An input-output carbon accounting tool: with carbon footprint estimates for the UK and Scotland

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Acknowledgements
The research reported in this paper has been carried out with the support of the ESRC Climate Change Leadership Fellow project “Investigating the pollution content of trade flows and the importance of environmental trade balances” (ESRC ref. RES-066-27-0029), based at the Universities of Stirling and Strathclyde. The authors also acknowledge the support and cooperation of the Organisation for Economic Cooperation and Development in hosting Dr Soo Jung Ha and working with her to construct the dataset used to analyse the pollution content of imports to Scotland and the UK. We are also grateful to colleagues at the Scottish Government and the Stockholm Environment Institute for advice and assistance in constructing the datasets used. Finally, we are grateful to Randall Jackson, Regional Research Institute, West Virginia University, and Kim Swales, Department of Economics, University of Strathclyde, for their comments and advice on the accounting methods employed here.

1. The research programme
In 2008, the UK Economic and Social Research Council (ESRC) awarded six Climate Change Leadership Fellowships (CCLFs) to address key research issues and innovative approaches in mitigating or adapting to climate change. Of the six Fellowships, led by Dr Karen Turner (University of Strirling, formerly of the University of Strathclyde) we have engaged in a programme of communication with the policy and wider user community, primarily through a series of ESRC funded public seminars and workshops. One outcome of these activities has been the identification of a need to develop a user friendly, systematic and transparent accounting system that allows examination of the structure of pollution problems to be examined from a range of potential policy perspectives. Thus a key aim of this Climate Change Leadership Fellowship has been the development of a basic pollution accounting framework, based on the input-output (IO) methodology now widely adopted in both the academic literature and the policy advisory communities, and applied here to the case of CO2. This research has involved collaboration with colleagues at the Universities of Stirling, Strathclyde, Cardiff, Surrey, West Virginia and also at the OECD, the Stockholm Environment Institute and the Scottish Government, a number of whom are among the co-authors of this paper. The purpose of this paper is to present the IO pollution accounting tool developed under the Fellowship, with case studies of carbon dioxide emissions at the UK national and Scottish regional levels. It is important to note that the development of the accounting tool relies on data for a single year (2004), some of which has had to be estimated in the absence of official statistics (such as UK IO tables in the analytical format). If there is a need to conduct pollution accounting on a regular basis, to form the basis for official indicators of sustainability, public investment in appropriate data provision will be a necessity.

2. Two ways to account for carbon generation
In recognition of the problems posed by failing to prevent climate change, an international agreement was reached in 1997 in Kyoto on reducing greenhouse gas emissions, particularly CO2. However, more than a decade later a number of issues hindering the reduction of emissions have yet to be resolved. Major challenges still remain in securing the cooperation of all nations and in designing and delivering effective (and efficient) collective action within and between nations. One crucial issue impacting on unilateral attempts to fulfill national emissions reductions targets under the Kyoto Protocol is the impact of international trade on any one country’s domestic emissions generation. The basic problem is that the generation of emissions in producing goods and services to meet export demand is charged to the producing nation’s emissions account. That is, pollution generation in any one country is partly driven by consuming activities in others.

Munksgaard and Pedersen (2001) highlight this issue in distinguishing between a ‘production accounting principle’ and a ‘consumption accounting principle’ in considering the structure of pollution problems. The former, which we shall label PAP, focuses on emissions produced within the geographical boundaries of the national economy. This is what is accounted for, and what individual national governments are responsible for reducing, under the Kyoto Protocol. In contrast, the latter, which we shall label CAP, focuses on emissions produced globally to meet consumption demand within the national economy. This is what increasingly popular measures such as carbon footprints attempt to measure, and what many people regard as more appropriate, given that human consumption decisions are commonly considered to lie at the heart of the climate change problem. In a closed economy, with no trade
in goods and services, emissions accounts constructed under the production and consumption accounting principles would be equal (by definition). However, where there is trade and pollution is embodied in that trade through emissions generated in one region or nation to meet consumption demand in another, these need not be equal. A foreign ‘trade balance’ in pollution will exist in terms of the difference between total emissions estimated on the basis of the production and consumption accounting principles, or more simply, the difference between the pollution embodied in exports and the pollution embodied in imports.

Thus, the question arises as to whether PAP and/or CAP measures should be used to monitor and track pollution generation at the individual country level and what, if anything, can be done about foreign ‘trade balances’ in pollution. In this paper we present the IO accounting tool developed as part of the ESRC CCLF to estimate CO2 emissions linked to economic activity for the UK and Scottish economies (in the accounting year of 2004) and consider what type of questions/issues can be addressed using PAP and CAP measures in each case.

3. Summary carbon (CO2 equivalent) Accounting Results for the UK and Scotland

Our results suggest that in 2004 the ‘carbon footprint’ of UK consumption 813.5 tonnes of CO2 equivalent was significantly higher than the level of CO2 emissions generated within UK borders (643.8 million tonnes of CO2) – see Section 5 and Table 1 below for a more detailed analysis. That is, UK CO2 generation is 26% higher under the CAP than under the PAP measure that is the basis of CO2 reduction targets under Kyoto. This implies that the UK ‘imports sustainability’ from its trade partners. This result might be expected in the case of an advanced economy where there has been a shift from domestic production of many manufactured goods towards a domestic focus on more service orientated activities with increasing imports of manufactured goods. However, it raises questions as to whether relying solely on PAP measures (as under the Kyoto Protocol targets) is then a good measure of the sustainability of the UK economy.

The Scottish results, on the other hand, are more complex. Here we find that Scotland also ‘imports sustainability’, but with a much larger difference between CO2 allocated under PAP (48.9 million tonnes of CO2 in 2004) and CAP (71.5 million tonnes of CO2) – i.e. a 46% increase as we move from measuring CO2 generated within Scotland, to considering Scotland’s ‘carbon’ (CO2 equivalent) footprint. See Section 6 and Table 3 below. However, a key underlying determinant of Scotland’s CO2 trade deficit, particularly with the rest of the UK is the fact that Scotland is a net exporter of electricity, which, given the (increasing) prevalence of renewable generation technologies in Scotland, means that the export side of its CO2 trade balance has a relatively low CO2 intensity and content. While of course there should be concern over the CO2 content of Scottish imports, the key implication that emerges from our results is that Scotland, by its choices in terms of choosing to foster renewable technologies in electricity generation, is helping to lower the carbon footprints of its trade partners, particularly the rest of the UK. This is illustrated by the fact that if we were to assume that UK average polluting technologies apply throughout the nation in the CO2 accounting exercise, not only is Scottish domestic CO2 generation (estimated under PAP) higher (at 66.7 million tonnes), we find that it would actually run a CO2 trade surplus with the rest of the UK, and its carbon footprint would only be 17% higher than its domestic CO2 generation, compared with the 26% difference at the UK level. Again, see Section 6 and Table 2 below for a more detailed analysis. Thus, it would seem that Scotland is ‘punished’ in CO2 trade balance terms by having adopted cleaner technologies in producing what are usually quite CO2 intensive exports. This is reflected in the fact that the actual Scottish carbon footprint is around 8% lower where Scottish renewable electricity generation technologies are incorporated in the calculation (Table 3) relative to what it would be if UK average technologies applied (Table 2).

Our carbon (in terms of CO2 equivalents) accounting results are detailed in Sections 5 and 6 below. However, reflecting points made in the introduction, the main question that we raise is whether the appropriate question in CO2 accounting terms is whether to adopt PAP or CAP measures when both measures are so clearly dependent on both consumption and technology decisions at home and abroad. Moreover, in the case of Scotland (and perhaps other UK regions), it raises questions as to the focus of indicators and targets within different regions that may play different roles in delivering on economic and environmental aspects of sustainable development objectives in the UK. This point links to the analysis in the second paper in this special issue of the Fraser Commentary, where we consider the case of Wales, a region of the UK characterised by relatively highly CO2 intensive production to meet export demand. There we consider how issues of jurisdictional control over polluting technologies impact on the arguments in favour of shifting focus towards consumption orientated measures.

4. The input-output accounting approach

Particularly in the environmental footprint literature (where focus is on accounting for emissions under the consumption accounting principle) input-output analysis has become
increasingly common as a technique to measure and allocate responsibility for emissions generation. See Wiedmann et al (2007), Wiedmann (2009), Turner et al, (2007) for reviews. This would seem a natural development, given that the focus of measures such as the carbon footprint is to capture the total (direct plus indirect) resource use embodied in final consumption in an economy. Input-output analysis is based around a set of sectorally disaggregated economic accounts, where inputs to each industrial sector, and the subsequent uses of the output of those sectors, are separately identified. Therefore, by the use of straightforward mathematical routines, the interdependence of different activities can be quantified, and all direct, indirect and, where appropriate, induced, resource use embodied within consumption can be tracked. This is commonly referred to as IO multiplier analysis³.

Ideally, a multi-region input-output method that incorporates multi-lateral trade will be used to account for emissions under the production and consumption accounting principles and to determine pollution trade balances. However, this effectively requires a world environmental input-output table. While several projects are underway around the world to construct such a framework (e.g. the World Input-Output Database project⁴) an appropriate one for UK regional and national analysis is not currently available. Moreover, as indicated above, a frequently stated concern at public events run as part of the CCLF project relates to a need to begin with a simple, transparent framework, that relies as much as possible on currently available rather than estimated data (given that the latter are commonly quite ‘black box’ in nature, largely due to the complexity of the estimation methods). Therefore, one of our objectives in the CCLF project has been to develop a simple IO framework, which, while less comprehensive in nature (for example, not incorporating international feedback effects where imports to country X from country Y may require exports from X as intermediate inputs to production Y) allow a standardised accounting framework to be built up in stages that can be clearly explained to practitioners and users of accounting outputs. A central aim of the current paper is to provide a non-technical overview of the IO tool developed and used here.

Input output (IO) tables are national balance sheets showing the value of all goods flows between production sectors in an economy and final demand groups over the period of a year. They are an example of single entry booking-keeping, where a sale (output) in one sector is simultaneously recorded as a purchase (input) in another. Where extended to include environmental data, such as emissions generated in production, the IO system can be used to account for emissions generation where both the quantities produced and the associated emissions can be accounted for. Figure 1 shows a schematic IO table where the components of each section have been highlighted in a series of numbered blocks

In an actual IO table, each block would be a series of columns and rows representing the inter-sectoral flows of goods and services between production sectors, primary inputs and sales to final consumers in value terms. It is important to note that where an IO table is reported in the analytical format required for multiplier analysis, sectoral level entries in Block 7, ‘Total Inputs’, and Block 8, ’Total Outputs’, must be equal.

Breaking the IO table into the blocks allows for an easy explanation of each IO table section in turn:-

Block 1 represents all production in the UK and accounts for emissions under the production and consumption accounting principles and to determine pollution trade balances. However, this effectively requires a world environmental input-output table. While several projects are underway around the world to construct such a framework (e.g. the World Input-Output Database project⁴) an appropriate one for UK regional and national analysis is not currently available. Moreover, as indicated above, a frequently stated concern at public events run as part of the CCLF project relates to a need to begin with a simple, transparent framework, that relies as much as possible on currently available rather than estimated data (given that the latter are commonly quite ‘black box’ in nature, largely due to the complexity of the estimation methods). Therefore, one of our objectives in the CCLF project has been to develop a simple IO framework, which, while less comprehensive in nature (for example, not incorporating international feedback effects where imports to country X from country Y may require exports from X as intermediate inputs to production Y) allow a standardised accounting framework to be built up in stages that can be clearly explained to practitioners and users of accounting outputs. A central aim of the current paper is to provide a non-technical overview of the IO tool developed and used here.

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Breaking the IO table into the blocks allows for an easy explanation of each IO table section in turn:-

Block 1 represents all production in the UK and accounts for sectors purchasing from other sectors within the UK economy.

Block 2 represents UK demands, which includes all UK households, government and capital formation demands.
The assumption with the conventional IO framework is that demand drives supply, so it is the demand groups within an economy that are responsible for the production sector producing a given level of output.

Block 3 represents the external demands, which include all the foreign producers and consumers that buy UK goods and services (export demands).

Block 4 represents purchases by UK producers from other countries to make UK goods and services. This can be thought of as UK producers buying parts for their own production. Note that in standard IO tables presented as part of national accounts, Block 4 would normally be represented as a single row showing the total value of imports to each production sector and final consumer. Here, and in the analysis that follows, we are grateful to colleagues at the Scottish Government and the Stockholm Environment Institute for assistance in identifying matrices for Scotland and the UK respectively where imports are broken down by commodity as well as by user. The same applies to Block 5.

Block 5 represents the goods and services UK consumers buy from abroad. All foreign goods that we see in UK shops would be included in this part of the table.

Block 6 represents payments to labour, profits and taxes, which are the value added components of the economy.

Blocks 7 and 8 represent total inputs (the sum of all the columns) and total outputs (the sum of all the rows) respectively. In an analytical IO table the respective input and output entries will be equal for each individual production sector.

So, which blocks do we consider for pollution generated under PAP?

Pollution generated under PAP (the production accounting principle) – the focus of Kyoto Protocol targets - takes into consideration pollution generated within the borders of the economy under study, whether this is to meet domestic or foreign (export) demand. This will equate to the sum of pollution directly generated in domestic production and directly by final consumers (most usually households, for example in burning gas in central heating systems or petrol in cars). Referring to the IO framework above, all pollution generated in production (Block 1) is attributable to (driven by) the final demands for domestic outputs in Blocks 2 and 3. Thus, as one of the components of final demand for a local economy, the external demand in Block 3 is included as a driver of domestic pollution generation. Thus PAP is considered by focussing solely on activity in Blocks 1 to 3, where Blocks 2 and 3 are responsible for the pollution generated in Block 1 (as well as any direct pollution generation within the economy under study by final consumers, which will generally only apply to Block 2 (unless tourists, external consumers who consume within the target economy are separately identified). Blocks 4 and 5, on the other hand, do not come into the PAP calculation. Thus, the PAP calculation allows us to look at emissions embodied in exports but it does not consider the other side of the pollution trade balance relationship; that is pollution embodied in imports.

What about pollution generated under CAP?
A CAP measurement (such as a carbon footprint), on the other hand, does take account of pollution embodied in imports. However, if we move to a CAP measure we no longer consider Block 3 (external demand) as this becomes part of another nation’s (or region’s) footprint. What this means is that we now include the goods that domestic producers and consumers buy from abroad, which are recorded in Blocks 4 and 5. This is illustrated in Figure 3. Measures under the CAP would be the sum of pollution generated in Block 1 to meet Block 2 demands, as well as the sum of the pollution generated in Blocks 4 and 5 to meet the demand requirements of Blocks 1 and 2. However, since demands in Block 1 and 4 are intermediate demands, all pollution embodied in imports are ultimately attributed, along with domestic pollution generation, to the domestic final consumers in Block 2. In short, the CAP calculation gives us the sum of all pollution generated to allow the demands of domestic final consumers to be met, whether this pollution is generated at home or abroad.

The problem of finding economic and pollution data for CAP measures
As noted above, it has been possible to access data to populate the different blocks identified in Figures 1-3 above. However, there is a problem in that commodities produced in different countries will have different pollution profiles (reflecting different production methods). One issue that should be considered is that pollution generated in foreign production will depend on the production technology decisions made in each individual country and each production sector therein. Concerns surrounding the methodologies employed for the estimation of country specific pollution can be addressed using the Domestic Technology Assumption (DTA). The DTA approach is sometimes adopted in the literature (see Druckman et al, 2008), as a way of overcoming a lack of available pollution data for other countries. What the DTA suggests is that by applying the same production technologies and therefore pollution intensity to foreign production of the commodities reported in Blocks 4 and 5 as is applied to domestic production (in Block 1) we are able to calculate a consumption measure based on the technology choices of the home economy. However, if the economy under study is (on aggregate) more pollution intensive than the countries it imports from this will lead to an overestimated footprint.
measure, and vice versa (of course this will depend on the mix of goods and services consumed, some of which will be more and some less pollution intensive). In the second paper in this special issue, it is also argued that the DTA method may be appropriate if we wish to focus on technology decisions that fall under the jurisdictional control of domestic policymakers. In this way, the DTA method is argued to consider the footprint from the perspective of the savings made by not producing at home, rather than the costs abroad.

A second approach that we have applied in the examples that follow in Sections 5 and 6 (and in the summary in Section 3 above) is to relax the DTA assumption. When and if actual country specific data do become available, the DTA assumption can be relaxed and the actual data inserted for whatever countries and/or sectors this is available for. With the assistance of our colleagues at the OECD we have been able to split out Blocks 4 and 5 to identify imports from 13 different regions in the rest of the world (see Appendix 1), and to assign corresponding pollution intensities. Thus, we are able to report the CAP calculations first making the DTA assumption then relaxing it. The difference in the two calculations solely reflects differences in polluting technologies between the economy under study and the countries that it imports from (given that the scale of activity is the same in both calculations).

5. Case study 1: the UK national economy
To demonstrate the use of the IO tool we consider the case of the UK in 2004\(^6\). The results of the PAP calculation (CO2 generated within UK borders in 2004) and the CAP calculation (CO2 attributable to UK final consumption in 2004), with the latter reported first under the DTA assumption then with this relaxed.

The top row of Table 1 shows the headline figures. Under PAP, 643.8 million tonnes of CO2 (equivalent) were produced in the UK in 2004. The second entry in the PAP column shows that just over 25% of this (163.7 million tonnes of CO2) were directly generated in the household sector. However, reading down the column we see how the remaining 480.1 million tonnes directly generated in UK

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**Figure 2: Components of the IO table used for calculation of a PAP measure**

1. Domestic Production Matrix (All production within the UK by UK production sectors)
2. Domestic consumption of UK production (UK households, UK Government, UK Investment)
3. External demands for UK production (foreign demand for UK production)
4. Foreign imports for UK production
5. Foreign imports for UK consumption (UK households, UK Government, UK Investment)
6. Total Inputs

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**Figure 3: Components of the IO table used for calculation of a CAP measure**

1. Domestic Production Matrix (All production within the UK by UK production sectors)
2. Domestic consumption of UK production (UK households, UK Government, UK Investment)
3. External demands for UK production (foreign demand for UK production)
4. Foreign imports for UK production
5. Foreign imports for UK consumption (UK households, UK Government, UK Investment)
6. Value Added
7. Total Inputs
8. Total Outputs
Table 1: UK CO2 generation (2004) under different IO accounting principles

<table>
<thead>
<tr>
<th></th>
<th>CO2 generated within UK - PAP</th>
<th>UK 'carbon' (CO2) footprint - CAP (DTA)</th>
<th>UK 'carbon' (CO2) footprint - CAP (relax DTA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total CO2 attributed (tonnes)</strong></td>
<td>643,806,114</td>
<td>712,677,329</td>
<td>813,536,304</td>
</tr>
<tr>
<td><strong>CO2 supported by UK final consumption</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic (UK) CO2 generation:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Directly generated (households)</td>
<td>163,676,326</td>
<td>163,676,326</td>
<td>163,676,326</td>
</tr>
<tr>
<td>Indirect - generated in UK production sectors, supported by:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>household final consumption</td>
<td>235,930,577</td>
<td>235,930,577</td>
<td>235,930,577</td>
</tr>
<tr>
<td>government final consumption</td>
<td>50,032,572</td>
<td>50,032,572</td>
<td>50,032,572</td>
</tr>
<tr>
<td>capital formation</td>
<td>41,479,167</td>
<td>41,479,167</td>
<td>41,479,167</td>
</tr>
<tr>
<td></td>
<td>491,118,642</td>
<td>491,118,642</td>
<td>491,118,642</td>
</tr>
<tr>
<td>Indirect CO2 embodied in imports supported by:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>household final consumption</td>
<td>149,133,532</td>
<td>232,247,838</td>
<td>232,247,838</td>
</tr>
<tr>
<td>government final consumption</td>
<td>22,242,094</td>
<td>31,905,450</td>
<td>31,905,450</td>
</tr>
<tr>
<td>capital formation</td>
<td>50,183,062</td>
<td>58,264,375</td>
<td>58,264,375</td>
</tr>
<tr>
<td></td>
<td>221,558,688</td>
<td>322,417,662</td>
<td></td>
</tr>
<tr>
<td><strong>CO2 supported by external demands for UK production</strong></td>
<td>152,687,472</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Implied CO2 trade balance (deficit):</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 embodied in exports minus CO2 embodied in imports (CO2 generation under PAP minus CAP)</td>
<td>(68,871,216)</td>
<td>(169,730,190)</td>
<td></td>
</tr>
</tbody>
</table>

In the CAP (DTA) calculation, the CO2 embodied in imports at 221.6 million tonnes exceeds the CO2 embodied in exports with the implication that the estimated carbon footprint, 712.7 tonnes of CO2 exceeds UK domestic emissions under PAP. Thus, regardless of the direction of the goods and services trade balance, the UK runs a CO2 trade deficit of 68.9 million tonnes and is effectively importing sustainability. Now, in 2004 the UK did run a trade deficit with imports exceeding exports by just over 12%. However, in the CAP (DTA) column of Table 1, the CO2 embodied in imports exceeds the CO2 embodied in exports by 45%. Thus, even assuming no differences in polluting technologies, this tells us that the UK imported more CO2 intensive goods and services than it exported. It is possible to speculate, then, that if the UK were not able to trade, its CO2 emissions under PAP would be much higher, and its ability to meet its targets under the Kyoto Protocol negatively affected.

However, if we do take into account differences in polluting technologies, by relaxing the DTA assumption in the final column of Table 1, the picture is much worse: the UK carbon (CO2 equivalent) footprint rises by 14% from 712.7 million tonnes of CO2 to 813.5 million tonnes. Underlying this is the huge (almost 46%) increase in the CO2 embodied in imports from 221.6 to 322.4 million tonnes. As explained above, this increase is entirely due to the fact we are taking differences in polluting technologies in the source country into account. This of course raises the question, considered in more detail in the second paper in this issue) as to what UK consumers and/or policymakers could do about this increase. We may choose how much to consume but what control do we have over how it is consumed? Of course, the same question could be raised in terms of UK consumers purchasing from UK producers. The key difference is that UK policymakers have some control over both the latter, but it is not clear that they could exert much, if any, impact on the technology decisions of producers in other countries. On the other hand, if CO2 accounting exercises such as this one reveal CO2 ‘hot spots’ in the supply chain, consumers may wish to change their consumption decisions and purchase from cleaner producers in cleaner countries. However, this would have implications for international trade and development. One solution may be to develop carbon...
accounting practices in order to assign levels of shared responsibility (and this has been explored in the literature; both in terms of a ‘sharing’ of the domestic national emissions balance between producers and consumers (Andrew & Forgie (2008), Lenzen et al (2007)) and in terms of sharing the emissions embodied in trade (Peters, 2008)); the former measure provides a different way of thinking about domestic responsibility for the national emissions balance, but in the case of the latter approach at least, it is not clear what additional value this type of approach would add.

The CAP and CO2 trade balance results reported for the UK in this study show a significant difference to those found in previous studies. Druckman and Jackson (2008) found that CO2 estimated under the CAP measure was 19% higher than under the PAP measure in 2004 using a quasi-multi-regional input-output model (QMRIO). Similarly Wiedmann et al (2008) estimated the difference to be 21% using a multi-regional input-output model (MRIO). In this study we find the CO2 estimated under the CAP measure for 2004 are 26% higher than under the PAP measure. While use of a fuller interregional framework allows additional effects such as interregional feedback effects and multiplier effects in source countries based on IO tables for those countries (rather than the UK combined use matrix approach used here), we would conclude that the OECD data used to estimate the pollution content of imports here are producing higher estimates than those estimated using GTAP data in the Druckman and Jackson (2008) and Wiedmann et al (2008) studies.

Finally, note that, while we focus on the headline results in this text, the IO approach builds these up from the sectoral level. For the interested reader we have included in Appendix 2 a detailed explanation of sectoral level effects building up the share of the UK Food and Drink sector (as an example) in the overall PAP and CAP calculations.

6. Case study 2: the Scottish economy

Next, we consider the case of Scotland within the UK economy in 2004. While corresponding IO tables for Scotland (augmented with matrices of imports to Scottish production and final consumption from the rest of the UK and rest of the world respectively), do not currently employ the Scottish CO2 intensity of the different production sectors as this is not publicly available. Therefore, in the first instance we apply the UK average CO2 intensities used in the UK analyses above. The results of the PAP calculation (CO2 generated within Scottish borders in 2004) and the CAP calculation (CO2 attributable to Scottish final consumption in 2004), with the latter reported first under the DTA assumption then with this relaxed, are shown in Table 2.

As in the UK case, CO2 emissions attributed to Scotland are considerably higher under CAP than PAP. The first column of Table 2 reports Scottish CO2 under PAP in 2004 at 66.7 million tonnes. In the first instance, where we use the DTA assumption in the CAP estimate the increase is only 3.5% to 69 million tonnes of CO2. However, when we relax the DTA assumption, introducing the OECD data on sources of imports and corresponding CO2 intensities, CAP is 16.6% larger than PAP at 77.8 million tonnes of CO2.

However, perhaps the most interesting point here is that while Scotland runs an overall CO2 trade deficit (importing more CO2 than it exports), the opposite is true in terms of Scottish trade with the rest of the UK, where CO2 embodied in exports (35 million tonnes) is considerably higher than CO2 embodied in imports from the rest of the UK (19.8 million tonnes), with the implication that Scotland runs a 7.8 million tonne CO2 trade surplus with the rest of the UK.

This is an issue that was explored previously by McGregor et al (2008) , and, as in that analysis, the main explanation for this relationship is the fact that Scotland is a net exporter of electricity to the rest of the UK. However, what the analysis in Table 2 fails to reflect is the fact that, with her higher capacity for electricity generation from renewable sources, Scotland is actually a relatively clean producer of electricity, with the implication that it may be better for the UK (in CO2 generation terms at least) that this relationship exists. In order to explore further, it is necessary to introduce more accurate information on the CO2 intensity of Scottish electricity production, rather than relying on the UK average as we have done in Table 2.

Table 3 compares the results of the PAP and CAP (with DTA relaxed) CO2 accounting exercise for Scotland if we introduce as single change. This is the introduction of a Scottish-specific CO2 intensity for the ‘Electricity production and distribution’ (IOC 38) sector. This was provided by colleagues at Scottish Government. It reflects the higher dependence on renewable technologies in Scotland and, at 2616 tonnes of CO2 per £1 million of output is around half the size of the UK average (5430 tonnes per £1 million). The point of this exercise is to examine the impact of reducing the pollution intensity of this key polluting sector of the Scottish economy on the total CO2 emissions balance.

The first column in Table 3 shows the estimated emissions that are generated so satisfy each type of final demand (in Blocks 2 and 3 in the schematics in Figures 1 and 2) under PAP. Here we can see that the total CO2 generated within Scottish (in 2004) under PAP at 48.9 million tonnes of CO2 equivalent is almost 27% less than the figure of 66.7 million tonnes reported in Table 2 (see columns 2 and 4 in Table 3 for percentage comparisons). This difference is entirely due to the replacement of the UK CO2 intensity with a Scottish-specific one in the electricity sector only. As in Table 2, total CO2 under PAP is split between domestic demands, which support 25.5 million tonnes, or 52% of CO2 generated. The
Table 2: Scottish CO2 generation (2004) under different IO accounting principles

<table>
<thead>
<tr>
<th>UK average CO2 intensities applied to all Scottish and UK activities</th>
<th>CO2 generated within Scot - PAP</th>
<th>Scot &quot;carbon&quot; (CO2) footprint - CAP (DTA)</th>
<th>Scot &quot;carbon&quot; (CO2) footprint - CAP (relax DTA)</th>
</tr>
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<tr>
<td>Total CO2 attributed (tonnes)</td>
<td>66,711,016</td>
<td>69,021,834</td>
<td>77,759,681</td>
</tr>
</tbody>
</table>

**CO2 supported by Scottish final consumption**

Domestic (Scottish) CO2 generation:

- Directly generated (households) 11,329,373
- Indirect - generated in Scottish production sectors, supported by:
  - household final consumption 15,288,628
  - government final consumption 3,630,530
  - capital formation 1,479,033
  - Total 31,727,564

Indirect CO2 embodied in imports supported by:

- Imports from the rest of the UK
  - household final consumption 15,116,687
  - government final consumption 1,912,391
  - capital formation 2,753,704
  - Total 19,782,783

- Imports from the rest of the world
  - household final consumption 12,352,490
  - government final consumption 2,078,502
  - capital formation 3,080,495
  - Total 17,511,487

Total emissions embodied in imports 37,294,270

**CO2 supported by external demands for Scotland production**

- Demand from the rest of the UK 27,584,391
- Demand from the rest of the world 7,399,060
- Total 34,983,452

**Implied CO2 Trade Balance (Deficit):**

CO2 embodied in exports minus CO2 embodied in imports (CO2 generation under PAP minus CAP)

- Rest of the UK 7,801,608
- Rest of the world -10,112,427
- TOTAL -2,310,819

remainder is attributable to export demands. However, the amount of CO2 attributable to export demand from the rest of the UK, at 17.6 million tonnes, is considerably (36%) lower than the 27.6 million tonnes in Table 2. Again, this is entirely due to the correction to better reflect Scottish electricity generation from less CO2-intensive renewable sources.

However, the key point to note is that the impact of this is to change the direction of the CO2 trade balance relationship between Scotland and the rest of the UK, with a 2.1 million tonne deficit replacing the 7.8 million tonne surplus in Table 2. Overall, the Scottish CO2 footprint, reported in the third column (with DTA relaxed) does fall by 8% from 77.8 million tonnes of CO2 in Table 2 to 71.5 million tonnes in Table 3 with this more accurate representation of real conditions. Note that this is entirely due to the reduction in CO2 generated within Scotland to support Scottish demands as the CO2 embodied in imports is not affected by the adjustment to reflect the CO2 intensity of Scottish electricity production. Thus, the reduction in CAP in moving from Table 2 to Table 3 is smaller than that in PAP, which takes into account the reduction in CO2 generation to support external demands also.
Table 3: Impact of Scottish renewables technologies on Scottish CO2 generation (2004)
Scottish-specific CO2 intensity for electricity generation (UK average CO2 intensities applied to all other Scottish and RUK)

<table>
<thead>
<tr>
<th>CO2 generated within Scot - PAP</th>
<th>Change relative to Table 2, Column 1</th>
<th>Scot 'carbon' (CO2) footprint - CAP (relax DTA)</th>
<th>Change relative to Table 2, Column 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total CO2 attributed (tonnes)</td>
<td>48,946,902</td>
<td>71,514,117</td>
<td>-8.03%</td>
</tr>
</tbody>
</table>

**CO2 supported by Scottish final consumption**

**Domestic (Scottish) CO2 generation:**

Directly generated (households):

|                      | 11,329,373 | 0.00% | 11,329,373 | 0.00% |

Indirect - generated in Scottish production sectors, supported by:

- Household final consumption: 10,029,030 (34.40%)
- Government final consumption: 2,875,185 (8.03%)
- Capital formation: 1,248,411 (19.68%)

Total: 25,482,000 (68.71%)

Indirect CO2 embodied in imports supported by:

- **Imports from the rest of the UK**
  - Household final consumption: 15,116,687 (0.00%)
  - Government final consumption: 1,912,391 (0.00%)
  - Capital formation: 2,753,704 (0.00%)

- **Imports from the rest of the world**
  - Household final consumption: 19,683,011 (0.00%)
  - Government final consumption: 2,840,354 (0.00%)
  - Capital formation: 3,725,969 (0.00%)

Total emissions embodied in imports: 46,032,117 (0.00%)

**CO2 supported by external demands for Scotland production**

- Demand from the rest of the UK: 17,644,815 (36.03%)
- Demand from the rest of the world: 5,820,087 (21.34%)

Total: 23,464,902 (32.93%)

**Implied CO2 Trade Balance (Deficit):**

- CO2 embodied in exports minus CO2 embodied in imports (CO2 generation under PAP minus CAP)
  - Rest of the UK: -2,137,968 (-127.40%)
  - Rest of the world: -20,429,247 (8.38%)

**TOTAL:** -22,567,215 (104.25%)

The key point is that on the face of it, from a consumption accounting perspective, Scotland does not seem to perform quite so well in Table 3, with a much bigger wedge between PAP and CAP, reflected in the larger net CO2 trade deficit. However, this is not due to higher CO2 generation to meet Scottish consumption (CAP falls between Tables 2 and 3). Rather, it is due to Scotland using cleaner technologies in its production to meet export demand. Surely this is a good thing? As well as reducing Scottish PAP and CAP emissions, it will reduce the carbon footprint of trade partners, primarily the rest of the UK who buy this cleaner electricity, and means a net reduction in total global CO2 emissions. This is the climate change problem that policy aims to address. Indeed, the Scottish results contrast with the Welsh case examined in the second paper in this special issue, where the relatively high CO2 intensity of Welsh production to meet export demands leads to it performing better on CAP than it does on PAP.
Thus, the conclusion that we draw here is that a CAP measure on its own is insufficient to consider the carbon and climate change implications of activity in an open economy. That is, the results of the analyses presented here would seem to raise the issue of whether the appropriate question in carbon accounting terms is whether to adopt PAP or CAP measures when both measures are so clearly dependent on both consumption and technology decisions at home and abroad. Rather, some mix of accounting principles would seem appropriate and, within that, considerations of issues such as shared responsibility with respect to what aspects of carbon generation can and should be considered the responsibility of producers and consumers will be relevant, particularly where these are located in different countries.

7. Conclusions

A key point highlighted in the results reported here is that if we are focussed on a CAP measure, then we are completely unconcerned with any reduction in the emissions embodied in what we export, since under CAP this is the responsibility of consumers in another jurisdiction. Rather, what we are interested in under CAP is reducing the emissions embodied in what we consume, and so we may want to focus on sectors where the reduction in their emissions intensity has large impacts in reducing the emissions embodied in domestic consumption, whether the pollution involved occurs at home or abroad. The strategy employed to meet any target set must take account of what the target itself does and does not cover. For example, pursuing a CAP target may lead to the potentially paradoxical situation where domestic governments are not incentivised by this target to constrain domestic pollution where this is generated to serve foreign demands.

It is important to note that we are not trying to suggest that there is little merit in consumption based targets. Rather, given the interest in the policy community in CAP based measures, we are taking this opportunity to pose questions such as why CAP rather than PAP targets are being promoted, what impacts it is that policymakers are concerned about, and what are the tradeoffs involved in the variety of measures that are available. We have argued elsewhere (see Jensen et al, 2010, and the second paper in this special issue) that there are other probing questions that need to be asked of policymakers pursuing footprint measures. For example, how useful is a CAP based measure when domestic policymakers have little say (and no jurisdiction) over the technologies employed to produce imported goods? While there are obvious and well known drawbacks to the use of PAP measures, CAP measures also have their problems. The difficulties involved in PAP and CAP measures are not insurmountable, but they do need to be discussed and understood.

More generally, a core aim of this paper has been to introduce a carbon accounting tool based on IO techniques. The IO tool presented in this paper maintains the rigour of the traditional IO framework but shows how the IO has been developed into a user friendly tool that will allow the policy community and stakeholders to begin addressing numerous policy concerns and questions, hopefully with more interaction with a more transparent empirical tool. We hope that we have managed to present our analyses in an easy to understand format, with the aim of facilitating deeper comprehension about sustainable issues and ensure that the added value from use of IO as an accounting tool is obtained. Additionally, with IO tables being increasingly regularly reported at a regional and national level, the tool could be a first step towards a standardised measure across countries and regions, which would help address policy concerns that are bigger than the national level.

Where the benefits of the IO tool for pollution accounting are true for all interested users, there are a few benefits that are especially valuable to the policy community. A few of these are highlighted below:

- Allow the evaluation of the success of policy goals through the creation of indicators of resource sustainability;
- Identify sectors or areas of the economy that could benefit from policy intervention;
- Provide a better understanding of supply chains and where major impacts occur within them, and
- Provide insight into the flows of such pollutants or resources embodied in products and services between the UK, the EU and the wider world.

We welcome feedback from all potential users of the type of tool we have developed. Please contact karen.turner@str.ac.uk

Appendix 1: Use of OECD data to determine the pollution content of imports

The OECD maintains detailed databases on international trade flows by country, and has recently added data on country and industry specific CO2 intensities, derived from underlying energy usage data to this database. Working with our co-author Norihiko Yamano from the OECD, the fellowship team have been able to access these data, and this paper reflects the first application of these data. This appendix is intended to give an overview of both the data themselves, and our specific application to create our weighted pollution intensities that we used here for the carbon footprint calculations for the UK and Scotland.

The underlying data comprise import tables using the International Standard Industrial Classification (revision 3)2 system. We started by extracting UK import matrixes for trade with all available countries. While all the data were in a consistent currency (US Dollars) they were not in a consistent year, and were adjusted using country specific inflation/deflation factors from the World Bank3. Clearly this
approach is vulnerable to criticism on the basis of currency fluctuations affecting the value of a dollar across time, but the approach taken did not generally require significant adjustment across years, and we think that our approach here represents a pragmatic approach to this problem. Having examined the range of countries that were covered by these data, we decided upon a regional classification approach, and aggregated the world (and our data) into 14 regions. These were:

1. United Kingdom
2. United States
3. Canada
4. Germany
5. France
6. Rest of OECD Europe and EU27
7. Russia
8. China
9. Developed Asia and Oceania
10. Developing Asia
11. Australia and New Zealand
12. Central and south America
13. OPEC countries (excluding Indonesia)
14. Rest of the World

Also, we had to decide on a sectoral aggregation across the economic sectors that can be mapped to a classification that is consistent with both the UK input-output data and also the environmental data available from OECD. To this end, we settled upon a 45 sector aggregation which is contained in Table A1 below. This table shows the mapping from the full 123 SIC used in the full input-output case to the 45 sector aggregation used here in this analysis. Our main purpose here is to establish what percentage of UK imports of sector i’s output are imported from region n. To this end, and using the consistent and aggregated (both in terms of regions and sectors) imports matrixes we worked out the share of total UK imports that were contributed (at the sectoral level) by each region.

Due to limited data on imports we had to estimate these across sectors/commodities 28-34 and 34-45 using a constant import share for each region. In the case of sectors 28-34 and 35-45, we believed that aggregating the available data across sectors for each region and estimating import shares based on them, provided the most consistent approach, and prevented the absence of data on imports from one sector leading to unusual and unexplainable results. So in effect (remembering principal purpose in using the OECD trade data is simply to obtain the share of imports from each sector contributed by each region) what our assumptions here are doing is to use proxy shares that we consider reasonable to fill the data gaps that exist. We do not believe that the assumptions that are outlined above and that we made in constructing our data compromise the integrity or usefulness of our approach. Using these data, we proceeded to estimate these sectoral level shares and create the share matrix [SM]. In a similar fashion, with no import data for sectors 26 and 27 (collection purification and distribution of water, and construction respectively) we made a decision to assume a split in import propensities for these sectors across the France, Germany and the rest of OECD Europe and EU27 regions.

Having now obtained our import share matrix (the percentage of imports of each foreign sector/commodity output imported to the UK from each region) we proceed to estimate regional sectoral CO2 intensities (tonnes of CO2 per monetary unit of output). We use the OECD CO2 emissions from fuel combustion by sector as the basis for this intensity calculation, by first aggregating into our 14 regions the total CO2 emissions from fuel combustion by sector. Having done this, we had a matrix of total sectoral pollution which we divided by the matrix of regionally aggregated total sectoral output. In other words, we divided the total pollution generated in each sector in each region by the total of regional sectoral output for each sector from the OECD input-output data that we adjusted to be year
<table>
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<th>Description</th>
<th>45 sector</th>
<th>123 sectors</th>
<th>Description</th>
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<th>123 sectors</th>
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<th>45 sector</th>
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<td>Jewellery and Related Products</td>
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<td>Sports Goods and Toys</td>
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<td>Paints, Dyes, Printing Ink, etc</td>
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<td>Electricity Production and Distribution</td>
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<td>Printing and Publishing</td>
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<td>Gas; distribution of gaseous fuels through mains; steam and hot water supply</td>
<td>24+25</td>
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<td>Pharmaceuticals</td>
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<td>87</td>
<td>Collection, purification and distribution of water</td>
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<td>Soap and Toilet Preparations</td>
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<td>88</td>
<td>Construction</td>
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consistent. This gives us a matrix of regional and sectoral pollution intensities [PI]. We use this matrix of regional and sectoral pollution intensities [PI] to construct our weighted output-pollution coefficient vector by multiplying the share matrix [SM] by the matrix of pollution intensities [PI]. This means that each element sMij (the share of total UK imports from sector i that are imported from region j) is multiplied by each element Pi j (the pollution intensity of sector i in region j) which if we sum each row (i.e. for all i=1,...,n) gives us a weighted output-pollution coefficient based on the propensity to import from each sector in each region, taking account of the underlying pollution intensity of production in these sectors and in these regions.

Appendix 2: Working through a sectoral example for the UK

UK Food and Drink (IOC 8-19)

PAP
In 2004, the composite UK Food and Drink sector had a direct CO2 intensity of 151 tonnes of CO2 per £1million output produced. In 2004, direct emissions in the Food and Drink sector accounted for 1.46% of total UK CO2 generation under PAP (643, 806, 114 tonnes in Table 3). However, this does not take account of CO2 generation in other sectors of the UK economy (under PAP) supported by final demand for Food and Drink sector outputs. A standard Type I multiplier analysis (i.e. indirect linkages with other UK industries) using the UK IO tables tells us that for every £1million of final demand for Food and Drink, an additional £0.98million of output is (indirectly) required throughout the UK economy (i.e. the output multiplier is 1.98). The impact on the CO2 intensity of UK Food and Drink is even more significant. For every tonne of CO2 directly generated in the Food and Drink sector itself, another 2 tonnes are required throughout the UK economy. That is, the output-pollution multiplier (CO2 generated throughout the UK economy) is 462 tonnes of CO2 per £1million of final demand for Food and Drink output (compared to the direct intensity of 151 tonnes of CO2 per £1million of output produced). Taking these backward linkage effects into account, 2% of total UK pollution under PAP is accounted for by Food and Drink sector production to meet final demand accounts for.

A key determinant of the UK Food and Drink sector multiplier is purchases from the relatively CO2-intensive Agriculture sector (IOC 1). The UK Agriculture sector has a direct CO2 intensity of 285 tonnes per £1million output. Intermediate purchases from Agriculture accounted for 10% of total inputs to the Food and Drink sector in our accounting year of 2004, or 19% of intermediate purchases from other UK sectors. In addition, 31% of imports to the Food and Drink sector are also Agriculture commodities (produced outside the UK).

If we focus on the linkage between UK Food and Drink and the UK Agriculture sector in the first instance, the intermediate input requirement from the former to the latter, accounts for 6% of the output multiplier in the Food and Drink sector (noted above as 1.98), or 13% of the indirect effect (0.98). That is, for every £1million of final demand for Food and Drink commodity output, £0.12million of output is required in the UK Agriculture sector. However, due to the relatively high CO2-intensity of the Agriculture sector (285 tonnes per £1million output), this equates to 36 tonnes of CO2 in Agriculture generated for every £1million of Food and Drink output. This is 8% of the total output-CO2 multiplier value for Food and Drink (462 tonnes of CO2 from above).

CAP
However, from a fuller CAP perspective, the composite commodity produced by the Food and Drink sector has a greater impact on the UK’s carbon footprint. First of all, consider the impact of considering import-induced output and CO2 effects in the DTA CAP calculation in the second column of Table 3 (712, 677, 329 tonnes of CO2) – i.e. assuming that the direct CO2 intensities of production for the UK apply to all commodity production (imported or domestically produced) – where 3.64% of this total is attributable to UK final demand for Food and Drink. Continuing with the focus on the backward linkage with Agriculture, the global output multiplier effect in this sector rises from £0.12million to £0.21million for every £1million of final demand for UK Food and Drink. The additional output effect is on imports/production outside of the UK. The impact on the Agriculture component of the Food and Drink output-CO2 multiplier is even more significant, rising from 35.5 tonnes (per £1million) if we consider only CO2 generation within UK Agriculture to 60 tonnes if we consider the additional CO2 that the UK saves by not producing all the Agriculture requirements of its Food and Drink sector domestically.

However, if we relax the DTA assumption – i.e. taking into account the actual direct CO2-intensity of commodity production in exporting countries – the impact is even more dramatic. Output multiplier values are unchanged; however, output-CO2 multiplier values change to reflect the different CO2 intensities. In the case of the UK Food and Drink intermediate input requirements of Agriculture commodities, 94 tonnes of CO2 are required around the world for every £1million of final demand (or 90 grammes per £1). The increase of 34 relative to the 60 tonnes of CO2 under DTA is due to the higher CO2-intensity of agricultural production outside the UK.

The OECD data used to relax the DTA assumption here (see Appendix 1) tell us that Agriculture production is only less CO2 intensive than the UK in Germany, France and the region of Developed Asia and Oceana. However, imports from these areas only accounts for 10% of total UK imports of Agriculture commodities. That is, 90% of imports are sourced from regions/countries where Agriculture is more CO2-intensive than in the UK. This will be due to a combination of the composition of Agriculture activity in the
source region/country, as well as differences in technologies.

References


UK Input-Output Table 2004. A UK IO table for 2004 was derived from the published Supply and Use Tables. This was done under the ESRC CCLF project (ESRC ref. RES-066-27-0029), with advice and assistance from the Scottish Government IO team and the Stockholm Environmental Institute. The table is available to download from: http://www.strath.ac.uk/fraser/research/2004ukindustry-byindustryanalyticalinput-outputtables/


The World Bank. Inflation and deflation factors. Available to download from:
Endnotes

1 More detailed analyses follow in Sections 5 and 6. The purpose of this section is to summarise the key findings.

2 Note that throughout the analysis here we use UK Environmental Accounts data that include emissions from UK aviation and shipping.

3 Background information for multiplier analysis is available to download from the Scottish Government at: http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Input-Output/Multipliers

4 The World Input Output Database Project. Information available from: http://www.wiod.org/

5 Here and in Figure 1 we discuss for the example of the UK but this could be done in the context of any region/nation under study.

6 In the absence of a published UK IO table in the appropriate analytical form, a UK IO table for 2004 was derived from the published Supply and Use Tables. This was done under the ESRC CCLF project with advice and assistance from the Scottish Government IO team and the Stockholm Environmental Institute. The table – available to download at: http://www.strath.ac.uk/fraser/research/2004ukindustry-byindustryanalyticalinput-outputtables/ – is reported at the 123 sector level that is standard in UK IO accounting. However, the analysis reported here is based on a 68 sector breakdown that maps to the UK Environmental accounts. Of course it would be possible to apply the pollution intensities from this breakdown at the 123 sector level also. Web links to both the UK Supply and Use Tables and the UK Environmental Accounts from the ONS, are available in the references section below.
