assuming:

- Identical fuel use patterns – i.e. we are assuming that the fuel used to produce £1 million of a particular sector's output is the same in Scotland as in the UK.
- Identical technology – i.e. we are assuming that the emissions factors for how much pollution results from burning each fuel are the same in Scotland as in the UK, *and* that non-combustion related emissions (from production processes that do not involve burning fuel) are the same.

→ Identical household expenditure patterns - i.e. we are assuming that the pattern of household consumption expenditures in Scotland is the same as that in the UK.

Since these assumptions are embodied in our 1998 environmental IO database for Scotland, all of our subsequent analysis is dependent upon them.

Who pollutes in Scotland?

We now use the Scottish environmental IO table to help us determine who pollutes in Scotland. For simplicity, although we conduct the analysis at the maximum level of disaggregation (75 sectors), we summarise the results in terms of only 25 sectors. We also focus, again for simplicity, on only two pollutants:

→ a composite indicator, Global Warming Potential (GWP), that captures the emissions of important greenhouse gases and weights them in terms of their potential to cause global warming; [5]
→ and carbon monoxide (CO) that tends to be associated with households' activities, especially travel.

While the choice of these pollutants is purely illustrative, they tend to figure prominently in public policy debates. To help us to identify who pollutes, in terms of emissions of GWP and CO, in Scotland we begin by examining the extent to which each sector is intensive in the production of these two pollutants.

Figure 1 plots the direct emission intensities for GWP. The most striking feature of these direct effects is the GWP-intensity of production in the electricity generating industry; it is more than twice as intensive in the production of GWP than Agriculture an Forestry, the second most GWP-intensive sector. Next in GWP intensity are the Air Transport, Oil Processing and Fuel Distribution, Chemicals etc and Sea Transport sectors. Among the least intensive are Electrical and Instrument Engineering, Financial and Business Services, Construction and Distribution.

So far we have only considered the direct effects of each sector on GWP. However, through their purchases of intermediate inputs from other sectors, each sector also contributes *indirectly* to pollution. The direct emissions of GWP generated by the Electricity sector, for example, implies that there is GWP embodied in that output. When other sectors purchase electricity in order to produce their own output they are then *indirectly responsible* for emissions in the Electricity industry. In fact, we can use the IO table's identification of the (often complex) supply chain for each sector to allow us to calculate the direct plus indirect GWP emission intensities for each sector.[6] These *direct and indirect* GWP intensities are also plotted in Figure 1, immediately adjacent to the direct GWP intensities of production. Since we are adding in indirect effects, these direct and indirect GWP intensities of production always exceed the direct intensities. However, the scale of the indirect effects, both in aggregate terms and relative to the direct effects, vary substantially across sectors, reflecting varying strengths of "backward linkages" in each case i.e. the extent of intermediate purchases from other Scottish sectors.

However, these effects ignore the fact that when the output of one sector increases, the associated increase in employment also raises household income and thereby stimulates consumption. This additional consumption increases GWP directly, through households' fuel use, and indirectly through the consumption of outputs that embody GWP pollution. We are able to add in any changes in GWP that are *induced* by this income-consumption interaction, taking full account of all inter-sectoral linkages.[7] The *direct plus indirect plus induced* GWP-intensity of each sector is also plotted in Figure 1. These are uniformly larger than the *direct plus indirect* GWP-intensities which, in turn, are always greater than the *direct intensities*. Of course, the extent to which induced effects increase the total impact on GWP again varies across sectors, and is greater, other things being equal, the greater the labour intensity of the sector and the higher the wage rate it pays, because these factors stimulate the income-consumption loop. In relative terms then, the biggest impacts are in Public Administration, Other Services and Financial and Business Services, where GWP-intensities can be more than doubled by taking account of induced effects.

Figure 2 summarises the results of a similar analysis, this time for a single pollutant, carbon monoxide (CO). There are two main points of contrast with Figure 1. First, the distribution of pollution intensities across sectors is quite different, with Coal Extraction etc being the most CO-intensive sector and Air Transport the second most CO-intensive sector across all three measures of intensity. Secondly, induced effects are especially marked in this case because of the strong links between household expenditure on travel and the emission of CO.

While inspection of the pollution-intensities of sectors is instructive, it is of only limited use in attempting to answer the question: who pollutes in Scotland? To assess the total contribution of each sector to the amount of each pollutant generated in Scotland we also need to take the scale of each sector into account. Figure 3 summarises the shares in total GWP attributable to production and the household sectors, and this does indeed look quite different from Figure 1. If we first consider the shares of GWP based solely on direct effects, the Electricity industry accounts for over 30% of total GWP generated in Scotland on this basis. This reflects the fact that the direct GWP-intensity of this sector is high and its output is large, relative to other GWP-intensive sectors. In contrast, on the basis of direct emission shares Air Transport, which exhibited the second highest GWP-intensity of production, accounts for less than 3% of total GWP. Indeed, households are the second most important sector in terms of their direct contribution to GWP, accounting for nearly 16% of the total. Agriculture and Fishing contribute just under 10%, Chemicals etc 7%, Oil and Gas Extraction 6%, and Public Administration and Services around 6%, despite the latter having one of the lowest direct intensities of GWP.

The most striking change as shares are computed on the basis of the addition of indirect and then induced effects, is that the share of total GWP attributable to the Electricity industry falls dramatically. Basing shares of total GWP pollution on the sum of direct and indirect effects causes Electricity's share to nearly halve because the Electricity sector sells much of its output to other Scottish sectors. The GWP embodied in these intermediate sales is attributed to these purchasing sectors when shares are computed on the basis of direct and indirect effects combined. Accounting for induced effects too results in a further dramatic cut in the Electricity sector's share of GWP to just over 5% as Electricity's sales to domestic consumption are attributed to the sectors in which household income is generated.

The decline in the share of GWP attributable to Electricity as indirect and induced effects are accommodated is, of course, reflected in corresponding increases in the shares of some other sectors. The most dramatic changes in terms of indirect and induced effects occur to Public Administration, which has by far the largest share when induced effects are also taken into account (nearly 25%, as compared to the next highest share of 7% attributable to Chemicals etc). Public Administration's labour intensity and scale are important explanatory factors here. Another sector that experiences substantial reductions in shares as (especially) indirect and induced effects are incorporated is Agriculture and Forestry, whose share nearly halves when indirect effects are included. Again, this reflects the importance of this sector's sales to other sectors in Scotland, to whom the GWP embodied in their output is consequently attributed.

Figure 4 illustrates a comparable analysis for CO emissions. Here there is an even more striking contrast between sectoral CO-intensities (Figure 2) and shares of the total amount of CO generated in Scotland. The most obvious feature of the shares based on the direct and the direct plus indirect impacts is the total dominance of exogenous final consumption, which accounts for 60% of the total CO produced in Scotland in 1998. Not surprisingly, the picture changes dramatically when income-expenditure effects are accommodated and all of the CO previously attributable to households is re-distributed on the basis of the strength of the income-consumption loop in each sector.

These results serve as a strong health warning against overly simplistic interpretations of emission intensities and pollutant shares based on simple (i.e. direct) sectoral shares of pollutants. While the Electricity industry would appear to bear the main responsibility for GWP on this basis in Scotland, if responsibility is attributed on the basis of the totality of effects considered here (direct plus indirect plus induced) then its share of GWP falls from 30% to 5%. Those responsible for the formulation of environmental policies need to be fully informed on the qualitative and quantitative complexities of the attribution issue. The answer to "who in Scotland poses the greatest threat in terms of Global Warming" is not necessarily the electricity industry. Indeed, on at least one measure, the answer is clearly Public Administration and Services, an extraordinarily unlikely candidate on the basis of naïve analyses.

However, the analysis we have conducted so far does not address the question of who *ultimately* has responsibility for pollution in Scotland, since all production is undertaken with the eventual aim of satisfying final demands. So, for example, electronic industries' intermediate purchases of electricity are undertaken to allow them ultimately to export most of their output; and any intermediate sales are inputs into other sectors' attempts to meet their final demands and so on. Ultimately all intermediate purchases can be attributed to final demands. Accordingly, the sources of final demands, on this perspective, bear ultimate responsibility for pollution in Scotland. If there were no final demands for goods that embody GWP this form of pollution would not exist.

This perspective suggests another way of tackling the question of who pollutes in Scotland, by attributing pollutant generation to the various categories of final demand. Figure 5 summarises the results for the case in which household consumption is treated as exogenous. Here household consumption accounts, directly and indirectly, for by far the biggest share of the output of GWP (39%).[8] Exports to RUK and to ROW are the two next most important sources of GWP. The remaining categories of final demand account, directly and indirectly, for the balance of only 13%. With household expenditure endogenous, the GWP attributable to households is completely reallocated among the other elements of final demand, in accordance with their contribution to the induced effects on GWP. Here consumption expenditure is ultimately driven by the other exogenous elements of final demand. Figure 6 illustrates the resultant shares. Exports to RUK now dominate with a 38% share of total GWP generation, with Exports to ROW being second most important with a 28% share. However, in proportionate terms, the major changes occur in the other sectors, with the share of Local Government rising to 12%, 3 times its original level and Central Government going up four-fold (to 9%). The final demands whose share of GWP increases most are those who demand outputs from comparatively labour intensive or high wage sectors. The approach reflected in Figure 6 could be rejected on the grounds of appearing to absolve households from any ultimate responsibility for GWP, whereas many believe that their behaviour is critical in this respect.[9] Of course, this depends on the perspective of the researchers, and the purpose of the analysis, but there seems little doubt that households could modify their behaviour so as to reduce

GWP. It may therefore be useful to employ some measures which identify households' share of such pollution explicitly.[10]

Figure 7 attributes CO to the various elements of final demand. In comparison with Figure 5 it is clear that household consumption is much more predominant in the generation of CO than GWP in 1998, mainly because of its travel expenditures. Naturally, things change dramatically when household expenditure is made endogenous, so that the CO emissions due to household consumption is attributed to employing sectors, as in Figure 8.

Conclusions and possible extensions

This paper establishes the feasibility of constructing an environmental IO table for Scotland and illustrates the power of environmental IO analysis. Our analysis is only possible because of the provision of Scottish IO tables by the Scottish Executive and the creation of the trial NAMEA database by the Environmental Accounts branch of the Office for National Statistics (ONS). However, we regard the analysis that we present here as only a first step. To begin, there are a number of ways in which the data that we employ here could be much improved.

First, and most importantly, we know that the assumptions underlying our use of UK output-pollution coefficients are in fact invalid:

- → The mix of technologies employed in electricity generation in Scotland, a key polluting sector, is quite different from that employed in the UK as a whole. In particular "clean" hydroelectricity generation is much more prevalent in Scotland than in the UK as a whole.
- → Scottish household consumption is more energy intensive than UK household consumption, because of a greater proportionate spend on heating.
- → Overall our research on the Jersey economy confirms that the use of national instead of regional-specific output-pollution coefficients can be extremely misleading. This case study suggests that the "value added" by local knowledge of fuel use, emission factors and non-combustion related emissions can be very considerable.

In general, the use of UK output-pollution coefficients is not acceptable for serious analysis of pollution in Scotland, and we believe that a high priority should be placed on the development of a Scottish-specific counterpart to the NAMEA database. Furthermore, a widening of the scope of the NAMEA UK database, and any Scottish counterpart, would itself be very welcome.[11]

While these database improvements would be invaluable in improving the accuracy and extending the scope of descriptive analyses such as that conducted here, they are also important in facilitating any move from the present "prelude" to a full analysis of sustainability policies in Scotland. There are a number of developments that would move us towards such an analysis.

- → First, this paper has by no means exhausted the possible uses of the kind of attribution analysis that we employ here. There are interesting issues concerning, for example, the appropriate attribution of pollution generated by interregional and international trade flows,[12] aspects of which are recognised in the literature on "ecological footprints".[13] However, while such descriptive analyses are informative, they are strictly not able to tackle questions relating to marginal policy adjustments directly. This requires further analysis.
- → The most straightforward way to handle policy issues directly is through the use of the Scottish environmental IO model to analyse the impact of policy-induced (and other) changes in final demands.[14] However, while this use of environmental IO yields interesting additional information, it is circumscribed by its well-known, but restrictive, assumptions. In particular, IO models' assumption of an entirely passive supply side precludes a proper analysis of supply-side disturbances, including policies. Yet most regional and environmental policies are precisely of this type.
- → Finally, it is possible to develop multi-sectoral, economic-environmental models for policy analysis that overcome many of the limitations of the environmental IO framework. Environmental computable general equilibrium models (CGEs), are widely employed models of this type, which could, ultimately, be employed to provide a fuller analysis of the impact of environmental policies on a very wide range of environmental indicators, including, for example, genuine savings and green GDP.[15]

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Endnotes

1 Environmental Accounts Seminar, October 2nd, 2001, Victoria Quay, Edinburgh.

2 See also Moffat, I, Hanley, N and Wilson, M D (20001), Chapter 11.

3 There is some attempt to measure pollution directly in the UK through the Pollution Inventory. Ultimately any direct measurement is reconciled with the indirect method that we derive below.

4 In fact, the trial NAMEA data set distinguishes travel and non-travel related emissions, but consumption data are apparently not available for this breakdown, so we aggregate the emissions and divide by the total consumption estimate contained in the 1998 UK 1-O table to generate the 11 expenditure-pollution coefficients.

5 GWP is a weighted sum of carbon dioxide (weight 1), methane (weight 21) and nitrogen dioxide (weight 310).

6 These are Type I output-pollution multipliers.

7 These are Type II output-pollution multipliers.

8 Recall that households are the only final demand group for which we have information on direct emissions. The attribution of shares to other final demands is solely on the basis of their use of locally produced goods that involve pollution generation in their production.

9 In fact we intend to re-specify the model in a way that will modify the results reported in the text. In particular, we intend to accommodate the non-employment income of households as an injection into the local regional economy, rather than as a transfer. Households would always then retain some responsibility for pollution, and given the scale of such income flows, this will be non-trivial. However, the choice of whether to shift to a Type II multiplier analysis will remain.

10 See McGregor, Romeril, Swales and Turner (2001) for further analysis of this issue.

11 Extensions could include: incorporation of all elements of final demand, where relevant, and other (non-air) pollutants; accommodation of further sectoral disaggregation focussed on environmental issues; possibly provision of data that would allow the construction of composite indicators of sustainability that seek to be more comprehensive in their coverage, for example green GDP and "genuine savings". (Hanley, N, Moffat, I, Faichney, R and Wilson, M (1999) provide a time series of these indicators for Scotland.)

12 Some of these trade-related issues are explored, using a Jersey environmental IO table, in McGregor, Romeril, Swales and Turner (2001).

13 Wackernegel and Rees (1996).

14 In McGregor, McNicoll, Swales and Turner (2001) we provide examples of such analyses using the environmental IO table and model described here.

15 Conrad (1999) provides a review of the literature. In McGregor, McNicoll, Swales, Turner and Yin (2001) we illustrate the use of a 25-sector Scottish environmental CGE for analysing the impacts of supply as well as demand disturbances on the output of the pollutants considered here, as well as on economic activity.

Figure 1: Comparison of global warming potential intensities across Scottish sectors, 1998

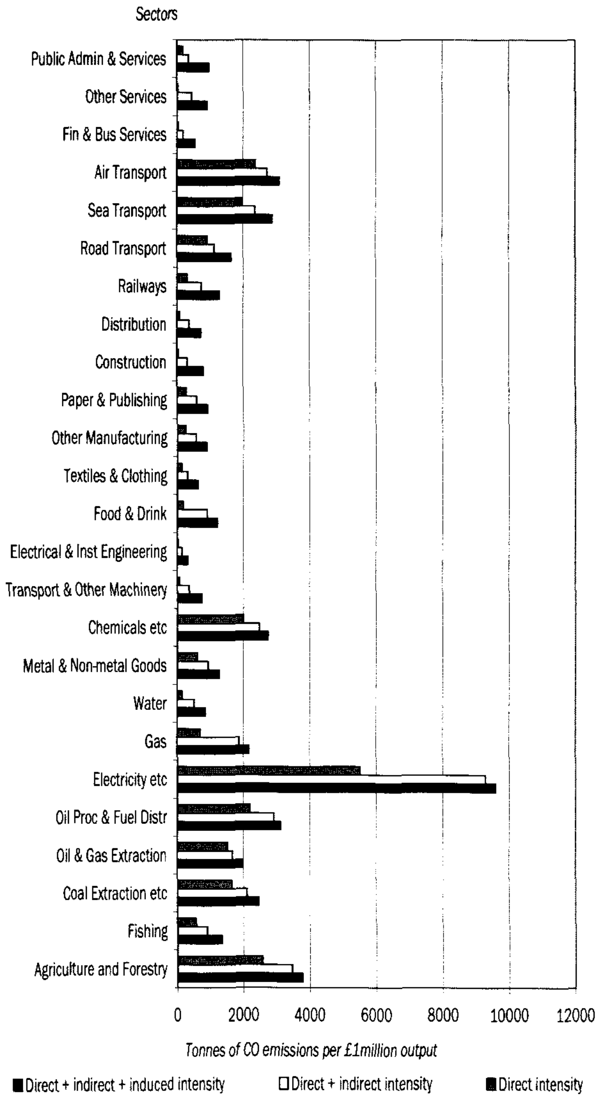
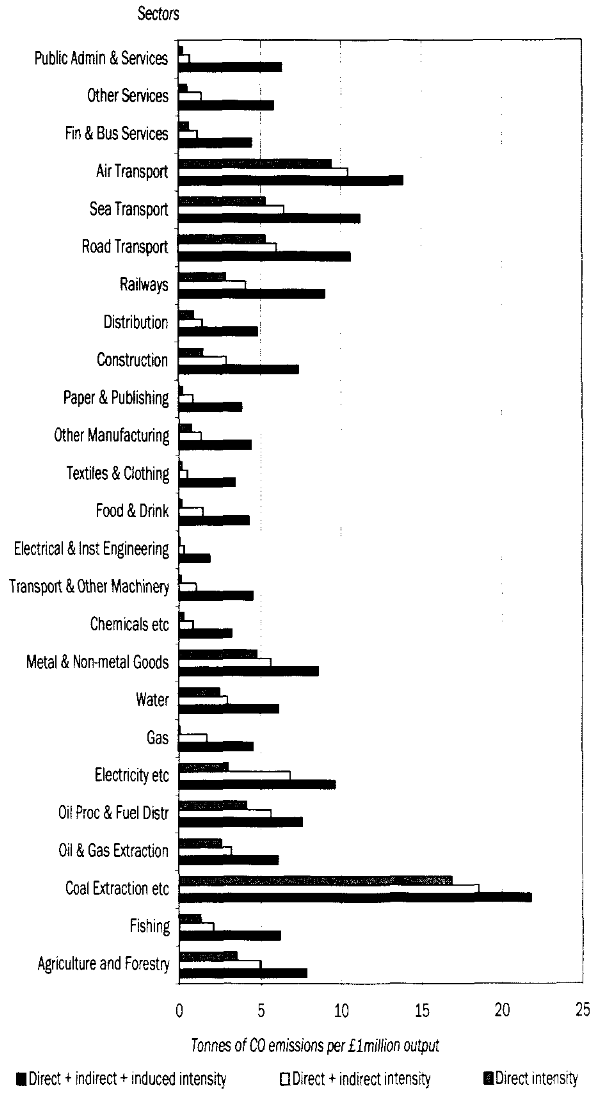


Figure 2: Comparison of carbon monoxide (CO) emissions intensities across Scottish sectors, 1998



Source: Fraser of Allander Institute

Figure 3: Share in Total Global Warming Potential of the Scottish Economy, 1998, Attributable to Production Sectors

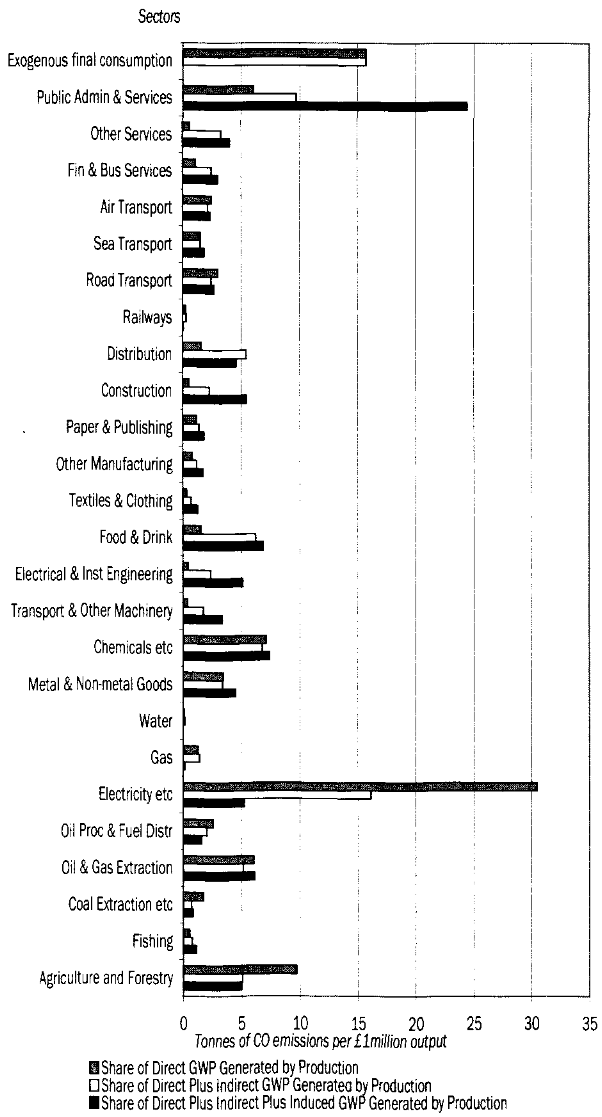
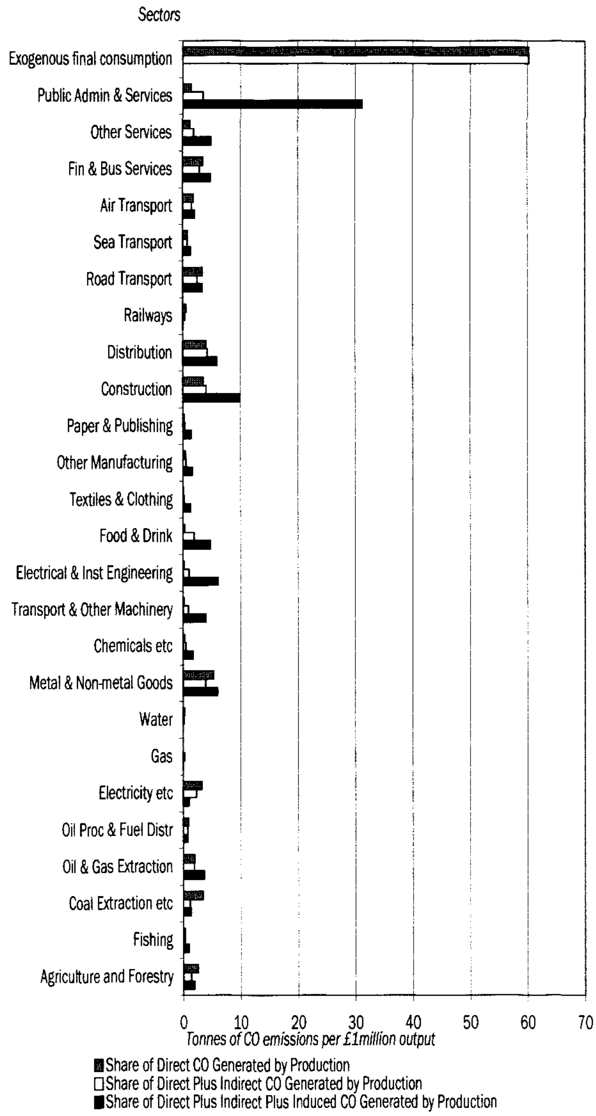


Figure 4: Share in Total Carbon Monoxide (CO) Emissions Attributable to Production Sectors in Scotland, 1998



Source: Fraser of Allander Institute

Figure 5: Final Demand Shares of Total Global Warming Potential in Scotland, 1998 (Household Expenditure Exogenous)

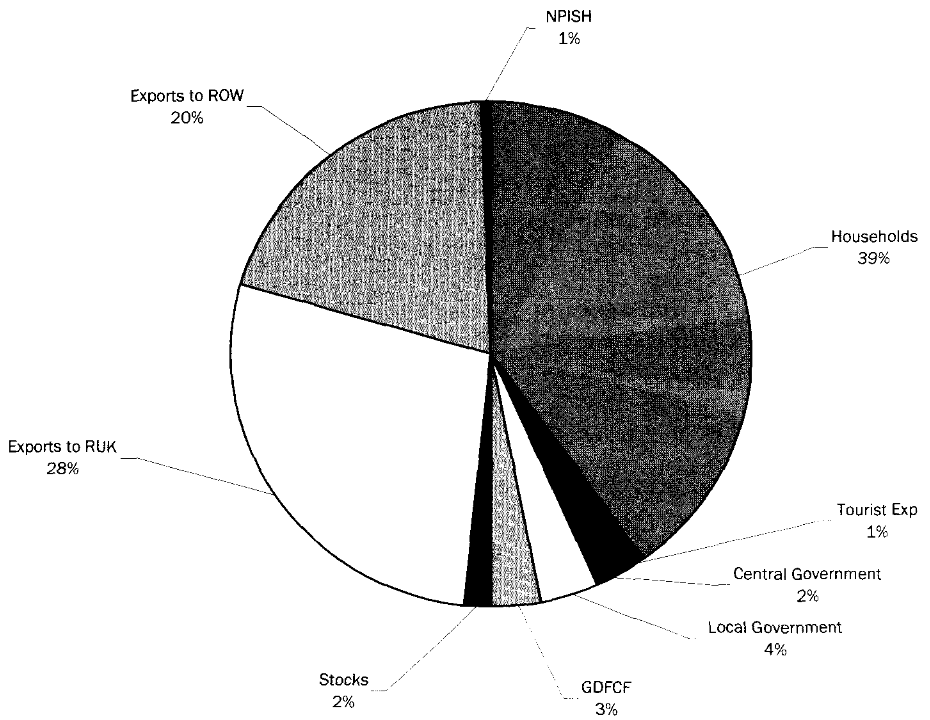
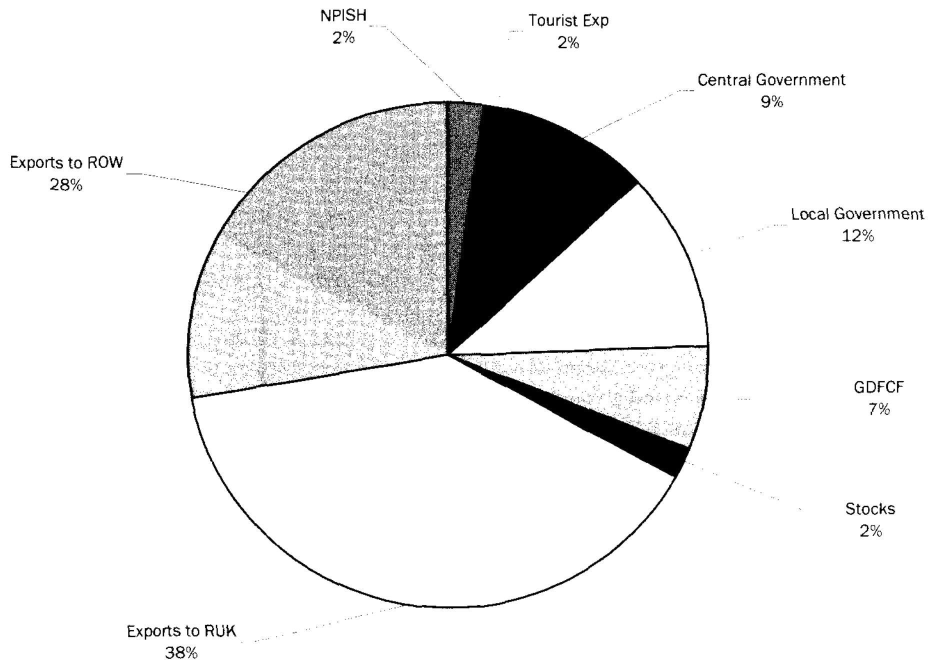


Figure 6: Final Demand Shares in Total Global Warming Potential in Scotland, 1998 (Household Expenditure Endogenous)



Source: Fraser of Allander Institute

Figure 7: Final Demand Shares of Total Carbon Monoxide Emissions in Scotland, 1998 (Households Exogenous)

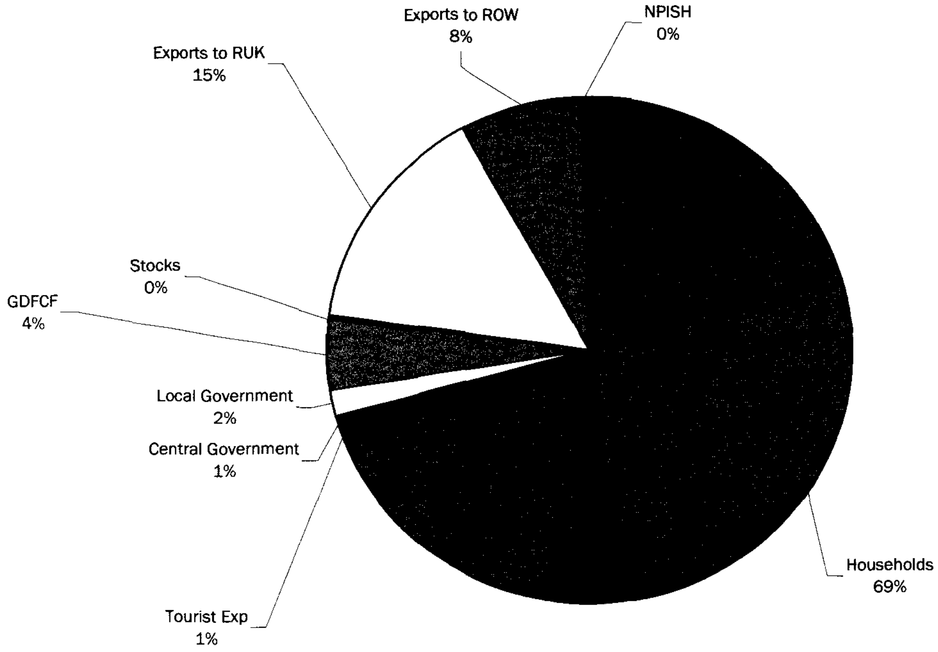
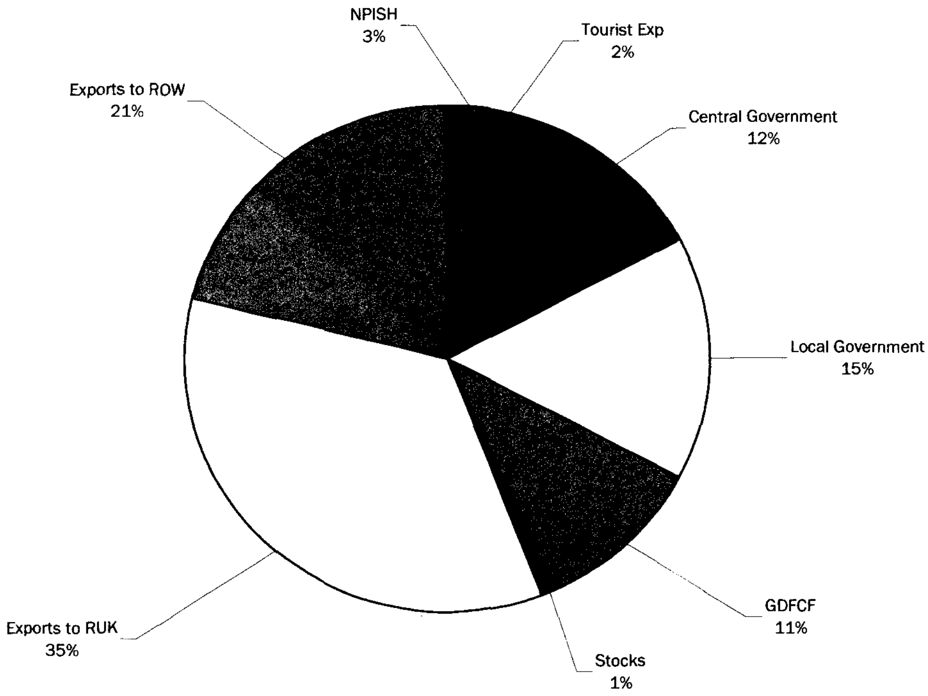


Figure 8: Final Demand Shares of Total Carbon Monoxide Emissions in Scotland 1998 (Household Expenditure Endogenous)



Source: Fraser of Allander Institute