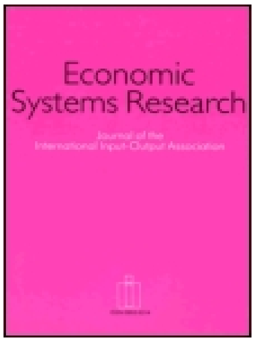

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THE ROLE OF INPUT–OUTPUT ANALYSIS FOR THE SCREENING OF CORPORATE CARBON FOOTPRINTS

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In developing a standardised approach for companies to inventory greenhouse gas (GHG) emissions along their value chains, key challenges identified by stakeholders and technical experts include: which emissions sources a company should include in their inventory and how to calculate them, what constitutes a full list of indirect supply chain activities, and how to determine which activities from such a list are significant by application of a cut-off threshold. Using GHG accounting based on input–output models from Australia and the United States, this work presents specific case study examples and general results for broad industry sectors in both economies to address the development of a complete upstream carbon footprint for screening purposes. This is followed by an analysis of the issues surrounding application of cut-off thresholds and the relationship with system capture rate and efforts in carbon footprint analysis. This knowledge can inform decision makers about where to expend effort in gaining progressively greater accuracy for informed purchasing, investing, claiming carbon credits, and policy-making. The results from this work elucidate several findings: while it is probably true that some companies will know what sources contribute most significantly in the supply chain, this is not likely to be true for all. Contrary to common perception, scope 1&2 emissions are not always more significant than scope-3 sources, and, for some sectors, the largest sources of emissions may be buried further upstream than many companies may have previously perceived. Compiling a list of core elements of significance across all sectors may be problematic because these elements are not necessarily significant for most sectors. Lastly, the application of cut-off thresholds results in highly variable performance in footprint capture rate and is not a reliable criterion for including emission sources in GHG footprints. Input–output analysis is a powerful tool in informing supply-chain GHG accounting, and there is a need for plain language education, training, support materials and information to be made easily accessible to a global business community.

Keywords: GHG accounting; Carbon footprint; Input–output analysis; Structural path analysis

1 INTRODUCTION

The Greenhouse Gas Protocol (GHG Protocol) is the most widely used international accounting tool for government and business leaders to understand, quantify, and manage greenhouse gas emissions. (http://www.ghgprotocol.org)

In 2008 the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) Greenhouse Gas (GHG) Protocol Initiative embarked on a consultative process to develop new guidelines for product and corporate

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GHG accounting and reporting for emissions resulting from product manufacturing and company operations. The Protocol was first published in 2001. Its wide acceptance is credited to the consensus-based process adopted in its original development, followed by two years of multi-stakeholder dialogue to produce the revised edition in 2004. The 2008/2010 round of consultation and development involves more than 300 stakeholders including business and non-government organisation (NGO) representatives, policymakers and academics from around the world. Draft guidelines for product level and improved scope-3 estimation[1] were produced in 2009, with final guidelines expected in 2010 following public comment. Academic representatives include input–output experts who support the use of input–output analysis (IOA) as one of a suite of tools that could be offered to assist in accounting for scope-3 and/or product GHG emissions.

Eight technical working groups (TWG) have been constituted and given a brief to 'provide a standardised approach for companies to inventory, analyse, and manage GHG emissions along their value chains' at product and company levels.[2] The new guidelines will address product life-cycle accounting, which the GHG Protocol Initiative website refers to as 'carbon footprinting', and scope-3 accounting and reporting 'pertaining to the full value chain of an organisation'.[3] The aim is to provide a standard approach to the inventory of GHG emissions 'along the value chains' and to enable the incorporation of the outcome of such an inventory into decision-making.

The project steering committee and members of the eight TWGs first met in late 2008. Delegates assigned to the TWG to develop guidelines for corporate scope-3 value-chain accounting identified key challenges around 'which emissions sources a company should include in their inventory and how to calculate them.'[4] Central to their discussions were questions such as 'what constitutes a *full list* of scope-3 activities'; and how to determine 'which items from such a list are *significant*'. These concerns echo the findings of the 2008 Carbon Disclosure Project's (CDP) Supply Chain Report in which identifying 'the highest impact areas in the supply chain first' (PriceWaterhouseCoopers, 2009, p. 4) was seen as one of the highest priorities.[5] Like respondents to the CDP supply-chain project, some members of the TWG suggested that significance to upstream scope-3 could be detected using criteria such as where an organisation's large expenditure items are, or by applying a cut-off such as all categories contributing over, for example, 5% of emissions.[6] In addition, currently, there are considerations for using input–output data as secondary data, where it is not feasible to obtain detailed data based on the specific processes involved ('process-based' approach), and using IOA for screening analysis to determine the parts of the supply chain with high impacts.

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[1] GHG protocols generally require reporting of emissions from sources under company's direct control ('scope 1') and emissions from direct purchased energy ('scope 2'), with less focus on indirect emissions upstream and downstream in the company's value chain ('scope 3').

[2] http://www.ghgprotocol.org/files/ghg-protocol-supply-chain-one-pager.pdf (accessed 6 March 2009).

[3] http://www.ghgprotocol.org/standards/product-and-supply-chain-standard (accessed 6 March 2009).

[4] http://www.ghgprotocol.org/ghg-protocols-product-and-supply-chain-initiative-launched-in-washington-dc-and-london (accessed 24 March 2009).

[5] The GHG Protocol Initiative has provided advice to the Carbon Disclosure Project's Supply Chain Reporting initiative through membership of its Expert Panel.

[6] For example: 'big spend equals big emissions' (PriceWaterhouseCoopers, 2009, p. 17).

Development of the corporate supply-chain accounting standard is being informed by product standard development. The idea of a cut-off threshold to determine the footprint boundary, or 'materiality threshold', is common in the field of life-cycle assessment (Lenzen, 2001; Suh et al., 2004) and is used by the British Standards Institute (BSI) in its Publicly Available Specification (PAS) 2050 (Specification for the assessment of the life cycle greenhouse gas emissions of goods and services; BSI, 2008, p. 4). PAS 2050, likely the most accepted standard for product carbon footprinting today, provides guidance on GHG emissions accounting at the product level, specifying that a GHG emitting source in the life cycle of a product shall be included in the assessment of GHG emissions if it makes a 'material contribution' of more than 1% of the total anticipated life-cycle footprint. In addition, PAS 2050 requires that 'at least 95% of the anticipated life-cycle GHG emissions of the functional unit' must be captured in the assessment (BSI 2008, p. 13). The International Organisation for Standardisation (ISO) is currently developing a new product accounting standard, ISO 14067 informed by the experience gained in developing PAS 2050 (Sinden, 2009). The possibility of using such materiality threshold has also been mentioned in the WRI TWGs, although no decision has been made to date. In general, materiality thresholds are used to 'ensure that very minor sources of life-cycle GHG emissions do not require the same treatment as more significant sources' (BSI 2008, p. 4). Determining which processes or suppliers are 'material' allows entities to gather detailed emissions data for such important sources while using more aggregate models for less important sources, thus limiting overall effort and time. However, such a requirement is paradoxical, and the extent to which data must be collected cannot be determined definitively through gathering of detailed process-based emissions data alone, because unless 100% of a footprint is already known, 95% cannot be calculated.

Input–output analysis is capable of capturing emissions from the entire supply chain, and can be used as a screening tool to inform estimation of the anticipated life-cycle emissions. In a review of methods for the PAS 2050 conducted for the United Kingdom's Department for Environment, Food and Rural Affairs (Defra), Minx et al. (2008) concluded that the use of detailed process-based emissions data alone is inadequate in meeting the requirements of PAS 2050, and they recommended that the IOA method be used in combination with detailed process-based emissions data in a 'hybrid' approach, which combines the strengths of the process approach and the input–output approach.

Work to date by the TWGs (in which the authors are involved) has brought to the surface some common and often taken-for-granted conceptions cited by organisations, for example:

- companies can estimate where most of the emissions come from and already know what factors are significant in the supply chain;
- direct emissions are almost always going to be more significant than indirect (supply-chain) emissions;
- scope-3 emissions that are 'close' to the organisation in the supply chain will be more significant than those further up the chain;
- it is unrealistic to expect companies to develop a full list of scope-3 emissions; and
- core elements common across sectors can be identified and sector specific items can be left to the company's discretion.

Further, despite a vast literature showing the usefulness of input–output analysis for corporate and product supply-chain emissions accounting (Matthews et al. 2008; Suh et al., 2004); significant debate has occurred in the TWGs about the use of input–output data for either screening assessments or as data for published assessments. Debate on this approach has covered a range of issues including:

- decision-makers' need for *complete footprints* to inform monitoring, for purchasing and investment decisions, for claiming carbon credits and for policy-making;
- reliability of input–output data;
- degree of accuracy that can be obtained from use of sectoral averages;
- difficulty and time consuming nature of IOA for organisations; and
- lack of expertise available to assist companies to undertake IO studies.

It has been recognised that while a complete footprint is always desirable, different levels of accuracy and completeness are necessary to address different needs. It has generally been agreed that IOA could be useful in screening for significance and in addressing scope-3 completeness issues where a high degree of specificity is not necessary. However, a certain degree of reticence has been common, whether due to beliefs about the accuracy of input–output data or due to unfamiliarity with the method itself. The challenge for the academic members of the TWGs has therefore been to demonstrate that IOA is not too difficult and time consuming for organisations to undertake and that it does have a place in the corporate tool-kit.

This paper has grown out of that challenge. We focus on what we believe are the two main roles that IOA can have in corporate and product GHG accounting: screening assessments for determining significance; and ensuring completeness of system inventories. We present general results for broad industry sectors and specific case study examples addressing the first step – development of a complete upstream carbon footprint for screening purposes, including a comparison of the results from two of the more detailed GHG accounting models available, for Australia and the United States. In so doing, we attempt to address some of the corporate community's concerns and misunderstandings surrounding IOA. Secondly, we also present analysis of the issues surrounding application of materiality thresholds and system capture, where we hope to inform the design of carbon footprint protocols and to help organisations understand the implications of the effort versus capture relationship. We apply IOA – in particular structural path analysis – as a methodology to allow a company to gain a broad understanding of complete upstream scope-3 emissions sources, providing the ability to prioritise or rank, in terms of their significance, the items that make up the complete footprint. Armed with this information, decisions can be made in a second step, about where to expend effort in gaining progressively greater accuracy for informed purchasing, investing, claiming carbon credits, and policy-making.[7]

[7] Greater accuracy can be gained through applying a bottom-up LCA to items identified as significant through the IO process. This is known as hybrid (input–output-assisted) LCA. It provides a 'best-of-both-worlds' assessment solution: IOA guarantees completeness and LCA can be used to replace sector averages with specific detail where greater accuracy is needed and more data are available (Bullard et al., 1978; Treloar, 1997; Heijungs and Suh, 2002; Suh et al., 2004; Minx et al., 2008).

2 METHODOLOGY: INPUT–OUTPUT ANALYSIS (IOA) AND STRUCTURAL PATH ANALYSIS (SPA)

Economic input–output models were first developed by Leontief in 1936 (Leontief, 1986) to aid manufacturing planning. Using linear algebra common in the economics literature (Hendrickson et al., 2005) these models trace all transactions throughout the supply-chain network leading up to the final demand of produced commodities by consumers. Once the total economic purchases required for a given final demand bundle are calculated (across all supply chains in the economy), any environmental intervention can be estimated, using input–output analysis, by multiplying the output of each sector by its environmental impact per dollar output.

Applying IOA for estimating carbon footprints is not a new idea. We enumerate the scope-3 carbon footprint of an industry sector according to the ideas of Bullard et al. (1978) and Treloar (1997). Both authors suggested using IOA to obtain a first complete estimate of the entire upstream or downstream carbon emissions. Whilst Bullard et al. (1978) suggested a tiered hybrid LCA approach (see Suh et al., 2004), Treloar (1997) used structural path analysis (SPA) to undertake a screening or prioritisation exercise. This work follows the latter strategy. In this analysis, carbon footprints in the Australian model include emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), non-methane volatile organic compounds (NMVOC), hexafluoroethane (CF6), and hydrofluorocarbons (HFCs); while the US model includes CO_2, CH_4, N_2O, and HFCs.

In essence, an SPA 'unravels' the numerous contributions to a complete scope-3 carbon footprint into single supply chains (or sales chains[8]), called 'paths'. Thus, an SPA provides the most detailed breakdown of an input–output-based carbon footprint into its constituent parts. SPA was conceived by regional scientists in the mid-1980s (Crama et al., 1984; Defourny and Thorbecke, 1984), but has since been used by many researchers for studies in Ecological Economics and Industrial Ecology (Lenzen, 2002, 2006; Foran et al., 2005; Peters and Hertwich, 2006; Suh and Heijungs, 2007; Strømman et al., 2009).

The mathematical basis of SPA is presented elsewhere (Lenzen, 2002, 2006) and shall not be repeated here for the sake of accessibility of this work to a wider audience. SPA uses the same data sources as other input–output techniques: input–output tables that are regularly updated and released into the public-domain by numerous statistical agencies around the world, and that are governed by a UN Standard (United Nations Department for Economic and Social Affairs Statistics Division, 1999).

The result of an SPA applied to an industry sector is essentially a ranked list containing supply chains. The top item in this ranked list is the supply chain that causes more carbon emissions than all other chains, and so on. Thus, this list provides a rapid, yet complete, screening of a sector's full scope-3 carbon footprint, enabling guidance and priority setting for further data collection and follow-up analysis (Bullard et al., 1978; Treloar, 1997; Lenzen, 2002). Here, we compare results from two leading input–output footprinting models, from Australia in 2001 and the United States' 2002 benchmark IO model. To

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[8] We define a *supply chain* by a succession of sectors, where each supplier–recipient node is represented by the percentage of the purchase of the recipient from the supplier in the gross output of the recipient. We define a *sales chain* by a succession of sectors, where each supplier–recipient node is represented by the percentage of the sale by the supplier to the recipient in the gross output of the supplier.

the authors' knowledge, such a comparison between the two nations is unique to this analysis.

Although IO models can provide estimations of economic activities and environmental impacts across the entire supply chain, they have substantial uncertainties related to, for example: sectoral aggregation; price, temporal, and spatial variation; sampling and imputation of the basic data source; assumption of proportionality between monetary and physical flows; and assumptions about international trade. These uncertainties inherent in IOA are not unique to the approach used in this work, and readers can refer to Lenzen (2001), Hendrickson et al. (2005), and Williams (2006) for more detailed discussions on these uncertainty categories. Typical of a single-nation IO model, both the Australian and the US models used in this analysis incorporate imports and exports in their IO data, but assume that production occurring in foreign countries occurs at the same environmental intensities and supply-chain structures as the industries in the nation being modelled. Imports in supply chains can be better depicted using an integrated multiple nations ('multi-regional') IO model, in which the differences in environmental intensities and supply-chain structures in various nations are built into one model (Wiedmann et al., 2007; Wiedmann 2009a).[9] However, because each nation has different sector classifications for their input–output data, and sector-specific environmental intensities information is not always available for every nation, construction of a multi-regional IO model can be difficult as more assumptions pertaining to aggregation and allocation need to be made to harmonize the model structures in various nations. The different sector classifications in each nation also complicate direct comparisons between structural paths calculated using the two single-nation models.

In an upstream scope-3 calculation, supply chains start with an emitting upstream sector, and end with the purchasing industry sector under investigation. The meaning of *upstream chain* is best explained using an example. Consider the supply chain 'Beef cattle → Meat processing → Restaurant'. The emissions associated with this supply chain are caused, for example, by land clearing or enteric fermentation in animals slaughtered for meat that is supplied to a restaurant's kitchen. Another way of expressing this is to say that emissions from beef-cattle farming become 'embodied' in the restaurant meal. The logic of upstream responsibility is that by choosing to buy from a meat processor that buys in turn from the beef cattle sector, the restaurant indirectly enables the beef cattle sector to sell beef, and hence to produce, and hence to emit. The more the restaurant buys from the meat processor, the more it is responsible for the upstream emissions liability caused by meat processing through buying beef cattle. The crucial aspect here is the choice of buying from someone: to enable someone to produce, to emit, and to buy onwards, by buying from them an operating output.

3 RESULTS

We show results below in three subsections. First, we produce four case studies using detailed industry sectors in order to illustrate the screening ability of structural path analysis (SPA)-based IOA for greenhouse gas emissions. With this output it can be seen that

[9] See also the articles by Andrew et al. (2009), Nansai et al. (2009) and Wilting et al. (2009) in this issue.

input–output techniques using public data can provide guidance for companies in terms of what are important scope-3 contributions and what are not. We have chosen four sectors with a wide variety of business types to show the breadth of how IOA can be used: a primary extractive industry (oil and gas), a manufacturing industry (pharmaceuticals), a service industry (data processing), and publishing, an industry somewhere between manufacturing and services. Following the discussion of the case studies, we show aggregate results for broad economic sectors to discuss the role of IOA in compiling complete (i.e. including all sources of emissions) greenhouse gas inventories, followed by a more detailed discussion of the relationship between effort (i.e. number of data points gathered) and completeness of the scope-3 footprint for the case study sectors. While the results below illustrate the screening ability of IOA we have also taken the opportunity to address some of the concerns and misunderstandings of organisations that have been voiced by the TWG and referred to by respondents to the CDP's supply-chain project.

The analyses presented in the following six sections can be undertaken at higher detail than shown, for example for particular greenhouse gases (CO_2, CH_4, etc), particular sources (fuel combustion, fugitive emissions, agriculture, land use change, etc), and for more than 20 paths (in fact, many hundreds if needed). We have chosen 20 paths as a practical limit of the amount of effort many companies would be willing to spend on data gathering. As we shall see, this amount of effort leads to very different levels of completeness. SPA can also be used to extract any particular paths of interest, not limited to the top 20 paths shown.

3.1 Case Studies in Structural Path Analysis for Carbon Footprinting

We show, in this subsection, detailed results for our four case study sectors to elucidate how SPA can be used for screening purposes. In each case we show results from both the Australian and US industry sector and explain common results as well as differences. We will indicate the effect of a 5% cut-off point as suggested by some GHG Protocol TWG members, and also the effect of including only items with a 'material contribution' of more than 1%, according to the PAS 2050 guidelines. To avoid repetition in the text, results pertaining to the 5% cut off will be recorded, followed in parentheses by results pertaining to the 1% PAS cut-off.

3.1.1 Crude Oil and Gas Extraction

The percentage in the top left-hand cell of each SPA is the percentage of emissions covered in the top 20 items of the crude oil and gas extraction SPA (Table 1). In the case of crude oil and gas extraction, 93% of emissions are covered in the top 20 items in Australia and 89% in the US. Column one shows the ranked significance of items that make up the carbon footprint of the sector. The table shows ranks 1 to 20; however, a longer list of many hundred items can be generated. Column two shows the pathway of emissions through layers ('tiers') of the supply chain to the 'Crude oil and gas extraction' sector. For example, the top-ranking items in both SPAs (items 1 & 2 Australia and item 1 US) represent onsite scope-1 emissions. Items three and four (Australia) and item two (US) represent the sector's scope-2 emissions from the direct supply of electricity to the 'Crude oil and gas extraction sector'. The items ranked 10 and 11 in the Australian model and nine in

TABLE 1. SPA results for the carbon footprint of the crude oil and gas extraction sector in Australia (left) and US (right).

Crude Oil and Gas Extraction Australia					Crude Oil and Gas Extraction US				
93%	**Crude Oil and Gas Extraction**	**g CO_2-e/ $AU**	**Tier**	**% of total**	**89%**	**Crude Oil and Gas Extraction**	**g CO_2-e /$US**	**Tier**	**% of total**
1	**Natural gas**	10900	1	85.2%	1	**Oil and gas extraction**	1045	1	72.7%
2	**Crude oil**	480	1	3.8%	2	*Electricity → Oil and gas extraction*	116	2	8.1%
3	*Electricity supply → Natural gas*	170	2	1.3%	3	Oil and gas extraction → Oil and gas extraction	21	2	1.5%
4	*Electricity supply → Crude oil*	170	2	1.3%	4	Nonresidential maintenance and repair → Oil and gas extraction	15	2	1.1%
5	Hardwoods → Natural gas	40	2	0.3%	5	Electricity → Nonfinancial intangible assets → Oil and gas extraction	12	3	0.8%
6	Hardwoods → Crude oil	40	2	0.3%	6	Pipeline transportation → Oil and gas extraction	11	2	0.8%
7	Natural gas → Natural gas	16	2	0.1%	7	State and local Electricity → Oil and gas extraction	11	2	0.7%
8	*Electricity supply → Electricity supply → Natural gas*	15	3	0.1%	8	Industrial gas manufacturing → Oil and gas extraction	9	2	0.7%
9	*Electricity supply → Electricity supply → Crude oil*	15	3	0.1%	9	Petroleum refineries → Oil and gas extraction	6	2	0.4%
10	Gss oil or fuel oil → Natural gss	7	2	0.1%	10	Cement manufacturing → Oil and gas extraction	6	2	0.4%
11	Gas oil or fuel oil → Crude oil	7	2	0.1%	11	*Federal electric utilities → Oil and gas extraction*	5	2	0.3%
12	Sanitary and garbage disposal → Crude oil	7	2	0.1%	12	Oil and gas extraction → Petroleum refineries → Oil and gas extraction	4	3	0.3%
13	Sanitary snd garbage disposal → Natural gas	6	2	0.0%	13	Coal mining → Oil and gas extraction	4	2	0.2%

14	Iron and steel semi-manufactures → Natural gas	6	2	0.0%	14	Petrochemical manufacturing → Oil and gas extraction	3	2	0.2%
15	Iron and steel semi-manufactures → Crude oil	6	2	0.0%	15	Electricity → Management of companies and enterprises → Oil and gas extraction	3	3	0.2%
16	Brown coal → Electricity supply → Natural gas	4	3	0.0%	16	Iron and steel mills → Oil and gas extraction	3	2	0.2%
17	Road freight → Natural gas	4	2	0.0%	17	Nonfinancial intangible assets → Oil and gas extraction	3	2	0.2%
18	Electricity supply → Coal, oil and gas extraction → Natural gas	4	3	0.0%	18	Oil and gas extraction → Natural gas distribution → Oil and gas extraction	3	3	0.2%
19	Brown coal → Electricity supply → Crude oil	4	3	0.0%	19	Rail transportation → Oil and gas extraction	3	2	0.2%
20	Road freight → Crude oil	4	2	0.0%	20	Pipeline transportation → Natural gas distribution → Oil and gas extraction	3	3	0.2%

Note: Items in bold font represent Scope-l emissions, items in italic are Scope-2 emissions, and everything else is Scope-3 emissions in accordance with the GHG Protocol definitions.

the US are the emissions from the refinery that produces the fuels that are used onsite. The items ranked 14 & 15 (Australia) and 16 (US) probably refer to iron and steel used in the construction of rigs, explicitly seen in the purchase of maintenance and repair construction in the US in line four. Item 13 in the US model includes seam gases emanating from coal mines. In general, the scope-3 emission sources extracted from the two models reveal the importance of construction materials, chemicals, some transportation, and brand name licensing (i.e. the use of oil companies' licensed names in advertising).

Column three shows the amount of GHG emissions in units of CO_2 equivalents (CO_2-e) per dollar of expenditure. For example, for every Australian dollar of final demand that the crude oil sector produces there is 0.17 kg of CO_2-e emitted (Australia) because of the use of electricity by the crude oil sector (item 4). This represents 1.3% of the total emissions (column five). Column four shows to which tier of the supply chain this item belongs, for example tier 1 is the sector itself, tier 2 includes the immediate suppliers of the sector, tier 3 represents the suppliers of the suppliers etc. Note the distinction between the terms 'tier' and 'scope'. The word 'scope' is used in accordance with the GHG Protocol definition to distinguish between direct emissions, emissions from direct use of electricity, and indirect supply-chain emissions; while the word 'tier' refers to the number of layers in the supply chain. Scope-1 emissions are those emissions that originate in tier 1, and they are marked by bold in the tables. The items in the list that originate in tier 2 and that begin with *electricity* represent scope-2 emissions for the sector, and they are marked in italic font in the tables. Moreover, paths that have the electricity sector in all tiers above and including tier 2 also belong to scope 2 (representing transactions within the national grid). All other items are considered scope 3 under the GHG Protocol definition.

Comparing the model results, scope-1 emissions directly occurring at the rig/drilling site account for 89% (Australia) and 73% (US) of the total emissions, with the electricity supplied to the crude oil and gas extraction sector accounting for a further 3% and 18%. This means that scopes 1 and 2 together account for over 90% of the total. However, even in this industry, where the source of emissions seems obvious, there is 10% that would not be accounted for if scope 3 were to be omitted. If only items contributing over 5% of emissions were to be included, only scope 1 (Australia) and scopes 1 and 2 (US) would be accounted for and one tenth of all emissions would be missed. Although here we are dealing with sectors, the same applies at the company level.

The Australian SPAs for the sector groups crude oil and natural gas and publishing (see below) feature pairs or triplets of paths that have identical CO_2 intensities. This is due to isolated prorating of CO_2 emissions according to monetary sectoral output, which was carried out in order to disaggregate industry sectors and their CO_2 emissions, which were previously aggregated in the published tables (see Gallego and Lenzen, 2009).

3.1.2 Publishing

Similar to the crude oil sector, the top 20 items in the Australian publishing sector (Table 2) account for most of the emissions (72%). However, unlike the crude oil sector, the top two emissions sources in the Australian model are not of scope 1 and 2. Instead the most significant category is buried in tier 3 of the supply chain. It is softwoods supplied to the 'Pulp, paper and paperboard' sector that supplies the publishing sector, accounting for 54% of all emissions. The electricity supplied to the 'Pulp, paper and paperboard' sector

TABLE 2. SPA results for the carbon footprint of the Australian publishing sector, representing 'Newspapers', 'Printing and stationery', 'Recorded media and publishing', 'Books, maps and magazines' (below left) and a composite publishing industry in the US, consisting of book, newspaper, periodical, and directory publishing (below right).[11]

Publishing Australia

72%	**Publishing**	**g CO_2-e /$AU**	**Tier**	**% of total**
1	Softwoods → Pulp, paper and paperboard → Printing and stationery	690	3	14.7%
2	Softwoods → Pulp, paper and paperboard → Recorded media and publishing	660	3	14.0%
3	Softwoods → Pulp, paper and paperboard → Newspapers	600	3	12.8%
4	Softwoods → Pulp, paper and paperboard → Books, maps, magazines	590	3	12.5%
5	Hardwoods → Pulp, paper and paperboard → Printing and stationery	110	3	2.3%
6	Hardwoods → Pulp, paper and paperboard → Recorded media and publishing	100	3	2.1%
7	Hardwoods → Pulp, paper and paperboard → Newspapers	100	3	2.1%
8	Hardwoods → Pulp, paper and paperboard → Books, maps, magazines	90	3	1.9%
9	*Electricity supply → Printing and stationery*	80	2	1.7%
10	Electricity supply → Pulp, paper and paperboard → Recorded media and publishing	50	3	1.1%

Publishing US

31%	**Book Publishers**	**g CO_2-e /$US**	**Tier**	**% of total**
1	*Electricity → Newspaper publishers*	50	2	5.0%
2	Paper mills → Newspaper publishers	48	2	4.8%
3	Couriers and messengers → Periodical publishers	22	2	2.2%
4	*Electricity → "Directory, mailing list, and other publishers"*	20	2	2.0%
5	*Electricity → Periodical publishers*	19	2	1.9%
6	*Electricity → Book publishers*	19	2	1.8%
7	*Electricity → Paper mills → Newspaper publis hers*	16	3	1.6%
8	Couriers and messengers → Book publishers	16	2	1.6%
9	Couriers and messengers → Newspaper publishers	13	2	1.3%
10	Couriers and messengers → "Directory, mailing list, and other publishers"	12	2	1.2%

(*Continued*)

TABLE 2. Continued

Publishing Australia				Publishing US			
11	Electricity supply → Pulp, paper and paperboard → Printing and stationery	50	3	1.1%	11	Paper mills → Printing → Periodical publishers	11	3	1.1%
12	Electricity supply → Pulp, paper and paperboard → Newspapers	50	3	1.1%	12	Electricity → Printing → Periodical publishers	11	3	1.1%
13	Electricity supply → Pulp, paper and paperboard → Books, maps, magazines	40	3	0.9%	13	Paper mills → Printing → "Directory, mailing list, and other publishers"	11	3	1.0%
14	*Electricity supply → Recorded media and publishing*	28	2	0.6%	14	Electricity → Printing → "Directory, mailing list, and other publishers"	10	3	1.0%
15	*Electricity supply → Newspapers*	26	2	0.6%	15	Air transportation → Periodical publishers	8	2	0.8%
16	Pulp, paper and paperboard → Printing and stationery	25	2	0.5%	16	**Newspaper publishers**	7	1	0.7%
17	*Electricity supply → Books, maps, magazines*	25	2	0.5%	17	Truck transportation → Newspaper publishers	7	2	0.7%
18	Pulp, paper and paperboard → Recorded media and publishing	24	2	0.5%	18	**Periodical publishers**	7	1	0.7%
19	Pulp, paper and paperboard → Books, maps, magazines	22	2	0.5%	19	Air transportation → "Directory, mailing list, and other publishers"	6	2	0.6%
20	Pulp, paper and paperboard → Newspapers	22	2	0.5%	20	**Book publishers**	6	1	0.6%

[11] The United States lacks fully consistent GHG data from land use change in current inventories, whereas the Australian government has made quantifying land use change and its GHG impacts a major endeavour in its inventory efforts. Because of substantial land use change emissions in the Australian forestry sector, forestry (hardwoods and softwoods) shows up in many production chains, particularly for publishing. However, in the US, which lacks such data, the only emissions from forestry are due to fossil fuel usage in the sector, which is relatively small and thus does not show up in the top 20 paths.

is ranked 10–13, which is above the ‘Recorded media and publishing’ (rank 14), ‘Newspaper’ (rank 15) and ‘Books, maps and magazines’ (rank 17) sectors’ own electricity use. The US SPA paints a different picture with only 31% of emissions captured in the top 20 items. The difference is mostly due to the fact that the US input–output model does not include emissions from land use change, whereas the Australian model includes gross emissions from land clearing for agriculture (mostly beef cattle grazing) and forestry.[10] Aside from the differences due to land use change, the US model displays some similarities with the Australian model in that electricity supplied to the publishing sectors and the paper mill sector ranks high in the list. In the US model, the top item is the electricity supplied to ‘Newspaper publishers’ (scope 2). Even so, this only represents 5% of total emissions. Note that if only items that contributed 5% (1%) or above were to be included, 95% (72%) of emissions would not be accounted for in this sector in the US. In the Australian model, if only items contributing more than 5% (1%) of emissions were to be accounted for, 54% (33%) of all emissions would be missed. Furthermore, in the Australian model, scope-2 emissions from electricity supplied to the publishing sector rank ninth, 14th, 15th and 17th in significance, with onsite emissions (scope 1) ranked below 20 (less than 0.5%). If only scopes 1 and 2 were to be accounted for, as is currently required by the GHG Protocol, only approximately 4% of the total upstream footprint would be addressed. Items with much greater potential for emissions reductions would be completely missed. Similarly in the US, scopes 1 and 2 account for only 14% of the total emissions, indicating the importance of scope-3 emissions in life-cycle accounting.

3.1.3 Pharmaceutical Goods for Human Use

In the case of the pharmaceutical goods sector (Table 3) the top 20 items make up just 51% of the sector’s carbon footprint in Australia and 45% in the US. This means that many small items contribute to the total, which is unsurprising given the relative complexity in producing the sector’s product. Moreover, contrary to the common perception that scope-3 emissions ‘close’ to the organisation in the supply chain will be more significant than those further up the chain, 11 and eight of the top 20 items are in tier 3 of the supply chain or beyond in Australia and the US, respectively, indicating that the largest sources of emissions may be buried further upstream than many companies may have previously perceived.

Scope-1 and scope-2 emissions together make up 14% of the sector’s total emissions in Australia and 18% in US, ranking first and 14th in Australia and first and second in the US. Again, agricultural products are more prominent in Australia’s sector due to the inclusion of emissions from land use change. Truck transportation ranks higher in the US than it does in Australia, probably due to the larger transportation distances and the highly developed highway network in the US that result in more use of trucks to transport goods. Wood and plastics used for packaging show up, as do wood cellulose and animal by-products used as a binder/filler in the manufacture of tablets. In general, differences between the

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[10] In this analysis, the composite publishing sector is assumed to have one-quarter of its business in each of the four publishing types. By doing this, we demonstrate that it is possible to create unique SPAs to a certain mix of business.

TABLE 3. SPA results for the carbon footprint of pharmaceutical manufacturing in Australia and US.

Pharmaceuticals Australia					Pharmaceuticals US				
51%	**Pharmaceutical goods for human use**	**g CO_2-e /$AU**	**Tier**	**% of total**	**45 %**	**Pharmaceutical Manufacturing**	**g CO_2-e /$US**	**Tier**	**% of total**
1	*Electricity supply → Pharmaceutical goods for human use*	60	2	12.7%	1	**Pharmaceutical manufacturing**	29	1	9.7%
2	Hardwoods → Pharmaceutical goods for human use	40	2	8.5%	2	*Electricity → Pharmaceutical manufacturing*	29	2	9.6%
3	Oats, sorghum and other cereal grains → Pharmaceutical goods for human use	28	2	5.9%	3	Other basic organic chemical manufacturing → Pharmaceutical manufacturing	23	2	7.8%
4	Sanitary and garbage disposal → Pharmaceutical goods for human use	20	2	4.2%	4	Medicinal and botanical manufacturing → Pharmaceutical manufacturing	6	2	2.0%
5	Softwoods → Pulp, paper and paperboard → Paper containers → Pharmaceutical goods for human use	11	4	2.3%	5	Electricity → Management of companies and enterprises → Pharmaceutical manufacturing	6	3	1.9%
6	Natural gas → Pharmaceutical goods for human use	10	2	2.1%	6	Electricity → Other basic organic chemical manufacturing → Pharmaceutical manufacturing	4	3	1.5%
7	Electricity supply → Employment placement → Pharmaceutical goods for human use	8	3	1.7%	7	Electricity → Medicinal and botanical manufacturing → Pharmaceutical manufacturing	4	3	1.4%
8	Oats, sorghum and other cereal grains → Oats, sorghum and other cereal grains → Pharmaceutical goods for human use	8	3	1.7%	8	Truck transportation → Pharmaceutical manufacturing	4	2	1.2%
9	Beef cattle → Fresh meat → Hotels, clubs, restaurants and cafes → Pharmaceutical goods for human use	7	4	1.5%	9	Petroleum refineries → Other basic organic chemical manufacturing → Pharmaceutical manufacturing	3	3	1.1%
10	Basic chemicals → Pharmaceutical goods for human use	6	2	1.3%	10	Other basic organic chemical manufacturing → Other basic organic chemical manufacturing → Pharmaceutical manufacturing	3	3	1.0%

11	Electricity supply → Forwarding agencies → Pharmaceutical goods for human use	6	3	1.3%	11	Plastics material and resin manufacturing → Pharmaceutical manufacturing	3	2	0.9%
12	*Electricity supply → Electricity supply → Pharmaceutical goods for human use*	6	3	1.3%	12	*State and local government electric utilities → Pharmaceutical manufacturing*	3	2	0.9%
13	Electricity supply → Market research and other business management services → Pharmaceutical goods far human use	5	3	1.1%	13	Scientific research and development services → Pharmaceutical manufacturing	3	2	0.9%
14	**Pharmaceutical goods for human use**	5	1	1.1%	14	Cattle ranching and farming → Animal (except poultry) slaughtering and processing → Pharmaceutical manufacturing	3	3	0.8%
15	Paper containers → Pharmaceutical goods for human use	5	2	1.1%	15	Petroleum refineries → Pharmaceutical manufacturing	2	2	0.8%
16	Road freight → Pharmaceutical goods for human use	4	2	0.8%	16	Management of companies and enterprises → Pharmaceutical manufacturing	2	2	0.7%
17	Hardwoods → Paper containers → Pharmaceutical goods for human use	4	3	0.8%	17	Wet corn milling → Pharmaceutical manufacturing	2	2	0.7%
18	Electricity supply → Hotels, clubs, restaurants and cafes → Pharmaceutical goods for human use	4	3	0.8%	18	Oil and gas extraction → Petroleum refineries → Other basic organic chemical manufacturing → Pharmaceutical manufacturing	2	4	0.7%
19	Electricity supply → Plastic products → Pharmaceutical goods for human use	3	3	0.6%	19	Petrochemical manufacturing → Other basic organic chemical manufacturing → Pharmaceutical manufacturing	2	3	0.7%
20	Basic chemicals → Plastic products → Pharmaceutical goods for human use	3	3	0.6%	20	Industrial gas manufacturing → Pharmaceutical manufacturing	2	2	0.6%

Australian and US industries are probably because of higher impacts due to agricultural goods in Australia and higher impacts due to chemicals and petroleum products in the US. Again, model differences produce somewhat dissimilar results, for example prominent at ninth place in Australia is beef cattle for fresh meat supplied to ‘Hotels, clubs, restaurants and cafes’ used by the ‘Pharmaceutical goods for human use’ sector. Note that if a 5% (1%) cut-off were to be imposed, 73% (54%) of all emissions in Australia and 73% (63%) in US would be missed.

3.1.4 Data Processing Services

The top 20 items from the SPA for the data processing services sector (Table 4) make up only 43% of the total emissions in both countries. This means that over half of all emissions would not be captured even if an organisation were to identify the top 20 likely categories for investigation. Scope-1 and scope-2 emissions account for 17% in the US and 22% in Australia, with scope-2 emissions being the highest contributor in both countries. In fact, in Australia, scope-1 emissions do not appear until rank 69 and account for only 0.001% of emissions (not shown in Table 4).

Similar in both countries are the impacts due to travel and hosting, with hotel and restaurants ranking highly in both countries, and telecommunications, and air travel also appearing in the US list. Some surprising emissions sources occur in both countries. For example the second-highest-ranking item in Australia is buried deep in the supply chain: beef cattle supplied to the fresh meat industry for ‘Hotels, clubs, restaurants and cafes’ that are used by the ‘Data processing services’ sector. In the US ‘Cement manufacturing’ ranks in sixth and seventh place.

Of the 20 most significant contributors to the total emissions, seven items in Australia and eight items in the US, not including the sector’s electricity supply (scope 2) emissions, are from immediate suppliers (tier 2), constituting 7% of total emissions in Australia and 16% in the US. This means that if a sector were able to collect the embodied emissions passed on to it from the top seven or eight of its immediate suppliers it would still only be accounting for 7% (Australia) or 16% (US) of its total emissions.

If the sector were to account for only those items contributing 5% (1%) or more of the total emissions, then in Australia 78% (62%) of emissions would be missed, and in the US 87% (71%) would be missed.

If the sector were to account for the top 10 contributions to emissions, providing they could be identified because some are hidden in the supply chain, just over one third of the total would be accounted for in each country. This shows the importance of both being able to identify important emissions sources, but also being able to use model data to help achieve higher system capture rates than would be possible by simply gathering data from a company’s closest suppliers. In the following sections we take a more general look at this relationship between effort and completeness.

3.2 Economy-Wide Review of Capture Rate Associated with Materiality Thresholds

Given unlimited computational and data storage resources, SPA can generate an infinite number of paths in its outputs and companies can gather an infinite amount of data

TABLE 4. SPA results for the carbon footprint of data processing in Australia and US.

Data Processing Australia					Data Processing US				
43%	**Data processing services**	**g CO_2-e /$AU**	**Tier**	**% of total**	**43%**	**Data Processing**	**g CO_2-e /$US**	**Tier**	**% of total**
1	*Electricity supply → Data processing services*	70	2	21.5%	1	*Electricity → Data processing*	20	2	13.3%
2	Beef cattle → Fresh meat → Hotels, clubs, restaurants and cafes → Data processing services	7	4	2.2%	2	Air transportation → Data processing	7	2	4.9%
3	*Electricity supply → Electricity supply → Data processing services*	6	3	1.8%	3	Couriers and messengers → Data processing	6	2	4.4%
4	Sotwoods → Pulp, paper and paperboard → Printing and stationery → Data processing services	6	4	1.8%	4	**Data processing**	6	1	4.1%
5	Sanitary and garbage disposal → Data processing services	5	2	1.5%	5	Electricity → Real estate → Data processing	3	3	1.9%
6	Beef cattle → Meat products → Data processing services	5	3	1.5%	6	Cement manufacturing → Concrete manufacturing → Data processing	2	3	1.6%
7	Softwoods → Pulp, paper and paperboard → Trade advertising → Data processing services	4	4	1.2%	7	Cement manufacturing → Data processing	2	2	1.5%
8	Electricity supply → Computer and technical services → Data processing services	4	3	1.2%	8	Electricity → Hotels and motels → Data Processing	2	3	1.3%
9	Electricity supply → Hotels, clubs, restaurants and cafes → Data processing services	4	3	1.2%	9	Electricity → Lessors of nonfinancial intangible assets → Data processing	2	3	1.3%
10	Electricity supply → Market research and other business management services → Data processing services	4	3	1.2%	10	Truck transportation → Data processing	2	2	1.3%

(*Continued*)

TABLE 4. Continued

Data Processing Australia					Data Processing US				
11	Wholesale trade → Data processing services	4	2	1.2%	11	*State and local government electric utilities → Data processing*	2	2	1.3%
12	Natural gas → Data processing services	4	2	1.2%	12	Electricity → Food services and drinking places → Data processing	1	3	1.0%
13	Water supply; sewerage and drainage services → Data processing services	3	2	0.9%	13	Waste management and remediation services → Data processing	1	2	1.0%
14	Sotwoods → Data processing services	3	2	0.8%	14	Telecommunications → Data processing	1	2	0.9%
15	Electricity supply → Water supply; sewerage and drainage services → Data processing services	2	3	0.7%	15	Electricity → Telecommunications → Data processing	1	3	0.6%
16	Road freight → Data processing services	2	2	0.6%	16	*Federal electric utilities → Data processing*	1	2	0.6%
17	Brown coal → Electricity supply → Data processing services	2	3	0.6%	17	Hotels and motels → Data processing	1	2	0.5%
18	Electricity supply → Electronic equipment → Data processing services	2	3	0.6%	18	Electricity → Retail trade → Data processing	1	3	0.4%
19	Cement, lime → Data processing services	2	2	0.5%	19	Petroleum refineries → Services to buildings and dwellings → Data processing	1	3	0.4%
20	Beef cattle → Meat products → Hotels, clubs, restaurants and cafes → Data processing services	2	4	0.5%	20	Nonresidential maintenance and repair → Data processing	1	2	0.4%

from all of their suppliers. Realistically, however, there are financial and time constraints, and companies performing carbon footprint studies need knowledge about where (in a supply chain) to gather specific information and where to ignore or to use more averaged secondary data. Besides its screening purpose, as demonstrated in the previous section, input–output analysis can also assist companies in estimating minor contributions to their scope-3 footprints which, although small individually, can add up to substantial portions of a carbon footprint. As discussed above, standards such as PAS 2050 set requirements on where to draw boundaries (i.e. thresholds) and how much of the total emissions must be captured (i.e. capture rate). Here, we empirically test the relationship between these two variables and the amount of effort a company needs to put forth to achieve a certain capture rate. Figure 1 shows the relationship between capture rate and scope-3 contribution thresholds, ranging from 1% down to 0.01%, performed for every sector in the economy and then averaged into broad industry groups. The total analysed carbon footprint (or 'cradle-to-gate' emissions) in this study includes emissions from scopes 1 and 2 as well as upstream scope 3.

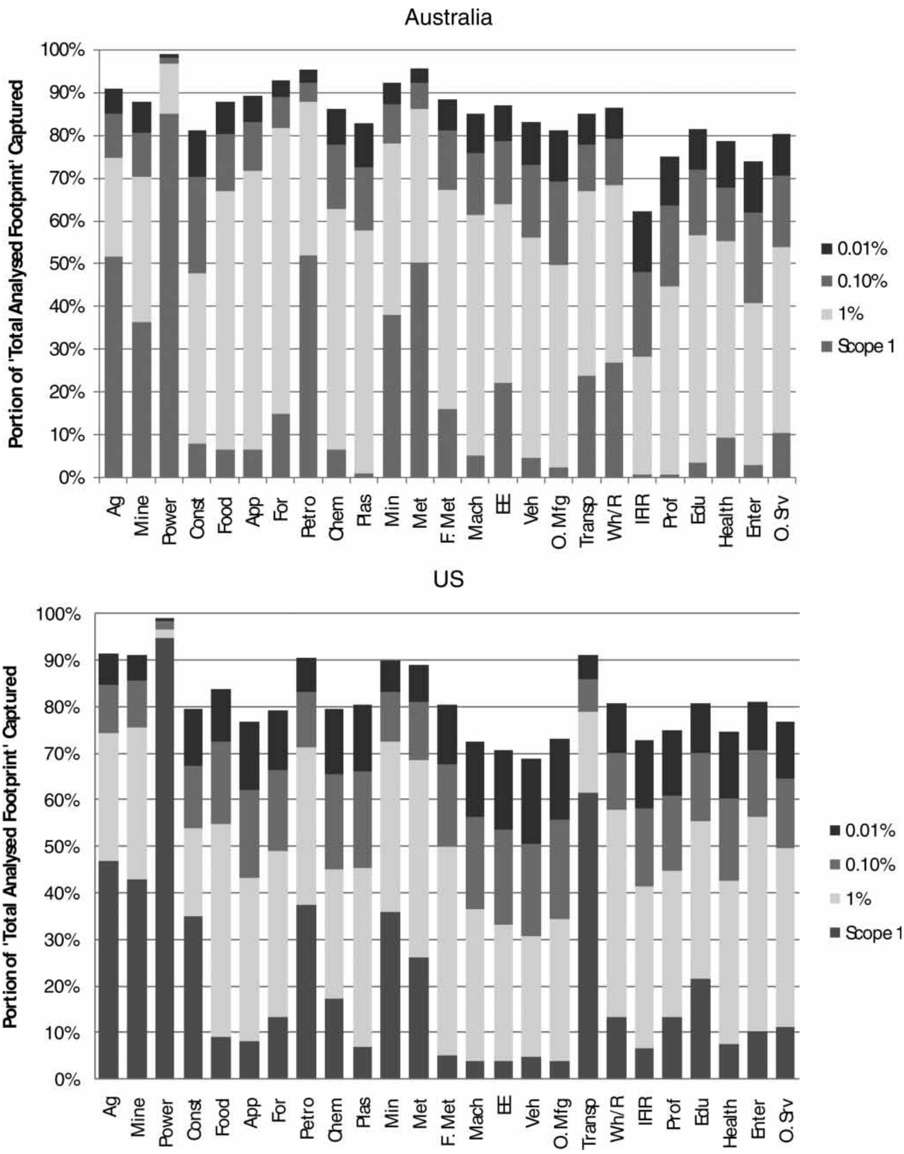
Of course, for every industry group the total amount of emissions 'captured' is greater for lower cut-off thresholds, because more processes are included. The additional capture achieved by using 0.1% threshold is shown below as sitting on top of the initial scope-1 emissions and the PAS 2050 standard, which is the 1% threshold. The additional capture achieved by using 0.01% threshold is represented by the top bar. In other words, the total portion of upstream footprint captured using the 0.01% threshold is the sum of all quantities represented by the 3 bars that are depicted above the bottom 'scope 1' bar (i.e. the sum of the 1%, 0.1%, and 0.01% bars). The results for Australia and US are shown together for comparison.

As seen in the figure, power generation is the only industry that can achieve a total capture rate of more than 95% using a 1% materiality threshold as required by PAS 2050. Except for the power generation sector, with 1% materiality threshold, sectors in Australia and US generally only achieve a total capture rate of 40–90% in Australia and 30–80% in US, far below the total capture rate of 95% required by PAS 2050. If the materiality threshold is changed to 0.1%, which inevitably means that there are many more nodes (suppliers) that need to be included in the footprint analysis, approximately 10–20% more of the total analysed footprint can be captured for many sectors that do not already have a high capture rate under the 1% threshold, but it is still inadequate for meeting the 95% capture requirement. With a 0.01% materiality threshold and hundreds or thousands more nodes included (see Section 3.3 for more discussions), most of the industries can still only achieve a total capture rate of 70–90%, still short of the 95% capture requirement. The lowest capture rates for any threshold are found in the sectors producing the most complicated products, or those products with the most number of components, such as vehicle manufacturing and electronics manufacturing. This result underlines the importance of being able to use secondary data in carbon footprint estimation, because only with excessive effort could companies in most industry sectors come anywhere close to achieving the kinds of capture rates required in current standards.

3.3 Case Studies

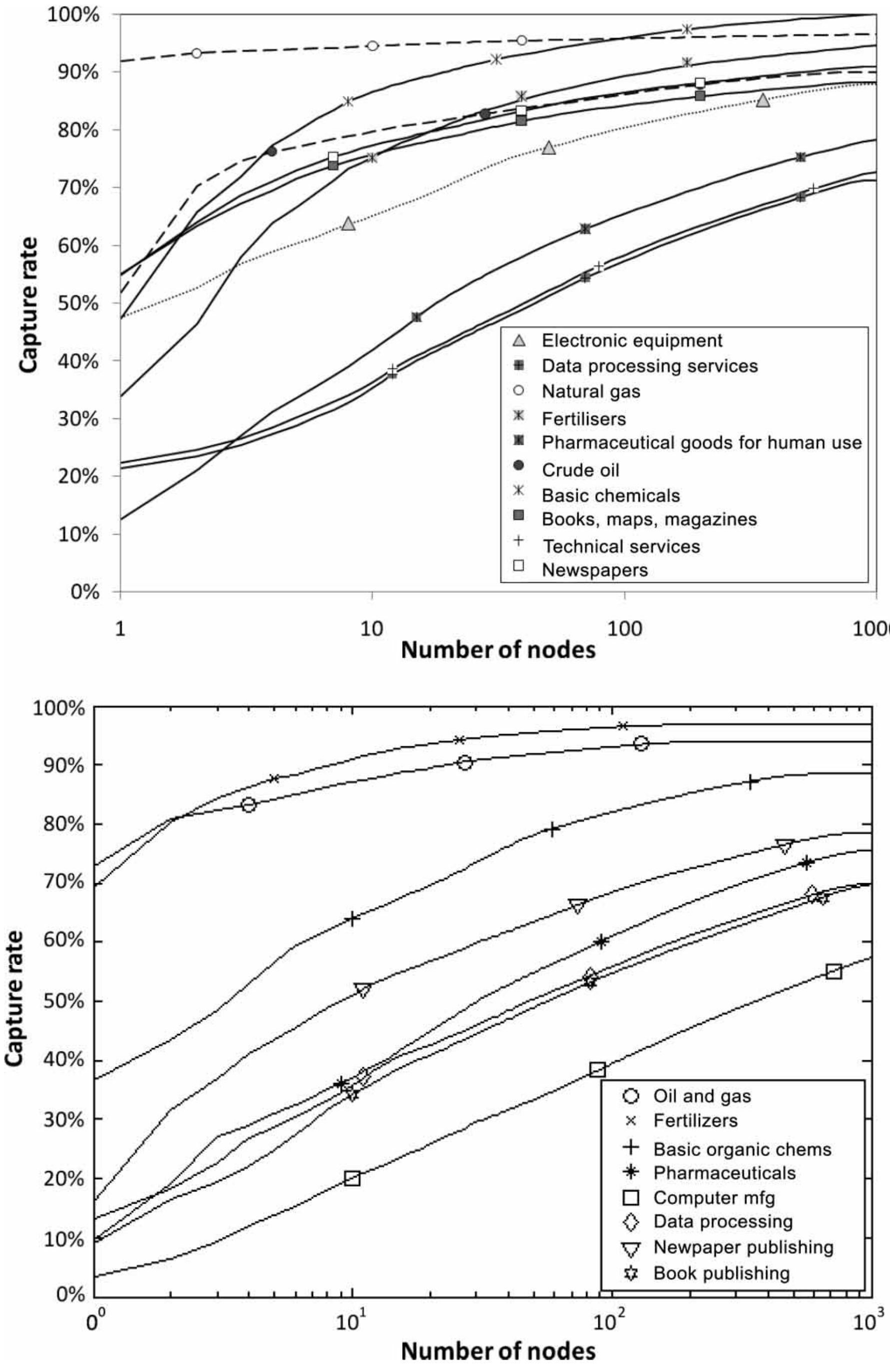
While Figure 1 shows the relationship between the threshold used to cut-off data collection efforts and the total achieved capture rate, the variable many entities may be most interested

FIGURE 1. Threshold-capture relationship for the carbon footprint of broad industrial sectors in Australian (top) and US (bottom) economy.



in is the amount of effort needed to achieve a certain degree of capture. We show this relationship for several detailed sectors from the four case studies below in Figure 2, again with Australian data at the top and US data below. This figure shows the number of supplier sectors (i.e. final 'nodes' at the end of each unique 'path' in the SPA tree) on a logarithmic *x*-axis, needed to achieve a certain capture rate on the *y*-axis. (Each SPA path may include several intermediate 'nodes', which are equivalent to the number of intermediate processes that need to be traced to reach the final node or the particular upstream

FIGURE 2. Node/capture rate/threshold relationship for the carbon footprint of case study sectors in Australia (above) and US (below).



Note: Symbol markers on the curves represent the 1%, 0.1%, and 0.01% thresholds (with 1% the leftmost point on a curve, followed by 0.1% and 0.01% respectively).

supplier in the path. The number of 'nodes' depicted in Figure 2 represents the number of 'final nodes' or 'paths' a company needs to identify and collect emissions data from.) The symbol markers show the path and capture rate at which the 1%, 0.1%, and 0.01% thresholds occur.

As the case studies above implied, for some sectors high capture rates are easier to obtain than for others. For instance, the oil and gas sector as well as the energy-intensive fertiliser production sector achieves above 90% scope-3 capture with only 10–30 paths or less in both economies, except for Australia's crude oil exploration sector. However, this is strikingly different in most manufacturing and service sectors. For Australia, fertiliser and electronics equipment sectors achieve 90% after 200 paths, while the data processing services and the technical services sectors fail to reach 80% after collecting 1000 distinct data points and passing the 0.01% threshold. The remaining Australian sectors shown in Figure 2 achieve 85–90% capture rate only after several hundreds of data are collected. For the US, pharmaceuticals, computer and electronics manufacturing, data processing, and publishing sectors fail to achieve capture rates above 80% even after collecting 1000 distinct data points and passing a 0.01% threshold. Falling in the middle are basic chemicals, where 10 paths achieve a capture of 40–50% and 100 achieve 70–80%. This is a function of what has been called the 'long tail' problem in life-cycle assessment and input–output analysis (Lenzen and Treloar 2003). These results demonstrate several issues: first, the 1% materiality threshold, as used in PAS 2050, produces a capture rate performance that varies widely among different sectors. Second, increasing the materiality threshold by an order of magnitude may trigger the inclusion of 10–100 more data points, but the additional performance gained is often less than 10–20% of capture rate. Third, a tremendous amount of effort would be required to achieve a high capture rate, such as the 95% capture rate specified in PAS 2050; and most sectors would not be able to reach this capture rate even after collection of 1000 distinct data points if they used process-based analysis.

4 DISCUSSION

The application of IOA in accounting for greenhouse gas emissions in the sectors chosen in our case studies illustrates the pitfalls of applying, what would, on the face of it, seem to be reasonable criteria for the selection of what should be counted. The case studies show that although in some sectors, such as crude oil and gas extraction and publishing, where just 20 items capture the vast majority of emissions, 'big expenditure' may equal 'big emissions'; however, in other sectors such as data processing, expenditure is spread over a very large number of items to make up the total emissions. In addition, while it is probably true to say that some companies will know what factors are the most significant in the supply chain, this is not likely to be true for all. Those in the electronics sector in Australia, for example, may know that electricity supply is likely to feature as significant, however they may not have considered the role played by beef cattle in their scope-3 emissions even though it is the second-most significant item in data processing (for an example of this see also Suh et al., 2004).

Accounting for scopes 1 and 2 may sometimes capture the top two items in an emissions hierarchy (e.g. crude oil and gas extraction). However, the case studies highlight the counter-intuitive result that scope-1 and scope-2 emissions are often of less significance than scope 3. In the case of the publishing sector, if it were to account only for scopes 1 and 2 it would be addressing just over 6% of total emissions in Australia and just over 13% in the US. In the case of the data processing sector, scopes 1 and 2 account for 17% of all emissions in the US and just less than 23% in Australia, with scope 1 not even registering among the top 20 items in this sector in Australia.

Accounting for scopes 1 and 2 plus scope-3 emissions that are ‘close’ to the organisation in the supply chain can also be misleading. In the Australian example of the data processing services sector, the top seven immediate suppliers (tier 2) account for only 6.7% of total emissions. In this example if scopes 1 and 2 plus the ‘close’ immediate tier 2 suppliers (scope 3) were to be accounted for, around 70% of emissions could be missed.

The case studies also demonstrate that compiling a list of core elements of significance across all sectors would be problematic. Even scope-2 emissions from the supply of electricity, which features in all the case studies, is not of consistent significance across sectors; while for most it is of prime significance for one sector, publishing in Australia, it does not feature until item nine on the list of significant emissions sources. No scope-3 items appear on the top 20 emissions lists across all four sectors analysed, with only truck transportation appearing in three of the four US examples, and natural gas, softwoods and hardwoods appearing on three out of the four Australian examples.

Even accounting for all emissions that contribute more than 5% to the total, as suggested by some TWG members, is not a reliable criterion. It could mean that more than half of all emissions are not included. Even with a materiality threshold of 1%, as required by PAS 2050, a significant portion of the total emissions are still being left out. The results on materiality thresholds, capture rate, and number of data points in Sections 3.2 and 3.3 demonstrate that the 1% materiality threshold may result in variable performance among the sectors, and it is insufficient for achieving a total capture rate of 95% as required by PAS 2050. Increasing the threshold to 0.1% will gain 10–20% more capture, but doing so may significantly increase the efforts required in the footprint calculation, triggering the inclusion of 10–100 more data points to collect.

Many organisations are unfamiliar with the National Accounts (and the input–output tables therein) published by their own statistical bureaus, and therefore question the reliability of input–output data. It would perhaps help if information such as the following were available and known:

- that input–output tables are actually compiled from real business accounts data;
- that there is a strong link between business accounting and national accounting (United Nations Department for Economic and Social Affairs Statistics Division, 2000);
- that carbon footprinting analyses should not use input–output data alone, but for powerful and efficient screening and as an essential component in subsequent Hybrid LCA; and
- that by the third or fourth tier, supply chains end up in such a large number of distinct producing entities, that average sectoral data become a better and better approximation of the real carbon footprint.

For many years, IOA has already been used by life-cycle assessment (LCA) practitioners to evaluate the environmental and social impacts of products and services. IOA can similarly be helpful in carbon footprint applications. The type of analysis used in this work can also be generated for other environmental or social indicators, as in the Australian Government’s ‘Balancing Act’ Triple Bottom Line study (Foran et al., 2005).

In this way, decision trade-offs between carbon, financial and social objectives can be enumerated in a consistent and comprehensive way. SPA lists have for some time been used by companies and government agencies. They can be created in a comprehensive and standardised way for any industry, because the underlying input–output tables are published by national statistical agencies in a common format governed by UN standards.

Scope-3 calculations can be made simple using input–output analysis because of the work of the Nobel-Prize winning economist Wassily Leontief. However, as members of one of the GHG Protocol Initiative's Technical Working Groups point out, although this work has made such calculations fairly straightforward it is nevertheless considered to be inaccessible to most organisations, neither is expertise thought to be readily available.

5 CONCLUSION

The GHG Protocol Initiative's website provides information on the consultative process currently underway to produce new guidelines for corporate scope-3 emission accounting and reporting. It says that companies are looking for ways to reduce emissions in the supply chain and that the new guidelines will take into account upstream and downstream impacts of a company's operations, thereby presenting the greatest opportunities for emissions reduction within the full value chain. This initiative is closely aligned with the 2008 Carbon Disclosure Project's Supply Chain Reporting initiative, with the GHG Protocol Initiative providing advice to the CDP through membership of its Expert Panel.

The GHG Protocol Initiative's Technical Working Group members are committed to the production of workable and useful guidelines for the assessment and reporting of scope-3 emissions across the full value chain. Members of this stakeholder group are high-level representatives of organisations that are leading the way in understanding and accounting for emissions. Discussion among group members indicates that there is a deep understanding of LCA and an appreciation of its role in emissions assessment. This is not the case for input–output analysis, which seems to have remained relatively inaccessible to a wide audience, supporting the perception that it is difficult and time-consuming to apply. The lack of widely available expertise that would allow companies to make use of IOA is apparent to group members. This has resulted in a general reluctance to engage with IOA as a possible solution to examining the full supply chain because it is thought that to do so may prove impractical for organisations.

The lack of widespread appreciation of what IOA has to offer as a powerful tool in the understanding of supply chains is confirmed in the Carbon Disclosure Project's Supply Chain Report 2009, in which many contributors cite a general lack of support and lack of knowledge as reasons for their seeming reluctance to engage in supply-chain thinking (e.g. PriceWaterhouseCooper, 2009, pp. 19–20). Such reports highlight the responsibility that the academic community has towards informing the general debate. It seems that the IOA community has thus far failed to convey to organisations and carbon footprint practitioners the relative simplicity as well as the usefulness of this approach. Misunderstandings about its reliability and its role in addressing scope-3 completeness for screening purposes also seem to have inhibited take-up. Such lack of understanding points to the need for education and training, support materials and information – all of which need to be easily accessible and flexible enough to cater for a wide range of needs. There is a role here for academic journals, as well as for tertiary education institutions, to produce plain language education and materials that will serve to demystify IOA and make it accessible to a global business community (Wiedmann, 2009b).

This is necessary because until those members of the corporate community who are leading the way on climate change incorporate IOA into their tool kits, input–output analysis is likely to remain an academic exercise rather than becoming a practical solution to some vexing questions. As the Kellogg company reports in the Carbon Disclosure Project Supply Chain Report 2009:

> . . . there is still a lot of education needed around carbon emissions reporting and the understanding that customers like Kellogg will increasingly be expecting this information. (PriceWaterhouseCooper, 2009, p. 3)

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