International Journal of Sustainable Engineering
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t782909026

SME application of LCA-based carbon footprints

Jessica Moss [a]; Chris G. Lambert [a]; Allan E. W. Rennie [a]
[a] Lancaster Product Development Unit, Engineering Department, Lancaster University, Lancaster, UK

Online Publication Date: 01 June 2008

To cite this Article Moss, Jessica, Lambert, Chris G. and Rennie, Allan E. W.(2008)'SME application of LCA-based carbon footprints',International Journal of Sustainable Engineering,1:2,132 — 141

To link to this Article: DOI: 10.1080/19397030802332930

URL: http://dx.doi.org/10.1080/19397030802332930

International Journal of Sustainable Engineering
Vol. 1, No. 2, June 2008, 132–141

SME application of LCA-based carbon footprints

Jessica Moss*, Chris G. Lambert and Allan E. W. Rennie

Lancaster Product Development Unit, Engineering Department, Lancaster University, Lancaster, UK

(Received 31 January 2008; final version received 8 July 2008)

Following a brief introduction about the need for businesses to respond to climate change, this paper considers the development of the phrase 'carbon footprint'. Widely used definitions are considered before the authors offer their own interpretation of how the term should be used. The paper focuses on the contribution small and medium sized enterprises (SMEs) make to the economy and their level of influence in stimulating change within organisations. The experience of an outreach team from the Engineering Department of a UK university is used which draws on the experience of delivering regional economic growth projects funded principally through the European Regional Development Fund. Case studies are used including the development of bespoke carbon footprints for SMEs from an initiative delivered by the outreach team. Limitations of current carbon footprints are identified based on this higher education-industry knowledge exchange mechanism around three main themes of scope, the assessment method and conversion factors. Evidence and discussions are presented that conclude with the presentation of some solutions based on the work undertaken with SMEs and a discussion on the merits of the two principally used methodologies: life-cycle analysis and economic input–output assessment.

Keywords: carbon footprint; life-cycle analysis; small and medium sized enterprise

1. Introduction

It is widely accepted that the world's climate is changing with a growing scientific belief that this is as a result of anthropogenic activity since the inception of the industrial revolution (IPCC 2007). The consequences of human dependency on fossil fuels are widely reported including claims of rising sea temperatures, species extinction and extreme weather events (Nicholls and Lowe 2004). With such events consistently topping media and political agendas, the need for action to be taken to slow down and reduce the impacts has never before been so urgent. Therefore, across all parts of society, there is a growing need to understand, manage and reduce greenhouse gas (GHG) emissions.

There are many methods to reduce emissions which include: energy management and reduction programmes; the development of new technologies for renewable energy generation; bio fuels; and fuel cells for use in transport (Sims *et al*. 2007). To make the most effective use of these new technologies, it is important to establish the most carbon-intensive sources of emissions, so that these can be tackled first. To do this, it is necessary to estimate the emissions which are released during a process or in the manufacture of a product. The tools which have been produced to perform this operation are now commonly known as 'carbon calculators' or 'carbon footprint tools'.

Despite the fact that it is a relatively new concept, there are already many carbon footprint tools available for use. However, not all of these tools are reliable and those that are may involve costly assessment processes. This paper evaluates the different types of tools available and determines their value for small and medium sized enterprises (SMEs), demonstrating those that best fulfil their requirements and the development that is needed to produce a tool specifically for SMEs.

2. Background

Scientific study has demonstrated that the temperature of the earth, which is constantly fluctuating, has risen more in the last century than would have been predicted (IPCC 2007). The patterns in temperature can be linked directly to the historic fluctuations in GHGs, thus suggesting that one has an impact on the other. In the past 150 years, since the industrial revolution, more GHGs have been released into the atmosphere than ever before, and likewise an unprecedented temperature increase has been observed.

The link between GHGs and temperature increase is the greenhouse effect, whereby a layer of GHGs in the atmosphere absorbs infra red radiation as it passes out of the atmosphere. When it is reemitted by the GHGs, some is emitted back to earth, thus increasing the temperature of the Earth above the

*Corresponding author. Email: j.moss@lancaster.ac.uk

ISSN 1939-7038 print/ISSN 1939-7046 online

DOI: 10.1080/19397030802332930
http://www.informaworld.com

normal warming effect of the sun. This is a natural phenomenon which keeps the Earth at a habitable temperature, but release of more GHGs inevitably increases the temperature of the Earth (Hardy 2003). Greenhouse gases include carbon dioxide (CO_2), methane and nitrous oxide, all of which are released in significant amounts by many processes, including industrial processes, transport and farming activities. The gas which is emitted the most by human activities is CO_2, hence the choice of 'carbon footprint', although many carbon footprints also consider other GHGs which are reported as CO_2 equivalents (CO_{2e}).

2.1 *Carbon footprints*

The term 'carbon footprint' has evolved from the ecological footprint developed by Wackernagel and Rees (1996). The ecological footprint measures an area of land, unlike the carbon footprint which is more often reported as a mass of carbon released into the atmosphere, although it has been reported in terms of area (Global Footprint Network 2007) and also in terms of monetary value (Trucost 2007). The ecological footprint takes into account many environmental issues such as land and resource use, not just global warming. The carbon footprint evolved out of this as the carbon element of the ecological footprint or the ecological footprint for CO_2 (Reaney 2000) when people wished to focus on global warming, and GHG emissions in particular. The expression 'carbon footprint' was used in the media as early as 2001 (Quinn 2001) but it was not used in scientific literature until 2005 (Haefeli and Telnes 2005, Spencer 2005).

Because it is an expression primarily of media origin, it is poorly defined in scientific terms with vague definitions, particularly among companies offering carbon offsetting. The UK government carbon calculator, 'Act on CO_2', defines it as 'your own personal measure of how much carbon dioxide you create and how much you contribute to climate change' (Directgov 2007). Meanwhile, the Global Footprint Network (GFN) (2007) suggests that a carbon footprint 'measures the demand on bio capacity that results from burning fossil fuels in terms of the amount of forest area required to sequester these carbon dioxide emissions.' A comparison of these two definitions identifies several discrepancies and both definitions are broad and unclear. The Global Footprint Network defines the footprint as being specifically from the burning of fossil fuels, whereas Directgov does not identify a source; Directgov implies a carbon footprint should be a personal measurement whereas GFN does not specify who should be responsible. Wiedmann and Minx (2007) produced a table showing many more definitions illustrating that there is little agreement in this area in the popular literature.

Wiedmann and Minx (2007) tried to define a carbon footprint that could be used in all situations. They suggested that '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.' To justify this definition, the authors explain that to report the footprint in mass units in which it is measured means no conversion to an area unit is needed, which reduces the errors arising from unnecessary assumptions. They also explain the need to include direct and indirect emissions so that the assessment gives a complete and true picture. However, the justification given for the footprint including only CO_2 emissions is inadequate, as the main argument focuses on the difficulty in measuring other gases and the fact that being called a 'carbon footprint' means it should include only carbon for clarity. The authors suggest that a full GHG footprint could be called a 'climate footprint'. However, problems regarding data are not grounds to ignore significant emissions as the data is improving all the time and the more it is used and analysed, the more it will improve. Moreover, to be a truly useful tool for limiting anthropogenic global warming, it needs to include all GHGs regardless of the name.

A more suitable definition of carbon footprint would be: 'The total mass of greenhouse gases directly and indirectly emitted by an individual, a company or throughout the full lifecycle of a product'.

2.2 *Small and medium sized enterprises (SMEs)*

There is no worldwide standard definition of an SME, but the European Commission defines an SME as an enterprise consisting of less than 250 employees with a turnover of not more than EUR 50 million (European Commission 2003). As 99.9% of all businesses are registered as small or medium and 58.9% of private sector employment and 51.9% of private sector turnover is provided by SMEs (BERR 2007), their cumulative impact on society, the environment and the economy is very important. A comparison of the number of companies with the contribution to turnover illustrates that SMEs are not rich compared with larger organisations.

The high number of SMEs means that their cumulative effect on climate change is likely to be large. However, until recently most of the focus has been on encouraging large corporations to take responsibility for their environmental actions, with little attention given to the important part that SMEs have to play. The corporate social responsibility (CSR) agenda has been encouraged for a long time in larger enterprises, but recognition of the need to encourage SMEs to take more responsibility for their actions is relatively new. There is now a push to encourage SMEs to act more responsibly and to give recognition to the many SMEs that are already doing so (European Commission 2007).

Lancaster Product Development Unit (LPDU) is the knowledge exchange and outreach team for Lancaster University's Engineering Department and is engaged with the industry base of England's North West (NW) region to contribute to economic growth. Owing to the constraints placed on this provision of assistance, funding regulations concerning size of business only allow the project team to work with SMEs. Since its formation in 2002, LPDU has worked with around 400 SMEs in England's NW funded largely through the European Regional Development Fund (ERDF) and has collated qualitative data in its baseline assessments of companies. The Unit works with a diverse industry base and so encounters a wide range of needs and requirements. Despite this diversity, there are some aspects of SMEs which remain the same whichever sector they are working in and these arise as a consequence of their size and structure.

Part of the LPDU work in collating initial information about a company, to verify its eligibility to receive public funding of this nature, is to gain an insight of how the company understands its environmental impacts and the action it is taking in this regard. Small and medium sized enterprises in England's NW region regularly report that they lack the resources required in order to achieve as much as they would like within their business relating to the impacts their company have. The notion of lack of power or resources coupled with lack of understanding and knowledge is something Pimenova and Van der Vorst (2004) also found to hinder a company's willingness to act. This is particularly prevalent with small and micro-enterprises where Managing Directors have reported that the priority for the company is to ensure economic viability. Indeed, senior management within SMEs engaged with LPDU have generally seen economic growth and environmental impacts as mutually exclusive.

Whilst working with SMEs, it is clear that intervention assistance from across Lancaster University relies on the interaction with senior management and therefore, the decision makers of the organisation. In working with larger businesses, people that make decisions at this level are often not as accessible and it is therefore acutely paradoxical that the resource-poor, smaller companies are the most accessible decision makers. This results in the potential for wider organisational change and for that change to occur in a reduced timescale. It is paramount therefore, that any business support initiatives or publically funded programmes that aim to enhance resource efficiency, reduce impacts and evoke change should not ignore the smaller business sector.

Along with the concern over GHG emissions as highlighted earlier, a growing area of public debate has been around the legislative framework on which impact reduction can be managed. There are many types of legislation now affecting every sector of business; research shows that despite this growth, SMEs are still unaware of their impacts. About 15% of the 4489 companies contacted in the SME-nvironment 2007 Survey considered that they undertook activities that could harm the environment (NetRegs 2007). Legislative compliance is arguably a driver for change, however this research shows SMEs still lack awareness of such legislation and in general they are reactive rather than proactive (Petts *et al.* 1999). Awareness is increasing as climate change inevitably makes its way higher up the political, public and media framework.

Owing to this lack of understanding there is a need to improve the environmental awareness of SMEs; this is one of the key potential roles of the carbon footprint. One of the possible methods of increasing the interest of SMEs in the environment is to stress to them the financial advantages to be gained from the assessment as modelled in Figure 1. A carbon footprint could help an SME demonstrate their commitment to reducing their environmental impact to their customers, thus improving their marketing potential. Another pressure on SMEs is

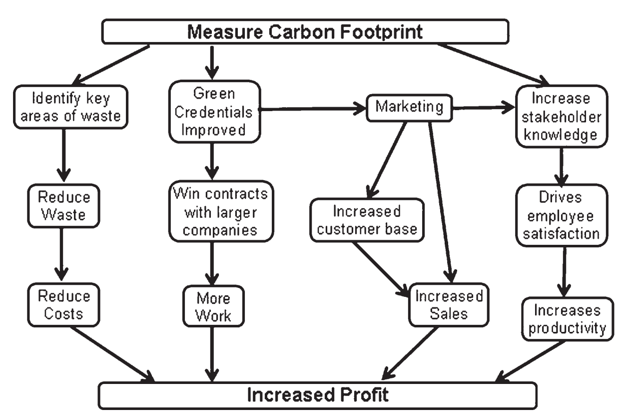

Figure 1. Financial advantages for SMEs of assessing their carbon footprint.

from larger companies who buy from them and need to prove to their customers that they use an ethical supply chain, therefore SMEs must prove their 'green' credentials to win contracts. A further reason why SMEs may wish to embark on a carbon footprint assessment would be that the findings highlight where there is a lot of waste energy. This can then be addressed and therefore money can be saved. It must also not be forgotten that many of the individuals who work in SMEs are genuinely concerned about the environment and wish to reduce their impact (NetRegs 2007).

The Sustainable Product Development Project is a North West ERDF Project that aims to increase regional economic growth by promoting the use of robust carbon footprint tools in SMEs from a variety of industry sectors. The Project intended to engage with 15 SMEs over its lifetime, working with each one to identify their footprint and promote actions to reduce it. Where appropriate, the Project also aimed to inform stakeholders of actions that had been taken within each business and to foster cluster opportunities between the companies, thereby offering benefits to those engaged with the Project. Further indirect and less tangible advantages were also achieved, such as closer working relationships for the SME with a research-led University, leading to potential student placements, research and development funding opportunities and future graduate retention.

The foregoing discussion demonstrates that SMEs need to take action to reduce their environmental impact and that they have certain specific requirements due to their size. Conducting an assessment would help them on several levels, therefore a tool is required that is easy to use and that provides them with information that is sufficiently accurate for policy making.

3. Limitations of current carbon footprints

Table 1 summarises some of the specific features of SMEs and how this impacts upon their requirements for a carbon footprint assessment. The carbon footprints currently available do not satisfy all of the highlighted requirements particularly in the scope and assessment methods used to find the carbon footprint. If these limitations could be overcome a simple and practical tool for SMEs would become much easier to develop.

3.1 *Scope*

There are many points at which the boundary of a carbon footprint assessment can be drawn, and the amount of the life-cycle which is covered is called the scope. Figure 2 shows a simple process map of a manufacturing company and the different boundaries which may be drawn for an assessment.

Some GHG calculators consider only boundary a), the direct emissions from a process; although most now also include energy indirect emissions, boundary b). This is the minimum level of completion recommended by large foot-printing organisations (Ranganathan *et al*. 2006, Carbon Trust 2007). This 'carbon added' approach is particularly popular as it does not require in-depth information about the quantities of raw materials bought by a company. It could also be argued that these are the only emissions for which a company is truly responsible. In many cases it is true that these are the most significant emissions arising from a company, but to assume this to be the case could lead to misjudgement of the size of the footprint.

Company A is a small company in NW England that received assistance from LPDU under the Sustainable Product Development Project, with three staff and a turnover of about £50,000 per annum. Its main operations are in the tourism sector, and therefore, as well as their general concern for the environment, they were keen to reduce their carbon footprint to attract 'eco-tourists'. Figure 3 shows the profile of the carbon footprint which was measured for Company A using a comprehensive tool developed by the SPD project. If the scope had been limited to direct and indirect energy emissions, the only two sections which would have been included

Table 1. Summary of the needs of SMEs.

Feature	Effect	Requirement
Few employees	No spare time for data collection or assessment	Simple tool without complicated data requirements
Low turnover	Little money to spare on consultants or carbon management employees	Possible to assess and understand by non-specialists
Lack of knowledge	Do not recognise the need to reduce environmental impact	Informative about environmental effects
Low understanding of CSR	Do not market any aspect of CSR which they do within community	Show SME through financial benefits that CSR is worthwhile
Need to make a profit	Cannot afford to take risks based on faulty information	Accurate enough to make informed policy decisions

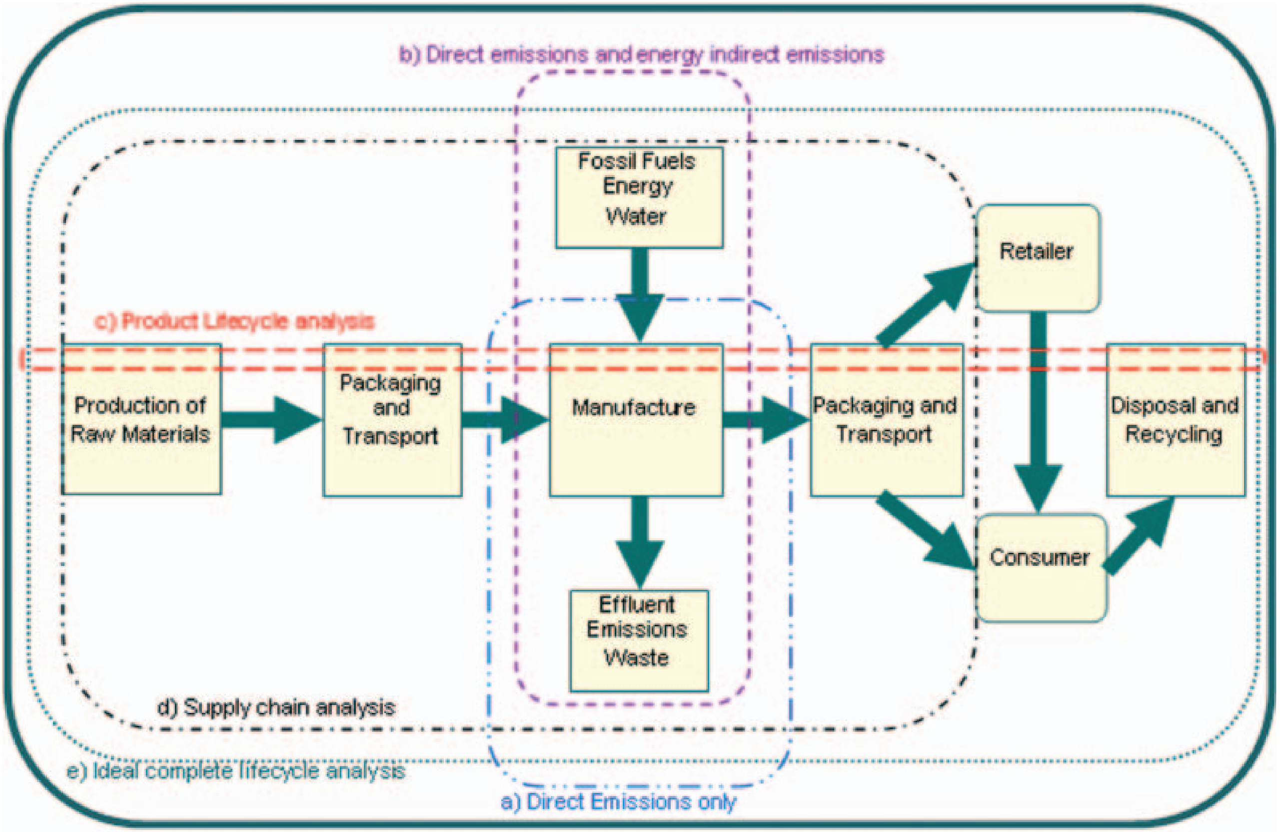

Figure 2. Boundaries of a product lifecycle.

are business travel and energy, 42% of the total footprint. This is a significant proportion of the footprint, but an even greater proportion of the footprint comes from indirect supply chain emissions. Although Company A does not physically cause these emissions to be released into the atmosphere, their

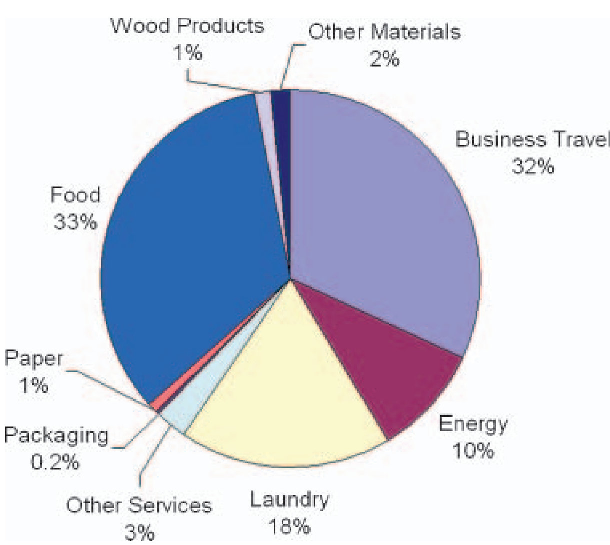

Figure 3. A breakdown of the carbon footprint for company A.

business decisions may cause someone else to release these emissions. Thus if less food is wasted there will be a subsequent reduction in the impact arising from the production and transport of that food. Likewise by introducing a towel-use agreement, they can reduce the amount of laundry and thus the emissions released as a result of this. Reducing energy consumption and business travel would have a positive impact, but if the other issues were neglected, the potential to reduce emissions would be decreased.

Another common boundary which is drawn in the scope of a carbon footprint assessment is to look at the full life-cycle of just one product, boundary c) in Figure 2. This can give important information to reduce the impact of the particular product and particularly if the company is prepared to redesign the product to take into account environmental costs. However, if the product line only represents a fraction of the company's total output, the full company impact is still being ignored, thus it again limits the potential of the company to find out what the major source of emissions is for the entire company and to target their efforts at the most significant overall emissions.

The ideal scope for any carbon footprint would be a full cradle to grave life-cycle analysis, boundary e) in Figure 2. However, this is rarely possible given the limited resources available to SMEs. Discretion must therefore be exercised to decide which parts of the footprint are essential for inclusion and those that will have little impact. The most important point is that the boundaries must be clearly reported, wherever they are drawn.

3.2 *Assessment method*

The process of assessing a company is essential to the value of a carbon footprint as it is this that determines the quality and use of the information obtained. This assessment process can be conducted with varying degrees of complexity and comprehensiveness; Figure 4 describes a comprehensive assessment method. This includes the preliminary stages of deciding the purpose of the assessment, Step 1, and defining the organisation and its processes, Steps 2 and 3. It next involves scoping and the setting of boundaries, Step 4, followed by actual data collection and necessary calculations, Steps 5 and 6, which are the stages most normally thought of as a carbon footprint. The final two stages require the reporting and communication of the carbon footprint to stakeholders and specification of the action to be taken to reduce the carbon footprint. It is these final two stages that will produce both environmentally and financially beneficial results. Having measured the footprint to provide a benchmark, the process must be repeated annually to monitor performance.

This is an involved process which requires a certain amount of technical and environmental knowledge to inform some of the subjective judgements which must be made. For anyone without the necessary expertise, it can be a very difficult and lengthy process; therefore consultants are often hired by the company to carry out this assessment. Few SMEs can afford the time to carry out this assessment independently but neither can they afford the cost of a consultant. Moreover, carbon footprints are meant to be a simple means of assessing one's impact upon climate change. If it proves necessary to employ a consultant, it might be more beneficial to undertake a full life-cycle analysis (LCA) and establish the full range of the company's environmental impacts.

The best alternative for an SME is to reduce the complexity and time involved in the assessment process. An extreme example would be online carbon calculator in which all but Steps 5 and 6 have been cut out or assumed based upon generic information. These calculators are quick and simple to use but may not produce reliable information. A comparison of 11 of these carbon calculators highlighted some of the problems involved (Wrigley 2008). The calculators provided little information about the origin of their embedded data, thus reducing the value of the assessment. Their scope was generally limited to direct and indirect energy emissions. This means that the results were all generally in agreement, but the output was not necessarily accurate. This was highlighted when data was input for a company which used extensive amounts of air-freight. Only one

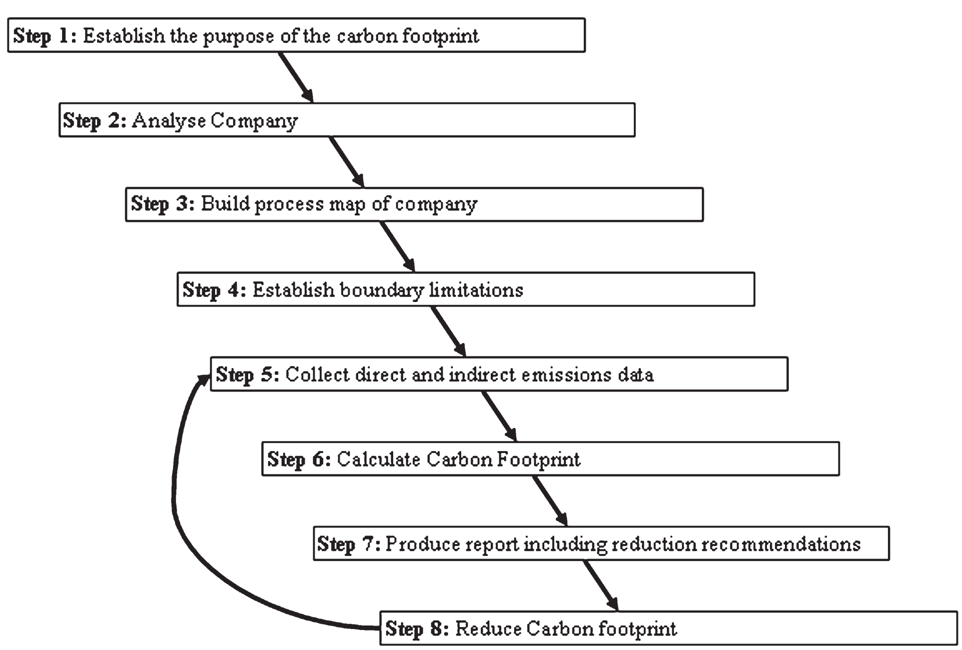

Figure 4. Proposed methodology for a carbon footprint assessment.

calculator included this within its scope, and its output was an order of magnitude higher than the other calculators. This demonstrates that these calculators are very imprecise assessment tools and may not provide the most useful management information. A further problem with online calculators is their availability. Within two months of the study being undertaken, one of the online calculators was no longer accessible and this would cause problems for an SME wanting to repeat the assessment in the future using the same calculator as their baseline tool.

If calculators are to become genuinely useful assessment tools, they will need to include the option for a much larger scope and they will need to become more transparent about the sources of their data so that companies can trust the outcome of the calculation.

Company B is also supported by the Sustainable Product Development Project, delivered through LPDU. It is a small manufacturing company in NW England with a turnover of approximately £500,000 employing 13 staff, providing bespoke adaptations to items supplied from their clients. They have an understanding of some environmental issues through their compliance with REACH regulations for chemical disposal, but wished to become more proactive. Therefore, they undertook a carbon footprint assessment. Company B was provided with a general carbon footprint tool that was comprehensive in its scope which enabled them to independently collect the data needed. However, they required consultation in the first stages to establish where the boundaries of their scope should be drawn and they also needed consultation at the end to help with the collation and interpretation of the data. The feedback received from Company B following the process was that they felt that they had needed a consultant's input to learn how to carry out this process and to make certain judgement calls, but that in the future they would be happy to repeat the process themselves. Company B began making changes to their energy use practices based upon what they learnt during the process, even before they had received the results of the footprint. They have since used the results of the footprint in a marketing campaign to attract local potential customers in an attempt to reduce their freight footprint. The Company was clearly comfortable with using this data because the source and credibility of the tool was trusted, along with the expert guidance that was provided.

Company B's experiences demonstrate several important points: (1) consultants are not essential to much of the process once someone has been educated in the methods; (2) the parts of the methodology where consultants are most required are those parts which cannot be quickly learned such as judgement as to the accuracy of data required for a specific aspect, and recommendations for mitigation methods which could be implemented; and (3), people feel more confident about the result when it has been endorsed by an environmental professional.

This shows that it may be possible for an SME to independently conduct comprehensive assessment methodology if guidance was provided through the steps by the tool, rather than assumptions being made about several of these stages. However, some verification may still be needed to increase the confidence of the SME in the outcome. Brief training in the assessment methods could also make the process much simpler and quicker for an SME.

3.3 *Conversion factors*

Conversion factors are the multipliers used to convert a quantifiable unit of resource into a mass of carbon, e.g. they show the amount of carbon released from burning 1 kWh of gas. It is rarely practical to directly measure all the emissions which are produced by a process and, therefore, conversion factors are essential to the estimation of any carbon footprint.

Most of the current conversion factors for carbon footprints are based upon an LCA methodology. This means that the conversion factor for each aspect measured in a carbon footprint analysis arises from a previous life-cycle study of that particular aspect, e.g. the conversion factor for 1 kWh of gas would be obtained from an LCA of gas extraction and distribution. Life-cycle analysis is a method of assessing the potential environmental aspects and impacts of a product and this is done by compiling an inventory of inputs and outputs, evaluating the potential environmental impacts of those inputs and outputs and then interpreting the results (ISO 14040:1997). Thus the described carbon footprint methodology follows the LCA methodology and it is therefore appropriate that the conversion factors should be taken from LCAs.

Although LCAs would appear to provide good and reliable conversion factors for use in carbon footprint assessments, there are disadvantages to their use. Because boundary conditions are subjective, different boundaries may be drawn in different studies even of the same product. Therefore, the data are inconsistent and thus the conversion factors become inconsistent within the tool. An example of this is the derivation of electricity conversion factors which are commonly taken from Defra (2007). This only considers direct emissions and not the emissions through the supply chain, therefore for electricity the production and transport of fuel is ignored and only the burning of it to make electricity is included within the carbon footprint. If this is then incorporated into a tool which also uses conversion factors for the material inputs from fuller LCAs, the estimates of carbon become inconsistent. For small numbers this is not important, but when multiplied by thousands to take into account the quantity purchased, these discrepancies are amplified and could lead to an underestimation of electricity emissions for the footprint.

During the development of a carbon footprint calculator to help with the assessment of company B, it was found that there were not LCA studies available for some of the aspects which needed to be considered. Therefore assumptions were made about the manufacturing process of some raw materials to estimate a conversion factor based upon the closest available data. These assumptions introduced large error margins into the estimation thus reducing the reliability of the result, but the only other option would have been to ignore these aspects. It was also found that deriving conversion factors from LCAs was a time consuming process as a selection of available LCAs had to be researched for each aspect to ensure the most accurate and relevant data was being used. This was time consuming when the developed tool was specific to Company B therefore it would be prohibitively so if conversion factors were to be found for a generic tool.

The experience of developing this tool has highlighted the difficulties in deriving conversion factors from LCAs, both due to the lack of data and the time required to compile the data. If LCA based conversion factors were to be used to produce a generic carbon footprint methodology for SMEs, substantial research would be required to produce a sufficiently comprehensive database of conversion factors that were derived from reliable and consistent LCA studies.

4. Proposed solutions

To improve the suitability of carbon footprints for SMEs, an online calculator would be the best option for the assessment. However, to make the process more comprehensive and informative, more consultant knowledge needs to be incorporated into the tool. Before starting data collection, it would be useful to have an option to help the SME select the scope of the footprint, and after the result had been calculated, mitigation advice could be sourced from a database. It is not possible to completely replace a consultant with an electronic tool and therefore it may be that an improved calculator would limit the contact required rather than eliminating it altogether. The ideal solution would be one in which the reliability and thoroughness of the complete assessment could be combined with the simplicity and ease of an online calculator to create an assessment process which was simple enough for non-experts but which still gave reliable information.

If a calculator approach is to be used, it should have a greater scope than current online carbon calculators. Increasing the scope will be a compromise between speed of data collection and assessment, however, the increase in the quality of the result can be sufficient to make this worthwhile. However, this will require gathering much more data than is currently available for conversion factors for raw materials. It may not be possible to model the use phase into such a calculator as this depends greatly upon the company product and consumer actions. There is considerable variability in this and the information is often poor. An ideal tool would incorporate at least an estimation of the use phase into the assessment as, depending upon the product, it can be a large source of emissions.

An alternative to using conversion factors based upon LCA is to use economic input-output (EIO) based conversion factors instead. This is a 'top-down' analysis which aligns GHG emissions with the turnover of an industry sector. Input–output tables are an economic tool developed by Leontief in the 1930s and show the inputs required to produce a unit of output for each economic sector (Hendrickson *et al.* 2006). These input–output tables are published annually by the government (BERR 2006). Greenhouse gases emissions data for each sector is also published annually (ONS 2007), and therefore they can be incorporated into the input–output tables to provide estimates of how much GHG is released per unit of output from a sector.

There are several advantages to using EIO to derive conversion factors for carbon footprints. As it takes an economy-wide approach, no boundary conditions need to be set, thus all direct and indirect emissions are included. As data comes from national economic accounts, conversion factors can be derived for every commodity within the economy and this makes a comprehensive assessment of an SME much easier. As the conversion factors are based upon economic data, they are reported in terms of CO_{2e}/monetary unit. This means that rather than extensive measurement of weights purchased, the only data required for an assessment based upon EIO are the company accounts. This makes the assessment much quicker and easier and therefore cheaper to carry out. A final advantage is that the EIO tables and the GHG emissions are publicly available data and, therefore, not only are the results reproducible but also there is no cost in producing the conversion factors. They do not have to be purchased from expensive commercial databases, as LCA conversion factors often are, and they do not rely upon finding relevant published LCAs and collating the data (Hendrickson *et al.* 2006).

There are, however, also disadvantages to EIO which could limit its usefulness within a carbon footprint calculator. Chiefly it does not provide the specific process data that is supplied by LCA. Because it is aggregated into economy sectors, it does not differentiate between different items within the sector, e.g. within the organic chemicals sector, some chemicals may emit much more GHGs per unit of money spent than others: EIO does not take this into account. A further problem is EIO assumes emissions from imported products will be the same as those for the emissions associated with the same product produced within the importing country. Another problem arises because the data are usually published several years after the year considered and it may, therefore, represent past practices and not allow for changes during the time lag. Consequently, it may be more appropriate to use a combination of LCA and EIO to allow for specific process data to be used where it is available but to fill in the gaps with EIO. More work would be needed to determine the extent to which each methodology should be used.

5. Conclusions and further work

Current carbon footprint assessments are not ideal for SME use. It would, therefore, be useful to design a tool with the specific requirements of SMEs in mind. This should be in the form of an online calculator but one which incorporates the capability to measure the full lifecycle of a company. It should also provide options and advice for selecting the scope of the assessment and deciding on the most effective mitigation choices after the assessment. Ideally it would be in a downloadable format to ensure permanence so that the tool is available for future comparison, although it would need to be updated as conversion factor information changed. To enable the maximum possible scope to be incorporated into the tool, EIO conversion factors could be used as well as those from LCAs, thus making more conversion factors available and simplifying the data requirements by asking for the information in terms of money.

There is other work to be carried out which would help in the development of such a tool which would be applicable to a wider audience than just the managers of SMEs. It would be helpful to develop an open access database with all the reputable lifecycle studies available to provide estimates of conversion factors for as many different raw materials as possible. This could be summarised in a simple form similar to the way in which an inventory of carbon and energy (Hammond and Jones 2006) has provided an accessible source of data for the construction industry.

Further work is required to standardise definitions and scope. If SMEs are to compete in the marketplace with larger organisations, they need to be able to report in the same terms. If larger companies report only limited operations in their carbon footprint they can market themselves as being more environmentally-friendly than SMEs. Therefore, standards should be defined based upon a desire for uniformity in reporting.

If carbon footprints are to be used as methods of encouraging SMEs to understand the need for and the benefits to be gained from CSR, then the two need to be developed together. This could mean the development of a combined assessment tool assessing the level of CSR commitment along with environmental factors. Or it could mean simply making SMEs more aware that by carrying out an environmental assessment they are partaking in socially responsible action.

This paper has shown that carbon footprints could be valuable tools in encouraging environmental proactivity in SMEs. At present, the tools available do not provide enough information to allow real policy change and the data available for calculating footprints are inaccurate and unreliable. Currently the only way to achieve greater accuracy would be to pay a consultant to carry out an assessment but this can be costly and SMEs often do not see the need. Therefore a tool needs to be developed which simplifies the process for SMEs whilst still providing accurate information, and encourages positive action by the outcome.

Acknowledgements

The authors would like to acknowledge Mike Berners-Lee, Managing Director of Small World Consulting Ltd, for the input he has provided during the preparation of this paper. Also the European Regional Development Fund for the part financing of this activity under the Sustainable Product Development Project.

References

BERR, 2006. *2004 current price input-output: annual supply and use tables*. Department for Business, Enterprise and Regulatory Reform.

BERR, 2007. *Statistical press release* [online]. London: National Statistics. Available from: http://stats.berr.gov.uk/ed/sme/smestats2006-ukspr.pdf [Accessed 6 November 2007].

Carbon Trust, 2007. *Carbon footprint measurement methodology Version 1.3*. London: The Carbon Trust.

Defra, 2007. *Guidelines to Defra's GHG conversion factors for company reporting* [online]. Available from: http://www.defra.gov.uk/environment/business/envrp/pdf/conversion-factors.pdf [Accessed 15 January 2008].

Directgov, 2007. *Calculate your carbon footprint!* [online]. Available from: http://www.direct.gov.uk/en/environmentandgreenerliving/actonco2/DG_067197 [Accessed 27 September 2007].

European Commission, 2003. Commission recommendation of 6 May 2003 concerning the definition of micro, small and medium-sized enterprises. *Official Journal of the European Union* [online]. Available from: http://europa.eu/eur-lex/pri/en/oj/dat/2003/l_124/l_12420030520en00360041.pdf [Accessed 15 January 2008].

European Commission – Directorate General for Enterprise and Industry, 2007. *Opportunity and responsibility: how to help more small businesses to integrate social and environmental issues into what they do.* European Commission.

Global Footprint Network, 2007, August 21. *Carbon footprint* [online]. Available from: http://www.footprintnetwork.org/gfn_sub.php?content=app_carbon_footprint [Accessed 27 September 2007].

Haefeli, S. and Telnes, E., 2005. Global greenhouse gas markets: where do we go from here? *In*: P.C. Fusaro and M. Yuen, eds. *Green trading markets: developing the second wave*. Oxford, UK: Elsevier Ltd, 33–40.

Hammond, G. and Jones, C., 2006. *Inventory of carbon and energy (ICE) version 1.5a Beta*. Bath: University of Bath.

Hardy, J.T., 2003. *Climate change: causes, effects, and solutions*. Chichester: John Wiley & Sons Ltd.

Hendrickson, C.T., Lave, L.B. and Matthews, H.S., 2006. *Environmental life cycle assessment of goods and services: an input-output approach*. Washington: Resources for the Future.

IPCC, 2007. IPCC. *Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge: Cambridge University Press.

ISO 14040, 1997. *Environmental management – life cycle assessment – principles and framework*. London: British Standards Institute.

NetRegs, 2007. *SME-nvirnonment 2007: UK dummary* [online]. Available from: www.netregs.gov.uk [Accessed 25 November 2007].

Nicholls, R.J. and Lowe, J.A., 2004. Benefits of mitigation of climate change for costal areas. *Global Environmental Change Part A*, 14 (3), 229–244.

ONS (Office for National Statistics), 2007. *Environmental accounts: emissions; greenhouse gases, 93 industries 1990 to 2005* [online]. National statistics online. Available from: http://www.statistics.gov.uk/statbase/Expodata/Spreadsheets/D5695.xls [Accessed 25 January 2008].

Petts, J., Herd, A., Gerrard, S. and Horne, C., 1999. The climate and culture of environmental compliance within SMEs. *Business Strategy and the Environment*, 8, 14–30.

Pimenova, P. and van der Vorst, R., 2004. The role of support programmes and policies in improving SMEs environmental performance in developed and transition economies. *Journal of Cleaner Production*, 12, 549–559.

Quinn, B., 2001. Bottom line: 'minimizing waste is good business'. *Pollution Engineering*, July, 26–27.

Ranganathan, J., *et al.*, 2006. *The greenhouse gas protocol: a corporate accounting and reporting standard* (revised edition). World business council for sustainable development and World Resources Institute, Washington, USA.

Reaney, P., 2000, October 23, *Over-consumption threatens human survival* [online]. Available from: http://www.planetark.com/dailynewsstory.cfm/newsid/8645/newsDate/23-Oct-2000/story.htm [Accessed 27 September 2007].

Sims, R.E.H., *et al.*, 2007. Energy supply. *In*: O.R.D.B. Metz, *et al.*, eds. *Climate change 2007: mitigation. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge: Cambridge University Press.

Spencer, P., 2005. Tsunami aid. *Refocus*, 6 (1), 3.

Trucost, 2007. *Carbon footprint analysis* [online]. Available from: http://www.trucost.com/carbonfootprint.html [Accessed 25 January 2008].

Wackernagel, M. and Rees, W.E., 1996. *Our ecological footprint: reducing human impact on the earth*. Gabriola Island, BC: New Society Publishers.

Wiedmann, T. and Minx, J., 2007. *A definition of 'carbon footprint'*. ISA-UK Research Report 07-01.

Wrigley, S., 2008. Online carbon calculators – unsuitable for SMEs? *The Environmentalist* 6 May.