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ISA^UK Research & Consulting
35 Boundary Close
Durham, DH7 7FB
United Kingdom
E: info@isa-research.co.uk
W: www.isa-research.co.uk, www.isa.org.usyd.edu.au

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A Definition of 'Carbon Footprint'

Thomas Wiedmann[1)*) *and Jan Minx*[2)]

1) ISA^UK Research & Consulting, Durham, DH7 7FB, UK (www.isa-research.co.uk)
2) Stockholm Environment Institute, University of York, Heslington, York, YO10 5DD, UK (www.sei.se)
*) Corresponding author. Email: tommy@isa-research.co.uk

Abstract

The term 'carbon footprint' has become tremendously popular over the last few years and is now in widespread use across the media – at least in the United Kingdom. With climate change high up on the political and corporate agenda, carbon footprint calculations are in strong demand. Numerous approaches have been proposed to provide estimates, ranging from basic online calculators to sophisticated life-cycle-analysis or input-output-based methods and tools. Despite its ubiquitous use however, there is an apparent lack of academic definitions of what exactly a 'carbon footprint' is meant to be. The scientific literature is surprisingly void of clarifications, despite the fact that countless studies in energy and ecological economics that could have claimed to measure a 'carbon footprint' have been published over decades.

This report explores the apparent discrepancy between public and academic use of the term 'carbon footprint' and suggests a scientific definition based on commonly accepted accounting principles and modelling approaches. It addresses methodological question such as system boundaries, completeness, comprehensiveness, units and robustness of the indicator.

Keywords

carbon footprint, ecological footprint, indirect carbon emissions, indicators, environmental accounting, input-output analysis, life-cycle analysis, hybrid analysis

Introduction

'Carbon footprint' has become a widely used term and concept in the public debate on responsibility and abatement action against the threat of global climate change. It had a tremendous increase in public appearance over the last few months and years and is now a buzzword widely used across the media, the government and in the business world.

But what exactly is a 'carbon footprint'? Despite its ubiquitous appearance there seems to be no clear definition of this term and there is still some confusion what it actually means and measures and what unit is to be used. While the term itself is rooted in the language of Ecological Footprinting (Wackernagel 1996), the common baseline is that the carbon footprint stands for a certain amount of gaseous emissions that are relevant to climate change and associated with human production or consumption activities. But this is almost where the commonality ends. There is no consensus on how to measure or quantify a carbon footprint. The spectrum of definitions ranges from direct CO_2 emissions to full life-cycle greenhouse gas emissions and not even the units of measurement are clear.

Questions that need to be asked are: Should the carbon footprint include just carbon dioxide (CO_2) emissions or other greenhouse gas emissions as well, e.g. methane? Should it be restricted to carbon-based gases or can it include substances that don't have carbon in their molecule, e.g. N_2O, another powerful greenhouse gas? One could even go as far as asking whether the carbon footprint should be restricted to substances with a greenhouse warming potential at all. After all, there are gaseous emissions such as carbon monoxide (CO) that are based on carbon and relevant to the environment and health. What's more, CO can be converted into CO_2 through chemical processes in the atmosphere. Also, should the measure include all sources of emissions, including those that do not stem from fossil fuels, e.g. CO_2 emissions from soils?

A very central question is whether the carbon footprint needs to include indirect emissions embodied in upstream production processes or whether it is sufficient to look at just the direct, on-site emissions of the product, process or person under consideration. In other words, should the carbon footprint reflect all life-cycle impacts of goods and services used? If yes, where should the boundary be drawn and how can these impacts be quantified?

Finally, the term 'footprint' seems to suggest a measurement (expression) in area-based units. After all, a linguistically close relative, the 'Ecological Footprint' is expressed (measured) in hectares or 'global hectares'. This question, however, has even more far-reaching implications as it goes down to the very decision whether the carbon footprint should be a mere 'pressure' indicator expressing (just) the amount of carbon emissions (measured e.g. in tonnes) or whether it should indicate a (mid-point) impact, quantified in tonnes of CO_2 equivalents (t CO_2-eq.) if the impact is global warming potential, or in an area-based unit if the impact is 'land appropriation'.

Many of these questions have been discussed in the disciplines of ecological economics and life-cycle assessment for many years and therefore some answers are at hand. So far, however, they have not been applied to the term carbon footprint and thus a clear definition is currently missing.

This report addresses the questions above and attempts a clarification. We provide a literature overview, propose a working definition of the term 'carbon footprint' and discuss methodological implications.

A brief literature review

A literature search in June 2007 for the term "carbon footprint" (i.e. where these two words stand next to each other in this order) in all scientific journals and all search fields covered by Scopus[1] and ScienceDirect[2] for the years 1960 to

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[1] Scopus (www.scopus.com) is currently the largest abstract and citation database of peer-reviewed

2007 yielded 42 hits; 3 from the year 2005, 8 from 2006 and 31 from 2007. Most articles deal with the question of how much carbon dioxide emissions can be attributed to a certain product, company or organisation, although none of them provides an unambiguous definition of the term carbon footprint.

In most cases 'carbon footprint' is used as a generic synonym for emissions of carbon dioxide or greenhouse gases expressed in CO_2 equivalents.

Table 1: Definitions of 'carbon footprint' from the grey literature

Source	Definition
BP (2007)	"The carbon footprint is the amount of carbon dioxide emitted due to your daily activities – from washing a load of laundry to driving a carload of kids to school."
British Sky Broadcasting (Sky) (Patel 2006)	The carbon footprint was calculated by "measuring the CO_2 equivalent emissions from its premises, company-owned vehicles, business travel and waste to landfill." (Patel 2006)
Carbon Trust (2007)	"… a methodology to estimate the total emission of greenhouse gases (GHG) in carbon equivalents from a product across its life cycle from the production of raw material used in its manufacture, to disposal of the finished product (excluding in-use emissions). "… a technique for identifying and measuring the individual greenhouse gas emissions from each activity within a supply chain process step and the framework for attributing these to each output product (we [The Carbon Trust] will refer to this as the product's 'carbon footprint')." (CarbonTrust 2007, p.4)
Energetics (2007)	"… the full extent of direct and indirect CO_2 emissions caused by your business activities."
ETAP (2007)	"…the 'Carbon Footprint' is a measure of the impact human activities have on the environment in terms of the amount of greenhouse gases produced, measured in tonnes of carbon dioxide."
Global Footprint Network (2007)	"The demand on biocapacity required to sequester (through photosynthesis) the carbon dioxide (CO_2) emissions from fossil fuel combustion." (GFN 2007; see also text)
Grub & Ellis (2007)	"A carbon footprint is a measure of the amount of carbon dioxide emitted through the combustion of fossil fuels. In the case of a business organization, it is the amount of CO_2 emitted either directly or indirectly as a result of its everyday operations. It also might reflect the fossil energy represented in a product or commodity reaching market."
Paliamentary Office of Science and Technology (POST 2006)	"A 'carbon footprint' is the total amount of CO_2 and other greenhouse gases, emitted over the full life cycle of a process or product. It is expressed as grams of CO_2 equivalent per kilowatt hour of generation (gCO_2eq/kWh), which accounts for the different global warming effects of other greenhouse gases."

Some articles, however, discuss the implications of precise wording. Geoffrey Hammond writes (Hammond 2007): "…The property that is often referred to as a carbon footprint is actually a 'carbon weight' of kilograms or tonnes per person or activity." Hammond argues "…that those who favour precision in such matters should perhaps campaign for it to be called 'carbon weight', or some similar term."

research literature. Scopus is updated daily and covers 30 million abstracts of 15,000 peer-reviewed journals from more than 4,000 publishers ensuring a broad interdisciplinary coverage.

2 ScienceDirect (www.sciencedirect.com) contains over 25% of the world's science, technology and medicine full text and bibliographic information, including a journal collection of over 2,000 titles as well as online reference works, handbooks and book series.

Haven (2007) mentions the carbon footprint analysis of an office chair as a "life-cycle assessment which took into account materials, manufacture, transport, use and disposal at every stage of development." [3] This hints at a more comprehensive approach, rarely described in other articles. However, there is no definition or methodological description. Eckel (2007) points out that the "Assessment of a business' carbon footprint is … not just calculating energy consumption but also with increasing every scrap of data from every aspect of the business practices." Again, no clear scope of analysis is provided.

While academia has largely neglected the definition issue, consultancies, businesses, NGOs and government have moved forward themselves and provided their own definitions. In the grey literature is a plethora of descriptions, some of which are presented in Table 1.

In the UK, the Carbon Trust [4] has aimed at developing a more common understanding what a carbon footprint of a product is and circulated a draft methodology for consultation (Carbon Trust 2007, see definition in Table 1). It is emphasised that only input, output and unit processes which are directly associated with the product should be included, whilst some of the indirect emissions – e.g. from workers commuting to the factory – are not factored in.

Life-cycle thinking can be found in many other documents and seem to have developed into one characteristic of carbon footprint estimates. A standardisation process has been initiated by the Carbon Trust and Defra aimed at developing a Publicly Available Specification (PAS) for LCA methodology used by the Carbon Trust to measure the embodied greenhouse gases in products (DEFRA 2007). Below, we discuss the pro's and con's of various methodologies.

The Global Footprint Network, an organisation that compiles 'National Footprint Accounts' on an annual basis (Wackernagel et al. 2005) sees the carbon footprint as a part of the Ecological Footprint. Carbon footprint is interpreted as a synonym for the 'fossil fuel footprint' or the demand on 'CO_2 area' or 'CO_2 land'. The latter one is defined as "The demand on biocapacity required to sequester (through photosynthesis) the carbon dioxide (CO_2) emissions from fossil fuel combustion. … [It] includes the biocapacity, typically that of unharvested forests, needed to absorb that fraction of fossil CO_2 that is not absorbed by the ocean." However, while individual documents have used such a land-based definition, for example the Scottish Climate Change Strategy (see Scottish Executive 2006), it has not changed the common understanding of the carbon footprint as a measure of carbon dioxide emissions or carbon dioxide equivalents in the literature.

A definition of 'carbon footprint'

We propose the following definition of the term 'carbon footprint':

"The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."

This includes activities of individuals, populations, governments, companies, organisations, processes, industry sectors etc. Products include goods and services. In any case, all direct (on-site, internal) and indirect emissions (off-site, external, embodied, upstream, downstream) need to be taken into account.

The definition provides some answers to the questions posed at the beginning. We include only CO_2 in the analysis, being well aware that there are other substances with greenhouse warming

[3] Note that a carbon footprint of a product derived in such a way cannot just be added to the carbon footprint of an office using this chair as this would lead to double counting. Furthermore, double (or multiple) counting would occur if companies involved in the life cycle chain of the chair (manufacturing, transport, disposal) reported their full emissions (see e.g. Hammerschlag and Barbour 2003, Lenzen 2007 and Lenzen et al. 2007).

[4] The Carbon Trust is a private company set up by the UK government "to accelerate the transition to a low carbon economy."

potential. However, many of those are either not based on carbon or are more difficult to quantify because of data availability. Methane could easily be included, but what information is gained from a partially aggregated indicator, that includes just two of a number of relevant greenhouse gases? A comprehensive greenhouse gas indicator should include all these gases and could for example be termed 'climate footprint'. In the case of 'carbon footprint' we opt for the most practical and clear solution and include only CO_2.

The definition also refrains from expressing the carbon footprint as an area-based indicator. The 'total amount' of CO_2 is physically measured in mass units (kg, t, etc) and thus no conversion to an area unit (ha, m^2, km^2, etc) takes place. The conversion into a land area would have to be based on a variety of different assumptions and increases the uncertainties and errors associated with a particular footprint estimate (see e.g. Lenzen 2006). For this reason accountants usually try to avoid unnecessary conversions and attempt to express any phenomenon in the most appropriate measurement unit (e.g. Keuning 1994; Stahmer 2000). Following this rationale a land-based measure does not seem appropriate and we prefer the more accurate representation in tonnes of carbon dioxide.

Whilst it is important for the concept of 'carbon footprint' to be all-encompassing and to include all possible causes that give rise to carbon emissions, it is equally important to make clear what this includes. The correct measurement of carbon footprints gains a particular importance and precariousness when it comes to carbon offsetting. It is obvious that a clear definition of scope and boundaries is essential when projects to reduce or sequester CO_2 emissions are sponsored. When accounting for indirect emissions, methodologies need to be applied that avoid under-counting as well as double-counting of emissions, therefore the word 'exclusive' in the definition.[5] Furthermore, a full life-cycle assessment of products means that all the stages of this life cycle need to be evaluated correctly (with "full" meaning "untruncated"). In the following section we discuss the methodological implications of these requirements.

[5] Compare with the discussion of 'shared reponsibility' as outlined by Lenzen et al. (2007).

Methodological issues

The task of calculating carbon footprints can be approached methodologically from two different directions: bottom-up, based on Process Analysis (PA) or top-down, based on Environmental Input-Output (EIO) analysis. Both methodologies need to deal with the challenges outlined above and strive to capture the full life cycle impacts, i.e. inform a full Life Cycle Analysis/Assessment (LCA). Here, only a brief impression of some of their main merits and drawbacks can be provided.

Process analysis (PA) is a bottom-up method, which has been developed to understand the environmental impacts of individual products from cradle to grave. The bottom-up nature of PA-LCAs (process-based LCAs) means that they suffer from a system boundary problem - only on-site, most first-order, and some second-order impacts are considered (Lenzen 2001). If PA-LCAs are used for deriving carbon footprint estimates, a strong emphasis therefore needs to be given to the identification of appropriate system boundaries, which minimise this truncation error. PA-based LCAs run into further difficulties once carbon footprints for larger entities such as government, households or particular industrial sectors have to be established. Even though estimates can be derived by extrapolating information contained in life-cycle databases, results will get increasingly patchy as these procedures usually require the assumption that a subset of individual products are representative for a larger product grouping and the use of information from different databases, which are usually not consistent (see e.g. Tukker and Jansen 2006).

Environmental input-output (EIO) analysis provides an alternative top-down approach to carbon footprinting (see e.g. Wiedmann et al. 2006). Input-output tables are economic accounts providing a picture of all economic activities at the meso (sector) level. In combination with consistent environmental account data they can be used to establish carbon footprint estimates in a comprehensive and robust way taking into account all higher order impacts and setting the whole economic system as boundary. However, this completeness comes at the expense of detail. The suitability of environmental input-output analysis to assess micro systems such as products or processes is limited, as it assumes homogeneity of prices, outputs and their carbon emissions at the sector level. Although sectors can be disaggregated for further analysis, bringing it closer to a micro system, this possibility is limited, at least on a larger scale. A big advantage of input-output based approaches, however, is a much smaller requirement of time and manpower once the model is in place.

The best option for a detailed, yet comprehensive and robust analysis is to combine the strength of both methods by using a hybrid approach (Bullard et al. 1978, Suh et al. 2004, Heijungs and Suh 2006), where the PA and input-output methodologies are integrated. Such an approach allows to preserve the detail and accuracy of bottom-up approaches in lower order stages, while higher-order requirements are covered by the input-output part of the model. Such a **Hybrid-EIO-LCA** method, embedding process systems inside input-output tables, is the current state-of-the art in ecological economic modelling (Heijungs and Suh 2002, Heijungs et al. 2006, Heijungs and Suh 2006). The literature is just emerging and few practitioners so far have acquired the skills to carry out such a hybrid assessment. However, rapid progress and much improved models can be expected over the next few years.

The method of choice will often depend on the purpose of the enquiry and the availability of data and resources. It can be said that environmental input-output analysis is superior for the establishment of carbon footprints in macro and meso systems. In this context a carbon footprint of industrial sectors, individual businesses, larger product groups, households, government, the average citizen or an average member of a particular socio-economic group can easily be performed by input-output analysis (e.g. Foran et al. 2005, SEI et al. 2006, Wiedmann et al. 2007). Process analysis has clear advantages for looking at micro systems: a particular process, an individual product or a relatively small group of individual products.

Practical examples

To date carbon footprints have been established for countries and sub-national regions (SEI and WWF 2007), institutions such as schools (GAP et al. 2006), products (Carbon Trust 2006), businesses and investment funds (Trucost 2006).

In this section we present two practical examples of a carbon footprint analysis that adhere to the definition suggested above. Both analyses were undertaken by researchers of the Stockholm Environment Institute at the University of York, employing an input-output based approach.

The 'UK Schools Carbon Footprint Scoping Study' (GAP et al. 2006) estimates that all schools in the United Kingdom had a carbon footprint of 9.2 million tonnes of carbon dioxide in 2001, equating to 1.3% of total UK emissions. Only around 26% of this total carbon footprint can be attributed to on-site emissions from the heating of premises, whereas the other three quarters are from indirect emission sources, such as electricity (22%), school transport (14%), other transport (6%), chemicals (5%), furniture (5%), paper (4%), other manufactured products (14%), mining and quarrying (2%) and other products and services (3%).

The second example is a calculation of the carbon footprint of UK households, taking into account direct and indirect emissions occurring on UK territory due to consumption activities of UK residents as well as the (indirect) emissions that are embodied in imports to the UK. The results, presented in the 'Counting Consumption' report (SEI et al. 2006), suggest that the carbon footprint of an average UK household was 20.7 tonnes of CO_2 in 2001. A breakdown of this total is presented in Figure 1.

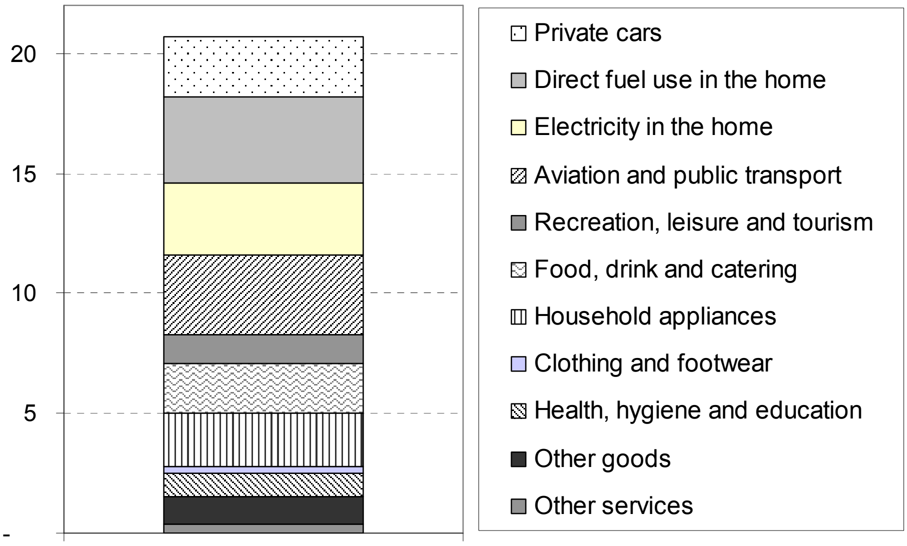

Figure 1: Carbon dioxide emissions associated with UK household consumption in 2001 (tonnes of CO_2 per household) (SEI et al. 2006)

Direct emissions occur through heating and car use. Indirect emissions are the emissions that occur during the generation of electricity and the production of goods and services (whether they are produced in the UK or in other countries). They make up 70 per cent of the almost 21 tonnes of CO_2 per household. Transport (private cars, aviation and public transport) accounts for 28% of total emissions. Electricity use in the home and use of fuels for space and water heating in the home account for almost one third of the emissions.

These findings have also been published by the UK Department for the Environment, Food and Rural Affairs (DEFRA) in the 'The Environment in your Pocket' publication (DEFRA 2006).

Conclusions

A review of scientific literature, publications and statements from the public and private sector as well as general media suggests that the term 'carbon footprint' has become widely established in the public domain albeit without being clearly defined in the scientific community. In this report we suggest a definition of the term 'carbon footprint' and hope to stimulate an academic debate about the concept and process of carbon footprint assessments.

We argue that it is important for a 'carbon footprint' to include all direct as well as indirect CO_2 emissions, that a mass unit of measurement should be used, and that other greenhouse gases should not be included (or otherwise the indicator should be termed 'climate footprint'). We discuss the appropriateness of two major methodologies, process analysis and input-output analysis, finding that the latter one is able to provide comprehensive and robust carbon footprint assessments of production and consumption activities at the meso level. As an appropriate solution for the assessment of micro-systems such as individual products or services we suggest a Hybrid-EIO-LCA approach, where life-cycle assessments are combined with input-output analysis. In this approach, on-site, first- and second-order process data on environmental impacts is collected for the product or service system under study, while higher-order requirements are covered by input-output analysis.[6]

Whatever method is used to calculate carbon footprints it is important to avoid double-counting along supply chains or life cycles. This is because there are significant implications on the practices of carbon trading and carbon offsetting (Hammerschlag and Barbour 2003, Lenzen 2007, Lenzen et al. 2007).

[6] For example by using the Bottomline[3] tool (see www.bottomline3.co.uk).

References

BP (2007), What is a Carbon Footprint?, Internet site: http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/downloads/A/ABP_ADV_what_on_earth_is_a_carbon_footprint.pdf

Bullard, C.W., Penner, P.S. and Pilati, D.A. (1978). "Net energy analysis: Handbook for combining process and input-output analysis". *Resources and Energy* 1(3): 267-313. http://dx.doi.org/10.1016/0165-0572(78)90008-7.

Carbon Trust (2006) "Carbon footprints in the supply chain: the next step for business". Report Number CTC616, November 2006, The Carbon Trust, London, UK. http://www.carbontrust.co.uk.

Carbon Trust (2007) "Carbon Footprint Measurement Methodology, Version 1.1". 27 February 2007, The Carbon Trust, London, UK. http://www.carbontrust.co.uk.

DEFRA (2006). "The Environment in Your Pocket". Department for Environment, Food and Rural Affairs, London. http://www.defra.gov.uk/environment/statistics/eiyp/index.htm.

DEFRA (2007). "Step forward on reducing climate change impacts from products." *DEFRA press release, 30 May 2007*, from http://www.defra.gov.uk/news/2007/070530a.htm.

Eckel, A. (2007). *Gravure* 21(2): 35-36.

Energetics (2007). The Reality of Carbon Neutrality, London. www.energetics.com.au/file?node_id=21228

ETAP (2007). The Carbon Trust Helps UK Businesses Reduce their Environmental Impact, Press Release, http://ec.europa.eu/environment/etap/pdfs/jan07_carbon_trust_initiative.pdf

Foran, B., Lenzen, M. and Dey, C. (2005). "Balancing Act: A triple bottom line analysis of the 135 sectors of the Australian economy". CSIRO Resource Futures and The University of Sydney, Canberra, ACT, Australia. www.cse.csiro.au/research/balancingact

GAP, SEI and Eco-Logica (2006). "UK Schools Carbon Footprint Scoping Study". Report by Global Action Plan, Stockholm Environment Institute and Eco-Logica Ltd for the Sustainable Development Commission, London, March 2006. http://www.sd-commission.org.uk/publications.php?id=389.

GFN (2007). "Ecological Footprint Glossary". Global Footprint Network, Oakland, CA, USA. Accessed July 2007 from http://www.footprintnetwork.org/gfn_sub.php?content=glossary.

Grubb and Ellis (2007). Meeting the Carbon Challenge: The Role of Commercial Real Estate Owners, Users & Managers, Chicago.

Hammerschlag, R. and Barbour, W. (2003). "Life-Cycle Assessment and Indirect Emission Reductions: Issues Associated with Ownership and Trading". Institute for Lifecycle Environmental Assessment (ILEA), Seattle, Washington, USA, May 2003. http://www.ilea.org/downloads/LCAEmissReductions.pdf.

Hammond, G. (2007). "Time to give due weight to the 'carbon footprint' issue". Nature 445(7125): 256. http://dx.doi.org/10.1038/445256b.

Haven, J. (2007). Environment Business 129: 27.

Heijungs, R. and Suh, S. (2002). The computational structure of life cycle assessment. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Heijungs, R. and Suh, S. (2006). "Reformulation of matrix-based LCI: from product balance to process balance". Journal of Cleaner Production 14(1): 47-51. http://dx.doi.org/10.1016/j.jclepro.2005.05.022.

Heijungs, R., de Koning, A., Suh, S. and Huppes, G. (2006). "Toward an Information Tool for Integrated Product Policy: Requirements for Data and Computation". Journal of Industrial Ecology 10(3): 147-158. http://dx.doi.org/10.1162/jiec.2006.10.3.147.

Keuning, S.J. (1994). The SAM and Beyond: Open SESAME!, Economic Systems Research 6(1): 21-50.

Lenzen, M. (2001). "Errors in Conventional and Input-Output-based Life-Cycle Inventories". Journal of Industrial Ecology 4(4): 127-148. http://dx.doi.org/10.1162/10881980052541981.

Lenzen, M. (2006). "Uncertainty in Impact and Externality Assessments - Implications for Decision-Making (13 pp)". The International Journal of Life Cycle Assessment 11(3): 189-199. http://dx.doi.org/10.1065/lca2005.04.201.

Lenzen, M. (2007). "Double-counting in Life-Cycle Assessment". Journal of Industrial Ecology: submitted.

Lenzen, M., Murray, J., Sack, F. and Wiedmann, T. (2007). "Shared producer and consumer responsibility - Theory and practice". Ecological Economics 61(1): 27-42. http://dx.doi.org/10.1016/j.ecolecon.2006.05.018.

POST (2006) "Carbon footprint of electricity generation". POSTnote 268, October 2006, Parliamentary Office of Science and Technology, London, UK. http://www.parliament.uk/documents/upload/postpn268.pdf.

Patel, J. (2006). "Green sky thinking". Environment Business(122): 32.

Scottish Executive (2006). Changing Our Ways: Scotland's Climate Change Programme, Edinburgh.

SEI and WWF (2007). The Carbon Footprints of Local Authorities in England, forthcoming.

SEI, WWF and CURE (2006). "Counting Consumption - CO_2 emissions, material flows and Ecological Footprint of the UK by region and devolved country". Published by WWF-UK, Godalming, Surrey, UK, 2006. http://www.ecologicalbudget.org.uk.

Stahmer, C. (2000). The magic triangle of input-output, Paper presented at the XIII International Conference on Input-Output Techniques, 21-25 August, Macerata, Italy.

Suh, S., Lenzen, M., Treloar, G.J., Hondo, H., Horvath, A., Huppes, G., Jolliet, O., Klann, U., Krewitt, W., Moriguchi, Y., Munksgaard, J. and Norris, G. (2004). "System boundary selection in life-cycle inventories using hybrid approaches". Environmental Science & Technology 38(3): 657-664.

Trucost (2006), Carbon Counts: The Trucost Carbon Footprint Ranking of UK Investment Funds, London.

Tukker, A. and Jansen, B. (2006). "Environmental impacts of products: A detailed review of studies". Journal of Industrial Ecology 10(3): 159.

Wackernagel, M. and Rees, W.E. (1996). Our Ecological Footprint - Reducing Human Impact on the Earth. New Society Publishers Gabriola Island, B.C., Canada.

Wackernagel, M., Monfreda, C., Moran, D., Wermer, P., Goldfinger, S., Deumling, D. and Murray, M. (2005). National Footprint and Biocapacity Accounts 2005: The underlying calculation method.

Wiedmann, T., Barrett, J. and Lenzen, M. (2007). "Companies on the Scale - Comparing and Benchmarking the Footprints of Businesses". International Ecological Footprint Conference, May 8-10, 2007, Cardiff, UK. http://www.brass.cf.ac.uk/uploads/Wiedmann_et_al_P36.pdf; http://www.isa-research.co.uk/docs/Wiedmann_et_al_2007_Cardiff_Companies_EF.pdf.

Wiedmann, T., Minx, J., Barrett, J. and Wackernagel, M. (2006). "Allocating ecological footprints to final consumption categories with input-output analysis". Ecological Economics 56(1): 28-48. http://dx.doi.org/10.1016/j.ecolecon.2005.05.012.