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An Input-Output-Based Alternative to "Ecological Footprints" for Tracking Pollution Generation in a Small Open Economy*

by

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Abstract:

The usefulness, rigour and consistency of Input-Output (IO) as an accounting framework is well known. However, there is concern over the appropriateness of the standard IO attribution approach, particularly when applied to environmental issues (Bicknell *et al.* 1998). It is often argued that the source and responsibility for pollution should be located in human private or public consumption. An example is the "ecological footprint" approach of Wackernagel and Rees (1996). However, in the standard IO procedure, the pollution attributed to consumption, particularly private consumption, can be small or even zero. Here we attempt to retain the consumption-orientation of the "ecological footprint" method within an IO framework by implementing a neo-classical linear attribution system (NCLAS) which endogenises trade flows. We argue that this approach has practical and conceptual advantages over the "ecological footprint". The NCLAS method is then applied to the small, open economy of Jersey.

Key words: environmental input-output, ecological footprint, pollution multipliers, Jersey.

1. Introduction

In the ecological literature there is a concern to account for the full environmental impacts of current production and consumption decisions. This information is needed as the first step in adjusting economic behaviour to meet environmental targets and to optimise true social welfare. Perhaps the most familiar expression of such concern is the "ecological footprint" concept (Van den Bergh and Verbruggen, 1999; Wackernagel and Rees, 1996, 1997) and Bicknell *et al*, (1998) show how Input-Output (IO) data can be used to calculate the ecological footprint. Here we wish to put forward an alternative IO based approach to environmental accounting. This retains the emphasis that the ecological footprint gives to final consumption as the ultimate source of pollution generation, but is more easily calculated and has greater practical relevance.

One key element of the ecological footprint method is the way in which it combines a vector of resource-use and pollution-generation flows into a scalar index of land use that is taken to be a measure of sustainability. It is important to stress from the start that we do not discuss here the debates over the desirability or practicability of such an index (Turner, 2002). We are, rather, concerned with the prior, and quite distinct, stage in the ecological footprint procedure. This is the allocation of resource use and pollution generation to final consumption in an open economy.

On this score, the ecological footprint approach has two important limitations. First, its precise calculation requires an enormous amount of currently unavailable data. Second, it attributes the direct and indirect pollutant generation and resource use embedded in the production of imported goods to consumption in the importing country. This seems to place the responsibility for pollution generation and resource use occurring in one legislative domain to decisions made in another legislative domain. However, self interest and international treaties generally require that governments take responsibility for pollutant generation and resource use within their own territories.

We therefore modify the standard environmental Input-Output (IO) method (Lenzen, 1998; McGregor *et al*, 2001a, 2001b) in a way that retains the focus on final consumption but overcomes these two problems. This approach, which we call a Neo-Classical Linear Attribution System (NCLAS), allocates all pollution generation and resource use within a territory to the various elements of final consumption within that territory. It does so by endogenising export demand and is much less data intensive than the ecological footprint calculation.

We use the NCLAS method to attribute CO_2 and six other air p[ollutant generation in the Jersey economy to the various elements of local final consumption (public and private) for the year 1998.[1] The States of Jersey have an IO table, with detailed household consumption expenditure broken down by income quintiles. They are also signed up to the UK's commitment to CO_2 reductions under the Kyoto agreement and place a high value on the local environment so that they have relatively extensive and accurate environmental data.[2] This attribution exercise therefore both provides an ideal test bed for the NCLAS method and generates results that are of genuine interest.

[1]Jersey is the largest of the Channel Islands, a group of islands that lie to the east of the French Normandy coast, about 100 km south of the English mainland. It is a UK crown dependency and, as such, is an independent, self-governing state. However, it has close economic links with the UK, sharing its language, currency, exchange and interest rates.

[2] This region-specific environmental database is unique in the wider UK context.

In Section 2 we discuss the use of the IO framework for physical attribution in general and environmental attribution in particular and in Section 3 we give a more technical account of the NCLAS approach. Section 4 applies the NCLAS method to data for the States of Jersey. We identify both the pollution intensity of, and the total pollution generated by, consumption from the public sector and household income quintiles. Section 5 is a short conclusion.

2. Use of IO Framework for Physical Attribution

It will prove instructive initially to discuss some general issues involved in using Input-Output (IO) as an accounting framework for physical variables, focussing specifically on resource use and the emission of pollutants. One general point should be made from the start. All the accounting systems discussed here attribute these physical quantities in a systematic and consistent manner. However, different accounting systems present the data in different ways that aid in the presentation of alternative perspectives. Whilst none is correct or incorrect in principle, they can be judged according to their tractability and usefulness.

Certain aspects of the extension of IO accounting to physical variables are familiar. However, when these techniques are applied to pollution generation some additional issues are raised. Moreover, we introduce here a novel attribution method – NCLAS, a Neo-Classical Linear Attribution System - which we apply in later sections of the paper. We begin with the attribution of resource use in a closed economic system. We subsequently extend the discussion to deal with an open economic system and then pollution attribution.

2.1 The Attribution of Resource Use in a Closed Economic System

A standard IO table is a set of accounts measured in money values. When IO is used for modelling purposes, the key set of endogenous variables is the vector of gross outputs of production sectors. The value of production for an individual sector is converted to physical output through the assumption of constant prices.[3] The core of IO analysis is therefore the production of gross output within a particular territory and this focus is naturally associated with the generation of value added at the sectoral level and Gross Domestic Product for the economy as a whole. Any physical variable that can be linked to sectoral outputs can be modelled using IO analysis, and where all sources of a physical variable are production related, then IO attribution techniques can be straightforwardly applied.

An obvious example is employment. Employment is not formally a component of the IO accounts. However, for every sector there is an immediate link between employment and the wage contribution to value added. Independent knowledge either of direct sectoral employment or sectoral average wages makes the connection between direct sectoral output and employment, and allows the use of IO techniques in employment attribution. Similarly, resource use, by which we mean the use of non-produced inputs (oil reserves etc.), can also be coupled with an element of value added - resource rentals - which is a component of other value added in the IO accounts. If direct resource use is linked to sectoral value added - and therefore to sectoral gross outputs - the whole of resource use can be attributed to the output of individual sectors.[4]

[3] Some authors have argued for a variable price interpretation of IO (El-Hodiri and Nourzad, 1988; Klein, 1952-53), but if prices are allowed to vary Computable General Equilibrium (CGE) analysis is generally required. (Dorfman,1954; Greenaway *et al.* 1993)

[4] This is on the assumption that none of the resource is consumed directly, but requires at least some initial extraction and/or processing. Exactly the same type of assumption is normally made for employment, where all employment is conventionally allocated to industrial sectors.

The power of IO analysis is the recognition that much gross output is used as intermediate inputs and that this intermediate activity can be attributed to final demands through multiplier analysis. Therefore IO can attribute resource use to final demands which are portrayed as the ultimate drivers of production. This attribution incorporates both the direct and the indirect resource use involved in production for that final demand.

From an ecological viewpoint, the IO approach seems ideal in an economic system that is closed to trade (Bicknell *et al*, 1998). Standard Type I multipliers can be used to attribute all resource use within the appropriate territory to the elements of private and public consumption occurring in that territory (Miller and Blair, 1985).[5] Such an attribution is a useful tool for decision making as it identifies resource intensive consumption expenditures. Similarly, it can be used to attribute responsibility for resource use across different life-styles: the rich versus the poor, urban versus rural etc. It also suggests the likely income distribution implications of policy-induced resource tax changes.

2.2 The Attribution of Resource Use in an Open System

In the conventional IO analysis of an open economy, there is an additional element of final demand, exports, and an additional source of non-domestically-produced supply, imports. The attribution method is, in principle, unchanged: the resource use in the economy under analysis is attributed to final demands (Lenzen, 1998; McGregor *et al*, 2001a, 2001b). However, in this case, some of these demands, exports, originate outwith the economy under

[5] Type I Input Output multipliers treat household consumption as exogenous. Type II multipliers endogenous household consumption as a linear function of wage income. The role of investment is partly to increase future consumption and partly to cover depreciation. In this paper we take all investment as depreciation, so that it is endogenised. However, no conceptual problems are raised by treating investment either partially or fully as exogenous consumption.

consideration. In fact, where conventional Type II IO multipliers are used - so that consumption expenditure is wholly or partially endogenised - either none or very little domestic resource use is attributed to household consumption. Similarly, in this standard IO account, the resource use indirectly embodied in the imports consumed directly, or indirectly through their use as intermediate inputs, is not attributed to the consumption within the economy being studied.

This means that the standard IO and ecological footprint attribution methodologies differ. The ecological footprint approach attributes to consumption within an economy both the domestic and the foreign resources embodied directly or indirectly in the production supported by that consumption. The ecological footprint therefore also draws a clear distinction between the resource use within an economy and the resource use driven by the public and private final consumption of that economy. However, whilst the ecological footprint is a valid accounting standpoint, and one that appears to have considerable intuitive and pedagogic appeal (Wackernagel and Rees, 1996, 1997), it is impractical and conceptually problematic.

But before we discuss these difficulties and suggest an alternative solution, it is important to say that the standard IO attribution, using Type II multipliers, is an appropriate environmental accounting technique under certain circumstances. These would be situations where economic activity in a particular territory is not primarily motivated by household consumption in that territory. Examples are where a remote region's resources are being exploited to develop exports important for the national economy or its advantageous location used to sight defence establishments. The relevance of the standard Type II IO option is enhanced if population is endogenous and thought to be a key element of the environmental problem. Therefore decisions about the development of wilderness areas should incorporate the environmental impact of the accompanying influx of workers. The standard Type II IO analysis accomplishes this through endogenising household consumption.

We now return to the problems with the ecological footprint approach. The major practical difficulty is that, in principle, it entails the consistent collection and collation of a large amount of data (Office of National Statistics, 2002). To identify and allocate the direct and indirect resource use embedded in imports requires detailed knowledge of their commodity breakdown and how they are used in the economy. Further, a compatible resource-augmented IO table for each of the countries that supply imports is needed, so that the direct and indirect resource use incorporated in these commodities is identified too. However, such an attribution would require a similar knowledge of the imports of these exporting country, and so on. Except for economies engaged in very restricted trading arrangements, the ecological footprint method strictly requires a world IO table that is consistently nationally and sectorally disaggregated. It also requires an associated set of resource accounts. Such a database is simply not available at present.[6]

In ecological footprint calculations, short-cut methods are used to estimate embedded pollution and resource use (Wackernagel and Rees, 1996). Within an Input-Output context, Bicknell *et al* (1998) calculate an ecological footprint for New Zealand using a national IO table and information on imports by commodity and use. This calculation is made on the assumption that the detailed production-function and land-use characteristics of the economies from which New Zealand is importing are identical to those for the New Zealand economy. However, apart from tractability, it is difficult to defend this procedure. There is no attempt by the authors to argue that the New Zealand economy is somehow representative. Therefore there is no empirical basis for the assumption that its IO relationships are a good approximation of the same relationships elsewhere. Given that Bicknell *et al*, (1998, p. 157) calculate that "… over 26% of the total land embodied in the goods and services consumed in New Zealand is imported", this 26% represents conjecture, not fact.

A second problem with the ecological footprint approach relates to a conceptual difficulty. It is not obvious that the resource use in one legal jurisdiction should be attributed to consumption activity within another. Where trade occurs voluntarily, responsibility for resource use might be thought to rest as much with the supplier as with the demander. For example, if a supplying country uses particularly resource-intensive methods of production, is this the responsibility of the purchasing country?[7] Further, attributing the responsibility to the ultimate consumer in the way suggested by the ecological footprint, requires, as we have seen above, information that the consumer has neither the ability, nor necessarily the legal power, to collect.

In the neo-classical, resource-constrained, view of the operation of the open economy, exports essentially finance imports (Dixit and Norman, 1980). Using the IO accounts, this approach can be used to retain the link between domestic consumption and domestic resource use by endogenising exports. In this method, an importing sector is attributed the resource use embodied in the domestic export production required to finance those imports. In a national context, this places the responsibility for resource use at the appropriate spatial level. It also

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[6] An IO analysis attributing UK pollution across regions to regional public and private consumption is attempted in Ferguson *et al* (2003). Even here there are data problems.
[7] Where the government in the supplying country has difficulty controlling the exploitation of its own resources, purchasing countries might agree to legal restrictions on their consumption. The ban on the ivory trade is an example.

utilises available data. We call this technique the Neo-Classical Linear Attribution System (NCLAS).

2.3 The Attribution of Pollution Generation in an Open System

Broadly the same arguments hold for pollution generation, but there is an important difference. In general, pollutants are created in use, rather than in production: for example, CO_2 is generated by the use (combustion) of fuel, rather than by the production of fuel, as such.[8] This means that, from the start, pollution within a particular territory is linked more closely with the direct and indirect domestic consumption of commodities, rather than their production. This can be dealt with in an IO framework. However, in general, the procedures are more complex than those that link endogenous physical quantities, such as labour and resource use, directly to production.

In a closed economy there is no difficulty. The production of pollutants can be allocated to the use of domestic commodities in production (as intermediate inputs) or in private or public consumption, as final demand. However, in an open economy, the use of imported commodities might directly generate pollutants. An example is where an economy combusts imported fuels, either in industrial processes or in consumption. It needs to be stressed that this is distinct from the problem raised in Section 2.2 - highlighted in the ecological footprint approach – over pollution embedded in the production of imports. That problem concerned pollution in an exporting economy that the ecological footprint attributes to the consumption in the importing economy. Here we are concentrating on pollution associated with the use of

[8] Of course the production of fuel causes pollution but primarily because the production of a specific form of fuel requires the combustion of other fuels. Examples are the use of coal, gas and oil in electricity generation.

imported commodities in the importing economy. In order to track this pollution, information is again needed on the composition of imports and their use.

One question is whether the territory within which the pollution is generated is still the correct focus for an attribution exercise. In a standard IO attribution, pollution occurring as a direct result of consumption is attributed to the consumer. However, where pollution is the indirect result of consumption, only that occurring within the economy is attributed, not any that is embodied in the production of imports. We again suggest that the NCLAS is an appropriate procedure. This attributes the direct and indirect pollutants generated in the production of exports to activities that require imports.

As argued in the previous section, this within-economy focus can be defended on both practical and conceptual grounds. The method is relatively tractable and the import data requirements, whilst not automatically included in standard IO accounts, are much less demanding than for the ecological footprint calculations. Moreover, the within-economy frame of reference is also sensible from a policy perspective. For pollutants with a local incidence, the appropriate responsible body is the local legislature. But even for pollutants that have an international or global significance, such as greenhouse gases, governments typically agree to international treaties that control the pollution generation within their own borders (see, for example, the Kyoto agreement). Governments do not generally agree to reduce their consumption of imports whose production generates pollution elsewhere, or to reduce their exports because the consumption of these exports will produce pollution in other countries.

Before discussing the specific attribution procedures that we have pursued, two further issues should be raised. The first is that it might seem paradoxical that the NCLAS formulation uses the IO accounts as the basis for a supply-constrained, neo-classical attribution procedure when IO is more usually associated with a Keynesian, demand-driven, approach. However, an IO table is simply a set of accounts that detail the flow of commodities and factor services within an economy over a given period of time. The table is a snapshot of the actual economy that applies, independently of how these flows are determined.

When IO is used conventionally as a modelling device, assumptions of constant returns and no resource constraints are imposed. In such a system, exogenous demands drive the level and industrial composition of economic activity, with consumption often endogenised. However, even for IO modelling such an interpretation is not necessarily implied: see, for example, the supply-driven IO approach outlined in Ghosh (1958). But the procedure we undertake in this paper is not modelling but attribution and consumption is given the central role. This is wholly consistent with an economy attempting to maximise consumption given resource (labour, natural resources and capacity) constraints. That is to say, this procedure is entirely compatible with a neo-classical point of view.[9]

Where attribution is concerned, the implied economic assumptions are much weaker than in standard IO modelling. These assumptions are simply that there is within-sector homogeneity of output, technology and import patterns, and that the economy is in long-run equilibrium. The linear attribution is similar in principle to the decomposition to dated labour in Sraffa (1960) who specifically states that the analysis is not dependent on constant returns to scale. This implies that the standard attribution processes can be applied even where production processes exhibit decreasing returns and where sector output is determined by the traditional neo-classical interaction of supply and demand

A second issue is that the appropriate NCLAS procedure identifies resource use embodied in the production of Gross Domestic Product, whilst the ecological footprint identifies resource use embodied in Gross National Expenditure. However, for the attribution of pollutants the situation is more complex. As we have seen, in this case the NCLAS technique allocates direct pollution generation to both production and consumption. Some pollution is generated simply by the consumption of imported commodities and is not linked to their production at all. The situation can be conveniently illustrated by considering fuel exported from one country to another. Using the NCLAS method, the resource use embedded in the fuel would be attributed to the exporting country, but the direct pollution effects of combusting the fuel would be attributed to the importing country.

3. A More Formal Account of Resource and Pollution Attribution

In this section we look a little more precisely at the problems of attributing resource use and pollution generation. Whilst the actual attribution in Section 4 using Jersey data is limited to pollutants, it is interesting to compare formally the principles of resource and pollution attribution. The approach in this section is analytic and we impose a number of simplifying assumptions to reveal the underlying differences in the attribution procedures. We stress, in particular, the additional difficulties encountered with pollution attribution.

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[9] We do not favour a neo-classical approach here out of any ideological or political conviction but rather because this seems more appropriate in a setting that focuses on resource use and sustainability.

The simplifying assumptions are as follows. First, we link resource use solely to commodity production and we link pollution solely to commodity use. This commodity use can be either for direct public or private consumption or as an intermediate input. Second, the pollution generated by the use of one unit of a particular commodity is assumed not to vary across different uses. Third, we are concerned with accounting for resource use and pollution generation within a particular territory. Fourth, we assume final demand can be broken down into domestic consumption and exports, where export use generates no direct pollution in the exporting territory.

3.1 Resource Use

In an accounting sense, over a given time period, the vector of total resource use, r, can be determined if we know, for the same time period, the matrix of average direct resource output coefficients, Ω, and the vector of sectoral gross outputs, q. It is given as:

$$r = \Omega q \tag{1}$$

where r is an r x 1 vector with element r_i being the total use of resource i, q is an q x 1 vector, where q_i is the total output of commodity i and Ω is an r x q matrix with element $\omega_{i,j}$ as the average use of resource i per unit of output of sector j.

It is trivial to allocate the resource use to the output of individual sectors.

$$R^Q = \Omega Q \tag{2}$$

where R^Q is a r x q matrix, where the element $r^Q_{i,j}$ is the total use of resource i from the production of sector j and Q is an q x q diagonal matrix where ith diagonal element is q_i. However, any mechanism for determining the elements of the q vector - treated as exogenous in equation (1) - can be used to drive resource use attribution. In particular, the standard IO attribution can be employed (Miller and Blair, 1985), so that equation (1) can be extended to:

$$R^E = \Omega(1 - A)^{-1} F \quad (3)$$

where R^E is an r x e matrix where the element $r^E_{i,j}$ is the total use of resource i directly or indirectly generated by final demand expenditure j, A is the standard q x q matrix of average IO input coefficients, so that $(1\text{-}A)^{-1}$ is the Leontief inverse, and F is the q x e matrix of final demands, where the element $f_{i,j}$ is the expenditure on sector i by final demand category j. In general, the final demand expenditures categories are the exogenous expenditures identified in the IO table: household consumption, public consumption, investment and exports. However it is also very straightforward to endogenise elements of final demand - as under our NCLAS attribution - as they have no direct resource use.

It will prove useful to express the final demand matrix as:

$$F = \Phi E \quad (4)$$

where Φ is a q x e matrix of average final demand coefficients, where element $\phi_{i,j}$ is the average expenditure on domestically produced commodity i, per unit of final demand expenditure j and E is a diagonal e x e matrix where the ith diagonal element is the total expenditure made by final demand category i.

Using equation (4), equation (3) can be restated as:

$$R^E = \Omega(1-A)^{-1}\Phi E \tag{5}$$

The matrix R^E gives pollution attributed to final demand categories, such as household consumption, public consumption etc. However, we can also attribute resource use to final demand by industrial sector. This is given in the r x q matrix R^D, defined as:

$$R^D = \Omega(1-A)^{-1} D \tag{6}$$

where element $r^D_{i,j}$ is the amount of resource i used directly or indirectly in the production of the final demand for the output of sector j, and D is a q x q diagonal matrix where the ith diagonal element, d_i is the total final demand for the output of sector i.

In the RHS of equation (3), the resource coefficient matrix and the Leontief inverse can be combined to generate an r x q matrix of resource use - final demand sector multipliers, M^{RF}, where:

$$M^{RF} = \Omega(1-A)^{-1} \tag{7}$$

and the element $m^{RF}_{i,j}$ is the amount of resource i used, either directly or indirectly, generating a unit of final demand for sector j. Equations (3) and (6) can thus be restated as:

$$R^E = M^{RF} F \tag{8}$$

and

$$R^{D} = M^{RF} D \tag{9}$$

Similarly, in equation (5) we can combine the resource coefficient matrix, the Leontief inverse and the final demand coefficient matrices to produce an r x e matrix of resource use – final demand category multipliers, M^{RE}, where:

$$M^{RE} = \Omega(1 - A)^{-1}\Phi = M^{RF}\Phi \tag{10}$$

and the element $m^{RE}_{i,j}$ is the amount of resource i used, either directly or indirectly, in production to meet one unit of final demand expenditure in category j. Using equation (10), equation (5) can therefore be restated as:

$$R^{E} = M^{RE} E \tag{11}$$

One key point is that interest in the equations outlined in this section derives from their description of a closed analytical system. A set of consistent IO accounts give the key vector of gross outputs, q, and the average intermediate-coefficient and final-demand matices, A and F. These data are combined with the direct resource-use coefficient matrix, Ω. The vector of total resource use is then given by equation (1) and this resource use is attributed in alternative ways in equations (2), (3) and (6) and represented in matrices R^{Q}, R^{E} and R^{D}. These matrices are derived as part of a consistent accounting framework, such that summing across the rows of any of these matrices generates the total resource-use vector.

When this method is applied to figures from an actual economy, if the IO accounts or the direct resource-use matrix are inaccurate, the attribution procedure will also be inaccurate though internally consistent. However, even if the IO table and the direct resource-use coefficient matrix are accurate, the assumptions outlined in Section 2 need to hold if the attribution interpretation given here is to be valid. Recall that these assumptions are that there is within-sector homogeneity and that the economy is in long-run equilibrium.

It is straightforward to illustrate the importance of the first assumption. Imagine an aggregate sector that actually comprises two separate segments with different production and import characteristics. If these two segments have different patterns of sales to intermediate and final demand, the procedures outlined here will not attribute resource use accurately. Similarly because economic activity occurs through time, the attribution process is valid if the economy were maintained unchanged in its present form. If the economy is not in long-run equilibrium this is not an appropriate supposition to make. Exactly the same general arguments apply to pollution attribution.

3.2 Pollution generation

Under the simplifying assumptions adopted here, the vector of aggregate pollution generation within the economy is given by:

$$p = \Pi u \tag{12}$$

where p is a p x 1 vector of total pollutant generation, with the element p_i the total amount of pollutant i, Π is a p x q matrix of direct pollution coefficients, where element $\pi_{i,j}$ is the amount of pollutant i generated directly by the use of one unit of commodity j, and u is a q x 1 vector of domestic commodity use. Element u_i of vector u is the total domestic use of commodity i whether such use occurs as direct private or public consumption or as an element of intermediate demand.

Analogous to the treatment of resource use in Section 3.1, it is straightforward to attribute pollution by domestic commodity use:

$$P^U = \Pi U \tag{13}$$

where P^U is a p x q pollutant – commodity use matrix where element $p^U_{i,j}$ is the amount of pollutant i generated by the use of commodity j, and U is a q x q diagonal matrix where the ith diagonal element is u_i. However, we wish to attribute pollution solely to elements of final private and public consumption. We therefore need to determine the relationship between commodity use and the elements of final consumption. This problem is more complex than that facing resource use attribution.

The first step is to note that the total domestic use of a commodity equals the domestic production plus imports minus exports, so that:

$$u = q + m - x \tag{14}$$

where m and x are q x 1 vectors of total commodity imports and exports with elements m_i and x_i being the imports and exports of commodity i respectively. One major practical problem is that although export and output vectors are identified in IO accounts, import vectors - by which we mean a vector of imports disaggregated by commodity - often are not. Moreover, if we wish to attribute pollutants to elements of final demand we need the breakdown of imports, not only by commodity but also by use. However, as we argued earlier, these data requirements are much lower than those for an ecological footprint approach.

Assuming that the import data are available, the problem becomes tractable if commodity use is split into intermediate demand and direct final consumption demand, identified here by I and D superscripts. Pollutants generated by the use of commodities as intermediate inputs are given as:

$$p^I = \Pi B^I q \qquad (15)$$

where B^I is a q x q matrix of total (imports plus domestic commodities) direct input coefficients, where element $b^I_{i,j}$ is the average direct input of commodity i needed for one unit of output of commodity j. The B^I matrix is the sum of the standard A matrix introduced in equation and a q x q import coefficients matrix, T^I, so that:

$$B^I = A + T^I \qquad (16)$$

where element $t^I_{i,j}$ is the average input of imports of commodity i per unit of domestic production of commodity j.

Again any means, including the standard IO method, for deriving the q vector can be used to underpin the pollution generation through the consumption of commodities as intermediate inputs, so that

$$P^{IE} = \Pi B^{I}(1-A)^{-1}F = \Pi B^{I}(1-A)^{-1}\Phi E \qquad (17)$$

where P^{IE} is a p x e pollutant–final demand category matrix, where element $p^{IE}_{i,j}$ is the amount of pollutant i generated in the production of one unit of final demand category j, and the matrices Φ, E and F are as in equation (4).

In a conventional IO approach, equation (17) attributes some pollution to final demand expenditure on exports. However, as argued in Section 2, in the NCLAS formulation favoured here, we endogenise export demand. From a resource-constrained neo-classical viewpoint, the production of exports simply finances imports.[10] Therefore with the NCLAS method the only categories of final demand included in the Φ, E and F matrices are private and public consumption.

Similarly to the treatment of resource use in Section 3.1, the matrices of direct pollution generation coefficients and of total commodity input coefficients, and the Leontief inverse can be combined to create a p x q multiplier matrix M^{PIF}:

$$M^{PIF} = \Pi B^{I}(1-A)^{-1} \qquad (18)$$

[10] We also endogenise investment as covering depreciation.

where the element $m^{PIF}_{i,j}$ is the amount of pollution of type i, generated in production, directly or indirectly, for each unit of final demand for industry j.

It is also useful to identify the p x e multiplier matrix, M^{PIE}, created by the product of the matrices of direct pollution generation coefficients, total commodity input coefficients, the Leontief inverse and final demand coefficients, so that:

$$M^{PIE} = \Pi B^{I} (1 - A)^{-1} \Phi = M^{PIF} \Phi \quad (19)$$

where the element $m^{PIE}_{i,j}$ is the amount of pollution generated of type i, directly or indirectly, per unit of expenditure for final demand category j.

The second step of the allocation procedure is to calculate the pollutants produced directly through commodity use in final consumption. Here:

$$P^{DE} = \Pi B^{E} E \quad (20)$$

where P^{DE} is a p x e matrix of total pollutants directly generated in the use of commodities as elements of final demand, where element $p^{DE}_{i,,j}$ is the total amount of pollutant i directly generated by one unit of final demand expenditure j, B^E is a q x e matrix of total domestic consumption (imports plus domestically produced) input coefficients where element $b^{E}_{i,j}$ is the domestic consumption of commodity i per unit of expenditure in final demand type j.[11]

[11] In the empirical work reported in Section 4 we adopt the NCLAS approach and endogenise exports. However, if exports were part of exogenous final demand, given that there is assumed to be no domestic consumption associated with exports, all the elements in the appropriate columns of the B^E and P^{DE} matrices would be zero.

Again, the B^E matrix is the sum of the Φ matrix of average final demand coefficients, introduced in equation (4) and a q x e matrix T^E of import final demand coefficients, so that:

$$B^E = \Phi + T^E \tag{21}$$

where the element $t^E_{i,j}$ represents the average import of commodity i, per unit of final demand expenditure j.

Again it will be convenient to combine the matrix of direct pollutant coefficients for commodities and the matrix of total input coefficients, to get a matrix of direct pollution coefficients for final consumption, D^{PE}:

$$D^{PE} = \Pi \mathrm{B}^E \tag{22}$$

where the element $d^{PE}_{i,j}$ is the direct amount of pollutant p generated by a unit of consumption of type j.

In order to derive the total pollution attribution we combine equations (16) and (20) and simplify using equations (19) and (22) to get the p x e matrix P^{TE}. This matrix gives the total pollutants attributed to each domestic consumption category. Therefore element $p^{TE}_{i,j}$ is the total pollution of type i generated by final consumption demand of characteristic j. This produces the following expression

$$P^{TE} = P^{IE} + P^{DE} = \Pi\left(\mathrm{B}^I \left(1 - A\right)^{-1} \Phi + \mathrm{B}^E\right)E = \left(M^{PIE} + D^{PE}\right)E \tag{23}$$

Comparing equation (21) with equation (5) clearly shows the additional problems raised by pollution attribution as against resource-use attribution.

Again, we can combine the direct and indirect pollutant effects attributed to final consumption categories in a p x e total multiplier matrix, M^{PTE}, so that

$$M^{PTE} = M^{PIE} + D^{PE} \tag{24}$$

where the element $m^{PTE}_{i,j}$ is the amount of pollutant i generated directly or indirectly by one unit of expenditure and use of final demand consumption category j. Therefore, using equation (24), equation (23) can be re-expressed as:

$$P^{TE} = M^{PTE} E \tag{25}$$

Before applying these techniques to Jersey data, we should discuss two of the simplifying assumptions made in this section. The first was that the use of a unit of a commodity will generate the same volume and type of pollution, independently of how, and for what purpose, it is used. This is generally not the case. For example, the pollution created by the use of commodities as intermediate inputs will depend upon the technologies in place in the relevant industries. The same type of argument also applies to final consumption. This is not a major problem, however, in that what is important are the combined ΠB matrices and these can be adjusted to take this heterogeneity into account.

A second assumption is that export expenditures generate no direct pollution. Generally this is the case. However, in so far as tourist expenditure is counted as an element of export demand, this will be associated with some direct domestic pollution generation, in that the commodity use occurs within the economy's territory. Again, this poses no serious difficulty. The appropriate adjustments are made to the coefficients represented in B^I where export demand is endogenised in the NCLAS attribution.

4. Results from the Neo-Classical Linear Attribution System (NCLAS) for Jersey

The results reported in this paper are based around the Jersey IO table and associated pollution coefficients for 1998.[12] As argued in Sections 2 and 3, although production is a key contributor to pollution within the economy's borders, the NCLAS approach attributes all such pollution to local consumption. The results reported in this paper give both the pollution intensities and total pollution contributions of the various elements of private and public consumption. We report results for 7 individual pollutants: carbon dioxide (CO_2), methane (CH_4), sulphur dioxide (SO_2), oxides of nitrogen (NO_x), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO) and nitrous oxide (N_2O). For illustrative purposes we focus on nitrous oxide and the composite Global Warming Potential (GWP) index.[13]

4.1 Direct emissions coefficients in NCLAS

The standard Jersey environmental IO system comprises a set of IO tables with 25 production sectors (q), 12 final demand sectors (e) and 7 pollutants (p). We have constructed from primary data the 7 x 25 matrix, ΠB^I, of direct emission intensities for production and the

[12] See Turner (2002) and McGregor *et al* (2001b) for fuller details of the construction of the Jersey environmental IO system.
[13] The GWP index is a composite of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions, weighted to reflect the global warming potential of each pollutant. The weights are 1, 21 and 310 respectively. Although N_2O has a high weight, the absolute size of the CO_2 and CH_4 emissions makes them more important determinants of the GWP value.

corresponding 7 x 12 matrix ΠB^{E} (= D^{PE}) for final demand categories. These matrices are shown as Tables A.1 and A.2 in the Appendix. Of the 12 final demand sectors only six are responsible for any direct emissions generation. These are household consumption, which is broken down into household income quintiles, and tourist expenditure

With this information, standard Type I and II IO pollution attribution analyses could be performed using a variant of equation (23). However, in order to put local consumption (private and public) at the heart of the attribution, we adopt the NCLAS approach where household and government expenditures are exogenous, whilst investment and exports are endogenous through links to other value added and imports respectively. We assume investment simply covers depreciation, thereby imposing a long-run equilibrium interpretation on the initial set of IO accounts. Similarly we assume that exports finance imports. This places a neo-classical construction on the analysis. In both cases, the now endogenous demands are treated as though they were industries with intermediate inputs (expenditures) but no value added.

The corresponding coefficients in the A matrix are defined as:

$$a_{i,j} = \frac{f_{i,v}}{\sum_i ova_i} \tag{26}$$

$$a_{i,x} = \frac{f_{i,x}}{\sum_i m_i} \tag{27}$$

where the values f_{ij} are elements of the matrix of final demands defined for equation (3) with subscripts j and x stand for the investment and export sectors, and ova_i and m_i represent sectoral other value added and imports respectively.

The endogenising procedures used here are rather crude. For the investment coefficients we are implicitly assuming constancy across sectors in capital's share of other value added and in both the rate of return on capital and the rate of depreciation. For exports we assume that a given share of an economy's exports is required to finance a corresponding share of the economy's imports. An issue in principle - and one that is important in practice for the Jersey economy - is that there might be a significant trade imbalance recorded in the IO table. For example, in 1998 Jersey ran a trade surplus, with the value of exports substantially exceeding the value of imports. The assumption that we are implicitly making is that the export activity is associated with other financial flows required for external balance.[14]

In the conventional IO attribution approach, the D^{PE} matrix of direct emissions intensities for final demand includes direct emissions for tourist expenditure (i.e. export consumption that actually takes place in Jersey). Therefore, when exports are endogenised in the NCLAS approach, information from the appropriate column of the D^{PE} matrix is incorporated into the ΠB^I matrix. Note that the other final demand sector endogenised in the NCLAS system, capital formation (stocks and GDFCF), is not responsible for any direct emissions generation. The appropriate column in the direct coefficient matrix is therefore simply a p vector of zeros.

[14] Similar problems occur in the endogenisation of household consumption in the calculation of conventional Type II multipliers. In general, these procedures might be better dealt within a Social Accounting Matrix (SAM) framework (McGregor *et al*, 2003; Pyatt and Round, 1985; Round, 2003; and Thorbecke, 1997).

4.2 Neo-classical output-pollution multipliers (M^{PIF})

We use the NCLAS system to measure the contribution of the various private and public final consumption sectors to total pollution generation in Jersey. We begin by constructing the 7 x 27 M^{PIF} matrix of output-pollution multipliers that relate direct and indirect emissions to the production of sectoral output to meet final consumption (equation 18). This is presented as Table 1.

The elements of the first 25 columns of this multiplier matrix show the amount of pollution generated in the production of domestic output to meet £1million local private or public final demand for that particular commodity. The elements of the import column indicate the implied domestic emissions per £1million imports demanded by households and government final consumption. The emissions attributed to imports are generated by the production of the exports required to finance those imports. The coefficients in this trade column are therefore essentially a weighted sum of the emissions intensities of the 25 standard production sectors; the weights being determined by how much output each sector contributes to total exports. There are also positive entries in the capital depreciation column of the M^{PIF} matrix. However, given that there is no final consumption demand for capital formation, these can be ignored.

In Figures 1 and 2, the NCLAS output-pollution multiplier values are shown graphically for two illustrative, but policy relevant, pollutants. These are the composite pollutant, the global warming potential (GWP) index, and the single, mainly traffic-related, pollutant, N_2O. Both Figures 1 and 2 give the NCLAS output-pollution multiplier value alongside the direct emissions intensities for each sector. That is to say, they report the figures for the appropriate rows of the ΠB^I and the M^{PIF} matrices. They identify those sectors where domestic production is pollution intensive. They also reveal the extent to which that pollution is generated directly or indirectly, that is, directly through the production of the commodity or indirectly through the production of the necessary intermediate inputs. Note that many sectors have a small or zero direct pollution intensity but do generate pollution indirectly through the requirement for the domestic production of intermediate inputs.

Figures 1 and 2 also allow comparison between the pollution intensity of domestic production and imports. From a purely Jersey-centric ecological viewpoint, if a sector's direct and indirect pollution intensity of domestic production is higher than that for imports, this suggests substituting imports for domestic production if possible.[15] For example, the emission multipliers for N_2O and GWP associated with the domestic production in 'Agriculture and Fishing' are higher that those for the production of exports required to finance a corresponding amount of imports. £1 million spent on imports generated, in Jersey, an implied 0.837kg of N_2O and added 154108 points to the GWP index. This compares with the 1.75kg of N_2O and 635887 GWP points generated directly or indirectly by production going to meet £1 million of domestic 'Agriculture and Fishing' final consumption.

In Figures 1 and 2, only the pollution generated, directly and indirectly, by the domestic production of individual commodities is recorded. Two further adjustments have to be made to identify the total pollution intensity of the final consumption of individual products. First, we need to add the direct pollutant impacts of consuming the commodity. Second, in general the consumption demand for a particular commodity will comprise both domestically

[15] Care needs to be taken here. Strictly we require a more comprehensive modelling exercise to identify marginal intensities (Conrad, 1999; Turner, 2002).

produced goods and imports. The appropriate pollutant multipliers for the production of a particular commodity for domestic consumption would be the weighted sum of the corresponding domestic production multiplier and the import multiplier. The weights would be the proportions of the final consumption of the commodity that is domestically produced and the proportion that is imported. Unfortunately we do not have detailed import information for Jersey broken down by commodity, so that such calculations cannot be made.[16]

4.3 Attribution to local (exogenous) private and public final demand in NCLAS

Through equation (23) we can use the NCLAS output-pollution multipliers (M^{PIE}) together with the direct pollutant consumption coefficients (D^{PE}) to determine the contribution of different categories of local final demand to total emissions in the economy. Note that here we have e = 6 local consumption final demand sectors: five household groups and government final consumption (GGFC).[17] Table 2 reports the consumption-pollution multiplier values. This table is the M^{PTE} matrix, defined in equation (24). The individual elements indicate the average amount of direct and indirect local pollution generated from one unit (£1million) of total final consumption by the appropriate local final demand category. Table 3 shows the total pollution attributed, directly or indirectly, to different domestic consumption categories. This is the P^{TE} matrix defined in equation (25).

Again as an illustration we look in more detail at the NCLAS attribution results for the GWP index and N_2O respectively. Figures 3 and 5 show the share of total emissions generated in

[16] The detailed fuel information that we need to calculate the B matrices comes from domestic information supplied by the Jersey Fuel Distribution sector (Turner, 2002).

Jersey in 1998 that are ultimately attributable to each category of local final demand. Essentially, Figures 3 and 5 report results from the appropriate rows of Table 3. Figures 4 and 6 similarly give the NCLAS final demand multiplier values for the GWP index and N_2O. That is to say, they show the figures from the appropriate rows of the Table 2.

Note that most of the emissions for both GWP and N_2O are attributable to private (household) final consumption and that private consumption is more pollution intensive than public consumption. This result is true across all seven individual pollutants identified for Jersey. It is also the case that the share attributable to each household group rises with income. However, the emissions intensity of household expenditure follows a different pattern. For the three pollutants CH_4, SO_2 and NO_X, emissions intensity falls monotonically with income. However, for CO_2, NMVOC and CO, the most pollution intensive consumption pattern is associated with the second lowest income quintile.

In the case of the GWP index, 91% of Jersey emissions are associated, directly or indirectly, to household consumption, and the shares attributable to the individual household sectors rises with income. Over 50% of total GWP emissions are attributable to the consumption of the top two quintile income bands, a result that holds across all pollutants. On the other hand, Figure 4 shows that the GWP-intensity of household expenditure is highest in the low, but not the lowest, income bands.

We see a similar picture with the single pollutant, N_2O, which in the Jersey environmental IO accounts is solely related to automotive fuel use. Here, 97% of all emissions are attributable to households, with the bulk of this (63%) being the direct emissions from households' own

[17] Since GGFC, Government Gross Final Consumption, is not responsible for any direct emissions generation

automotive fuel use. Again the contribution rises with income, with the top two income groups being responsible for 58% of household emissions and 56% of total emissions. However, Figure 6 shows that although the N_2O intensity of household expenditure tends to fall with income, the picture is slightly different with much more marked maximum at the second income quintile. In this case, the lowest and highest income bands share a relatively low N_2O intensity. This reflects the relatively low direct automotive fuel use of the lowest income households.

Generally, however, the NCLAS multipliers show that the emissions intensity of household expenditure in Jersey is negatively related to income. This is consistent with the fact that energy use, particularly for heating and lighting purposes (heating oils and electricity) per unit of household expenditure tends to fall as income rises. This suggests that a local tax on energy use intended to reduce emissions generation would indeed be regressive.[18]

5. Conclusions

In this paper we place local public and private consumption centre stage in considering pollution problems in a small open regional economy. We propose an Input-Output based attribution system that overcomes important informational and conceptual problems associated with the ecological footprint approach. This is a trade-endogenous neo-classical linear attribution system (NCLAS). The application of this method to the Jersey economy generates results that are both informative and intuitively appealing. Private household consumption is much more pollution intensive than public consumption, though the pollution

the appropriate column of the D^{PE} matrix is composed of zeros.

[18] Again care needs to be taken with such statements as strictly formal modelling is required to explore this issue in detail (Boyd and Uri, 1991; Stephan *et al*, 1992; Weise *et al*, 1995).

intensity of household expenditure generally falls with household income. Even so, the consumption of the top two household income quintiles is a dominant driver in the generation of key pollutants.

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TABLES

Table 1. Matrix of NCLAS pollution multipliers measuring (tonnes of) direct and indirect pollution generated in the production of commodity output (equation 18)

POLLUTANTS	SECTORS												
	Agriculture & Fishing	Quarrying & Construction	Manufacturing	Electricity	Water	Gas, Oil & Fuel Dist.	Jersey Telecom.	Wholesale & Retail Trade	Hotels, Rest. & Catering	Land Transport	Sea & Air Trans. & Trans Supp	Jersey Post	Banks & Building Soc.
Carbon dioxide (CO2)	333377.9	66703.3	177033.7	1361415.9	106510.1	83051.9	65544.5	75930.1	109554.5	102864.7	358199.3	56040.5	29040.6
Methane (CH4)	14379.4	235.6	1977.3	432.0	258.4	118.0	354.8	231.0	643.1	254.2	303.5	169.0	220.6
Sulphur dioxide (SO2)	5916.1	225.1	1840.3	9808.8	616.3	133.9	366.8	339.1	670.4	259.7	791.8	230.5	167.0
Oxide of nitrogen (NOx)	3015.7	443.4	1591.7	17802.0	1147.7	656.2	623.1	734.2	932.1	786.5	6024.8	572.3	268.7
Non-methane volatile organic compounds (NMVOC)	421.9	170.3	388.7	447.1	247.1	395.1	214.9	295.4	207.1	572.1	1582.6	157.5	111.5
Carbon monoxide (CO)	1975.5	768.8	1985.7	2019.4	1336.0	2126.2	1113.5	1626.7	1074.3	3246.2	4974.7	641.3	571.3
Nitrous oxide (N20)	1.7	1.0	1.0	0.5	0.6	1.5	0.5	0.7	0.4	1.5	0.5	0.4	0.2

	Insurance Companies	Inv. Trusts & Fund Mgrs	Computer Services	Legal Activities	Accountancy	Other Bus. Activities	Other Service Activities	Recreation, Culture & Sport	Education	Health, Social Work & Housing	Public Services	Public Admin. & Defence	Imports	Capital Depreciation
Carbon dioxide (CO2)	30557.7	37646.5	58557.9	30136.0	28143.3	32553.9	103003.5	112088.8	59159.8	70412.0	659528.8	38600.7	129330.5	28874.7
Methane (CH4)	179.7	247.3	305.5	147.6	151.6	125.9	149.9	562.6	181.5	202.7	417.3	217.8	1167.5	215.5
Sulphur dioxide (SO2)	168.2	212.2	275.5	169.5	163.2	135.1	893.2	619.1	278.7	329.7	597.4	205.7	812.4	161.8
Oxide of nitrogen (NOx)	287.5	349.6	521.2	285.5	277.7	254.8	659.0	949.3	485.9	589.7	4580.8	350.6	1258.3	262.3
Non-methane volatile organic compounds (NMVOC)	136.2	167.3	346.8	99.1	99.4	139.9	498.1	224.0	113.0	120.2	10580.3	111.8	556.8	110.3
Carbon monoxide (CO)	753.2	911.9	2015.9	527.9	533.2	777.1	2847.8	1139.0	552.8	578.8	42753.5	565.8	2890.5	564.5
Nitrous oxide (N20)	0.2	0.3	0.5	0.2	0.2	0.4	1.4	0.5	0.3	0.3	0.5	0.2	0.8	0.2

Table 2. Matrix of NCLAS final consumption pollution multipliers meausring direct and indirect pollution generated by domestic production and consumption of local final demand: tonnes of pollution in Jersey attributed to £1million local final consumption demand (equation 24)

POLLUTANTS	FINAL CONSUMPTION GROUP					
	Household 1	Household 2	Household 3	Household 4	Household 5	GGFC
Carbon dioxide (CO2)	271642	288003	261803	236987	231419	141412
Methane (CH4)	1053	967	899	811	805	239
Sulphur dioxide (SO2)	1216	1047	1037	844	768	331
Oxide of nitrogen (NOx)	2198	2180	2033	1787	1712	1061
Non-methane volatile organic compounds (NMVOC)	1809	2425	2214	2007	1731	1544
Carbon monoxide (CO)	10243	13969	12641	11524	9910	6329
Nitrous oxide (N20)	2	2	2	2	2	0

Table 3. Matrix of total pollution (tonnes) supported by different types of final demand - NCLAS attribution analysis (equation 25)

POLLUTANTS	FINAL CONSUMPTION GROUP					
	Household 1	Household 2	Household 3	Household 4	Household 5	GGFC
Carbon dioxide (CO2)	21721806	40441565	50437300	63036420	87978928	27449163
Methane (CH4)	84242	135826	173117	215792	305959	46325
Sulphur dioxide (SO2)	97273	147046	199734	224566	291905	64270
Oxide of nitrogen (NOx)	175760	306122	391640	475403	651027	205941
Non-methane volatile organic compounds (NMVOC)	144653	340516	426610	533834	658148	299750
Carbon monoxide (CO)	819109	1961511	2435320	3065235	3767524	1228547
Nitrous oxide (N20)	130	295	368	474	612	55

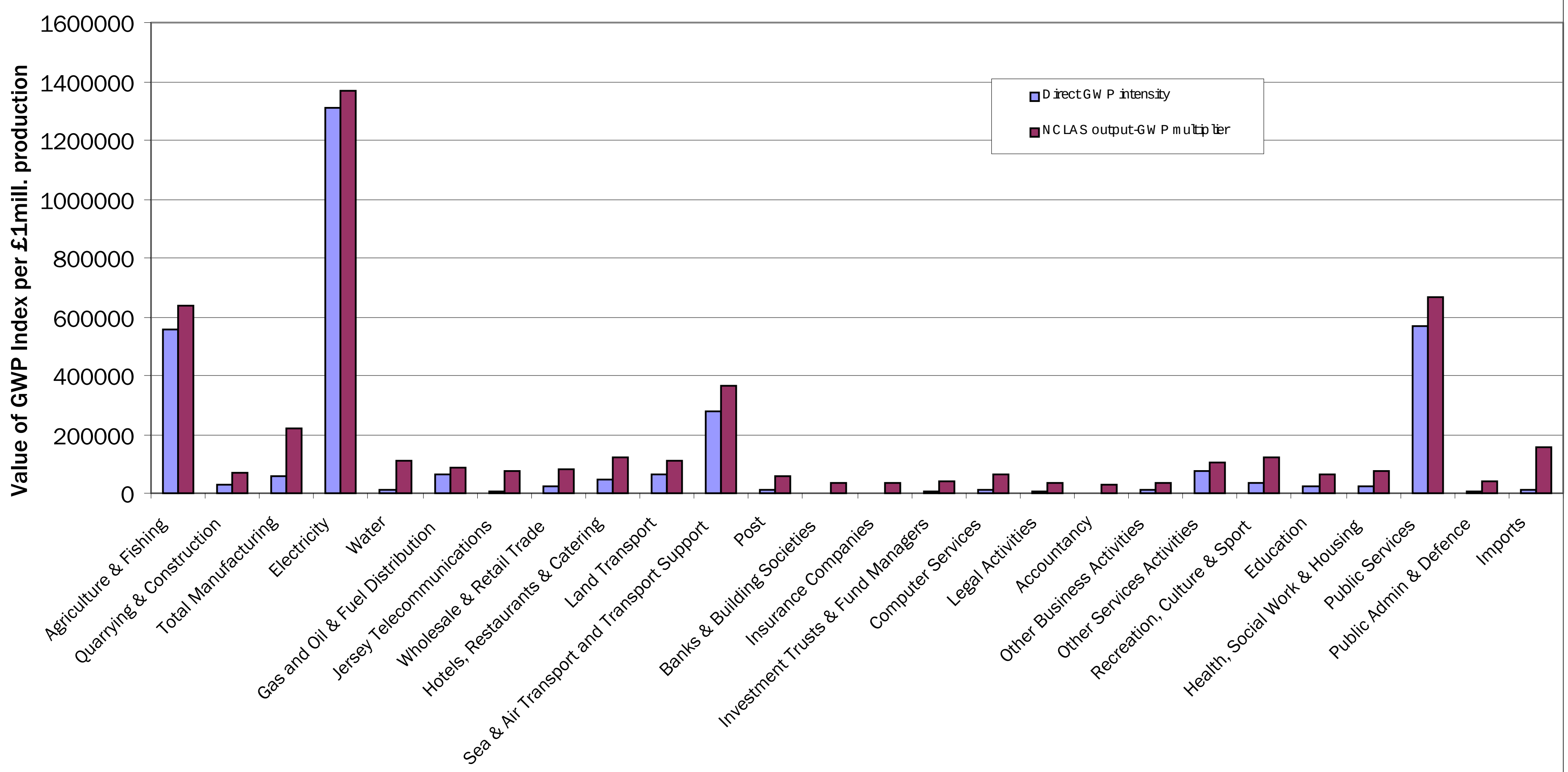
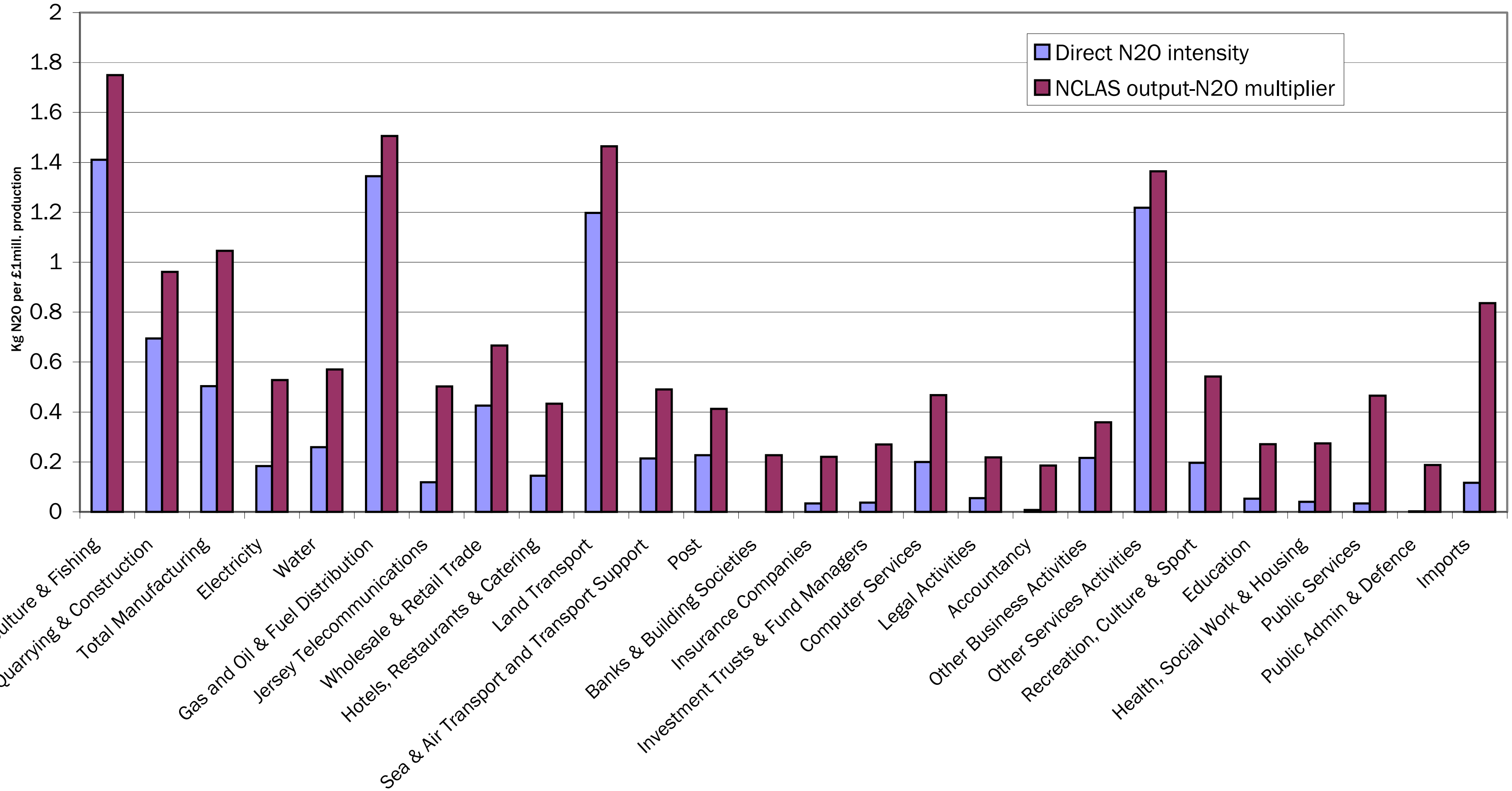


Figure 1. Direct and NCLAS multiplier GWP intensities of production in Jersey, 1998

Figure 2. Direct and NCLAS multiplier N2O intensity of production in Jersey 1998



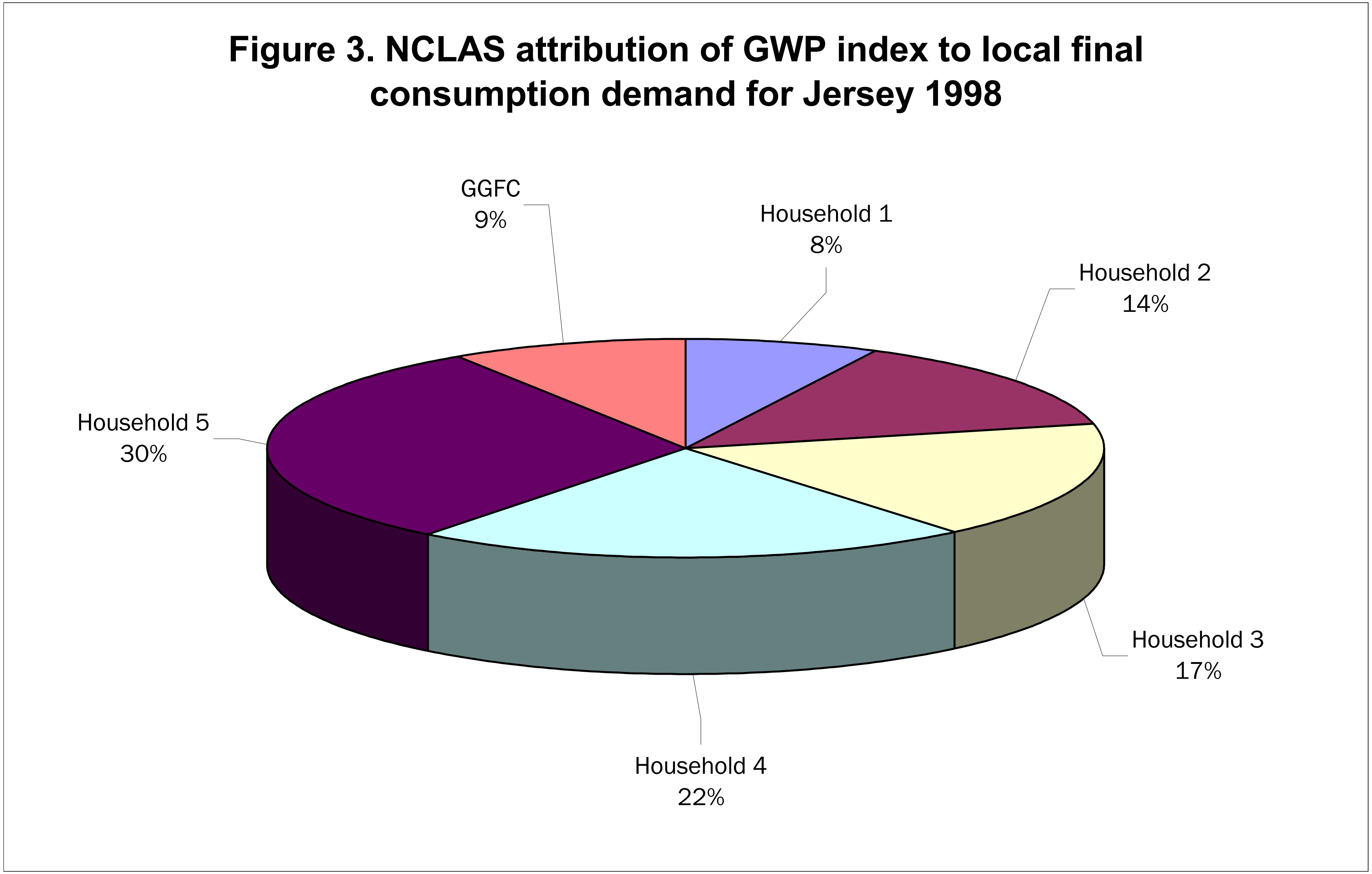
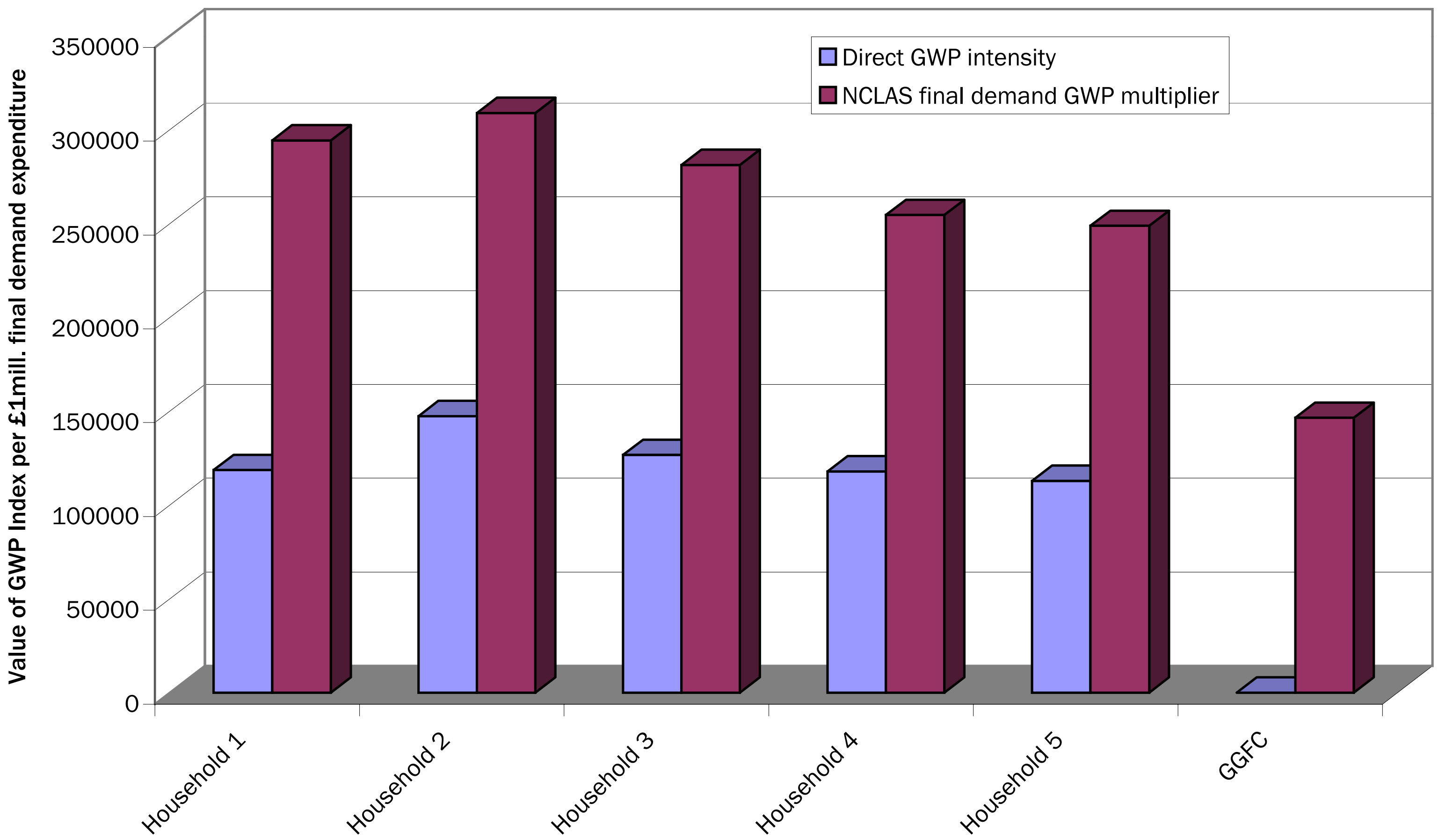


Figure 3. NCLAS attribution of GWP index to local final consumption demand for Jersey 1998
GGFC
9%
Household 1
8%
Household 2
14%
Household 3
17%
Household 4
22%
Household 5
30%

Figure 4. GWP direct intensities and NCLAS GWP total multipliers for types of final consumption, Jersey 1998



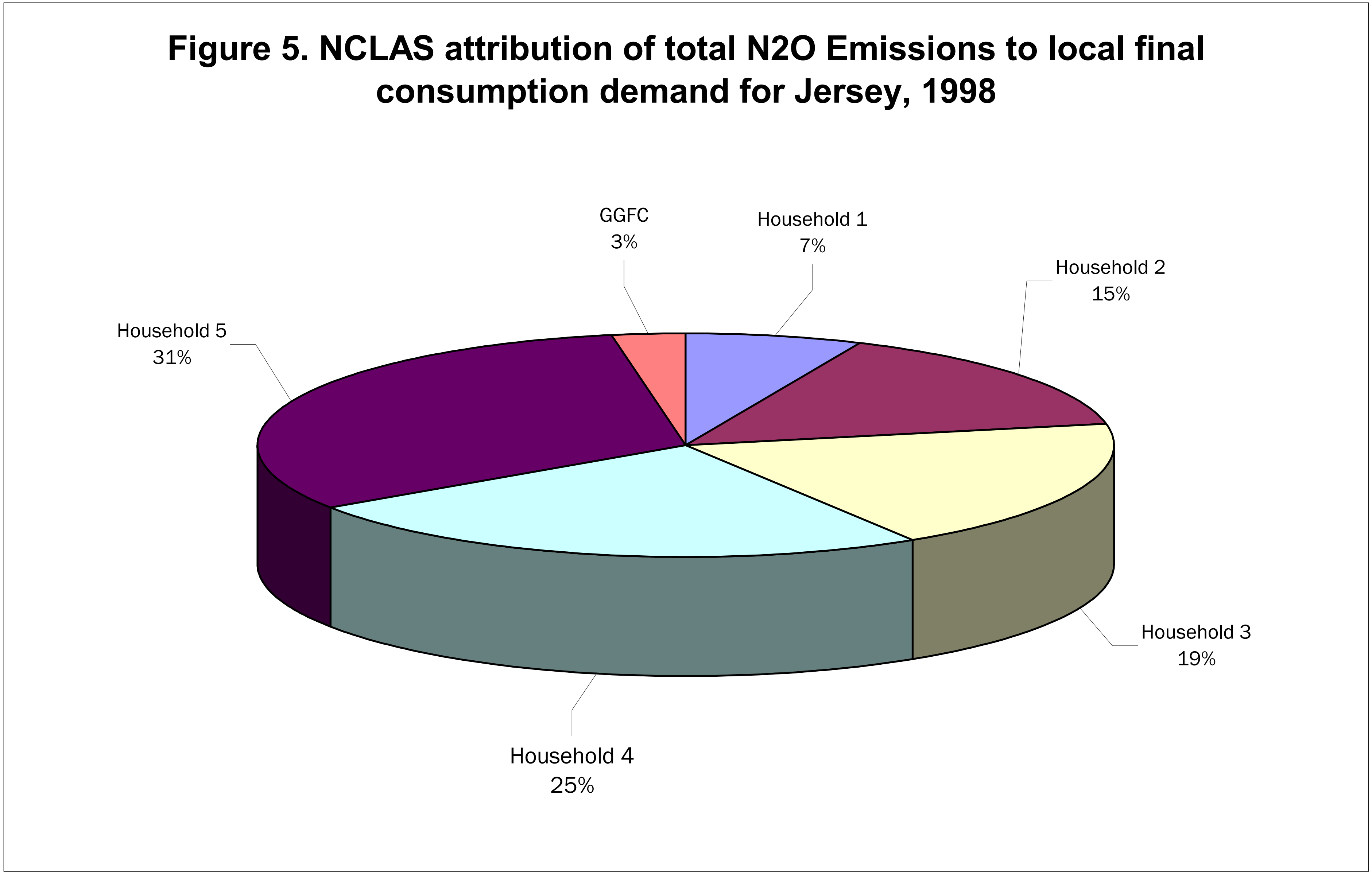
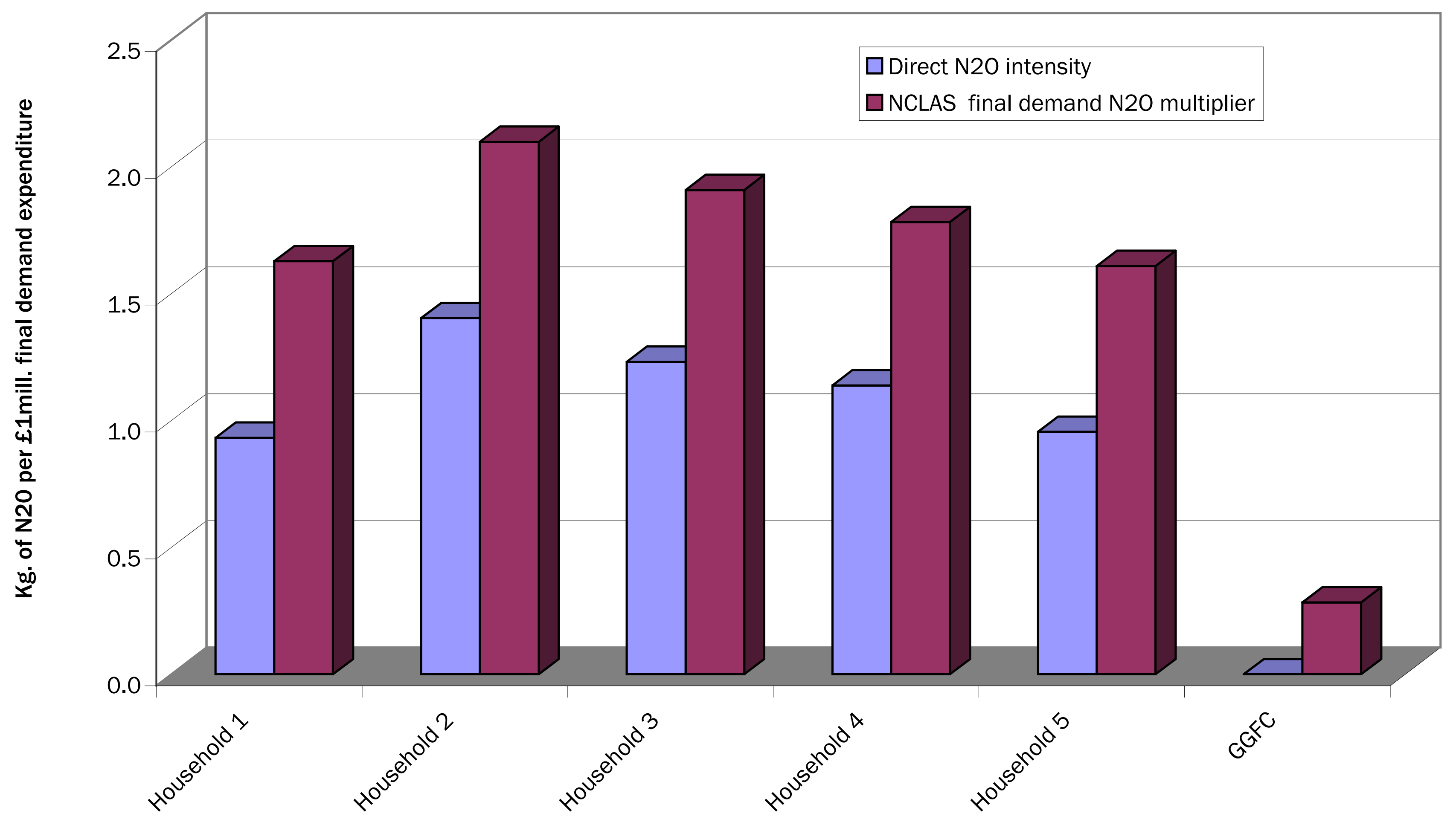


Figure 5. NCLAS attribution of total N2O Emissions to local final consumption demand for Jersey, 1998
GGFC
3%
Household 1
7%
Household 2
15%
Household 3
19%
Household 4
25%
Household 5
31%

Figure 6. Direct N2O intensities and NCLAS N20 total multipliers for types of final consumption demand, Jersey 1998



APPENDIX

Table A1. Matrix of industry average direct pollution coefficients (equation 12): tonnes of pollution directly generated by the production of £1million commodity output

POLLUTANTS	SECTORS												
	Agriculture & Fishing	Quarrying & Construction	Manufacturing	Electricity	Water	Gas, Oil & Fuel Dist.	Jersey Telecom.	Wholesale & Retail Trade	Hotels, Rest. & Catering	Land Transport	Sea & Air Trans. & Trans Supp	Jersey Post	Banks & Building Soc.
Carbon dioxide (CO2)	262119.4	30841.2	58068.4	1310789.9	12864.4	61379.5	5372.1	24447.2	43706.4	62988.3	278158.0	13973.4	79.9
Methane (CH4)	14010.9	1.2	3.3	3.7	2.6	9.4	0.6	4.7	2.0	12.2	20.5	0.3	0.0
Sulphur dioxide (SO2)	5419.7	14.0	662.0	9500.4	0.0	0.0	0.7	12.6	134.6	16.9	260.8	23.9	0.3
Oxide of nitrogen (NOx)	2244.2	102.8	339.3	17312.4	62.8	450.5	17.1	166.8	212.4	392.8	5105.4	48.7	0.4
Non-methane volatile organic compounds (NMVOC)	265.9	45.2	122.7	237.2	93.0	333.3	20.6	168.9	76.1	439.2	1432.4	13.8	0.1
Carbon monoxide (CO)	1158.9	125.0	664.8	938.2	547.5	1810.0	107.0	992.6	429.0	2569.7	4211.8	35.0	0.6
Nitrous oxide (N20)	1.4	0.7	0.5	0.2	0.3	1.3	0.1	0.4	0.1	1.2	0.2	0.2	0.0

	Insurance Companies	Inv. Trusts & Fund Mgrs	Computer Services	Legal Activities	Accountancy	Other Bus. Activities	Other Service Activities	Recreation, Culture & Sport	Education	Health, Social Work & Housing	Public Services	Public Admin. & Defence	Imports	Capital Depreciation
Carbon dioxide (CO2)	2731.7	3733.9	14152.9	3240.8	633.3	10652.2	74192.6	37431.6	20468.4	23732.7	568032.0	6200.2	9192.1	0.0
Methane (CH4)	1.2	1.3	5.3	0.7	0.3	2.0	11.3	1.5	0.1	0.1	128.3	0.0	13.7	0.0
Sulphur dioxide (SO2)	0.0	3.1	0.8	0.0	0.0	0.0	722.1	68.5	45.4	35.5	29.5	2.2	0.0	0.0
Oxide of nitrogen (NOx)	14.6	19.5	70.0	12.0	3.4	38.4	339.2	142.7	79.0	83.7	3572.1	18.5	45.9	0.0
Non-methane volatile organic compounds (NMVOC)	43.3	46.6	194.5	25.3	10.0	73.5	415.9	58.6	7.5	9.3	10397.0	2.7	160.4	0.0
Carbon monoxide (CO)	277.8	298.3	1237.0	152.8	64.4	433.6	2452.3	300.7	12.2	13.0	41820.5	3.0	954.7	0.0
Nitrous oxide (N20)	0.0	0.0	0.2	0.1	0.0	0.2	1.2	0.2	0.1	0.0	0.0	0.0	0.1	0.0

Table A2. Matrix of final consumption direct pollution coefficients (equation 13): tonnes of pollution directly generated by £1million final consumption expenditure

POLLUTANTS	FINAL CONSUMPTION GROUP					
	Household 1	Household 2	Household 3	Household 4	Household 5	Tourists
Carbon dioxide (CO2)	112638.5	142900.4	123172.7	115039.6	110763.4	38027.9
Methane (CH4)	270.7	192.1	149.6	118.8	89.8	56.5
Sulphur dioxide (SO2)	206.6	139.5	194.6	105.5	43.9	0.0
Oxide of nitrogen (NOx)	464.3	633.2	549.7	512.3	464.6	189.9
Non-methane volatile organic compounds (NMVOC)	1389.4	2008.9	1797.6	1627.0	1343.3	663.5
Carbon monoxide (CO)	8117.9	11854.9	10562.6	9602.2	7957.3	3949.7
Nitrous oxide (N20)	0.9	1.4	1.2	1.1	1.0	0.5

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