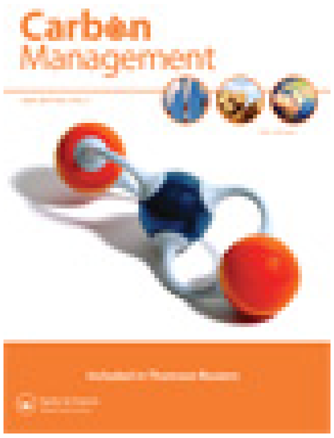

Carbon Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tcmt20

'Carbon footprinting': towards a universally accepted definition

Laurence A Wright[a], Simon Kemp[a] & Ian Williams[ab]
[a] School of Civil Engineering & the Environment, University of Southampton, Highfield, Southampton, SO17 1BJ, UK
[b]

Published online: 10 Apr 2014.

To cite this article: Laurence A Wright, Simon Kemp & Ian Williams (2011) 'Carbon footprinting': towards a universally accepted definition, Carbon Management, 2:1, 61-72

To link to this article: http://dx.doi.org/10.4155/cmt.10.39

For reprint orders, please contact reprints@future-science.com

'Carbon footprinting': towards a universally accepted definition

Carbon Management (2011) 2(1), 61–72

Laurence A Wright[1], Simon Kemp[1] & Ian Williams[†1]

As the threat of climate change becomes more acute, so does the need for adequate measures of impact(s), management and mitigation. Although carbon footprints are increasingly being used by organizations in the public and private sectors, a number of challenges and questions need to be addressed; among them, what does the term 'carbon footprint' actually mean? The term needs a universally accepted definition before a consistent, accurate, comparable and transferable methodology can be developed. This article investigates the range of current definitions proposed for a carbon footprint in the context of inventoried emissions, applications, boundaries and limitations. We argue that to only account for CO_2 emissions would result in the omission of almost a third of GHGs and a significant gap in their global management, whilst inclusion of all GHGs is very time-consuming and expensive, and should be considered only in system-specific life cycle-based assessments; this requires a separate definition, name and methodology. We suggest that as data collection for CO_2 and CH_4 emissions is relatively straightforward, these two carbon-based gases should be used in the determination of a carbon footprint. This should allow the carbon footprint to become a cost-effective, practical and repeatable metric that can be adopted by all types of organizations across the globe as a 'baseline' indicator. However, it is likely that a more comprehensive metric will be required in some circumstances and by some organizations, so we also propose further GHG inclusion for full life cycle assessment-based assessments; where complete data is obtainable it can be used to provide a 'climate footprint'. This name reflects the addition of noncarbon-based gases and encompasses the full range of gases used in the global political community's response in managing climate change. We conclude by considering lessons learnt with the proposal of sound and pragmatic definitions.

The threat posed by global climate change is now widely recognized and the Intergovernmental Panel on Climate Change urges that action must be taken to limit global average temperature rise to 2°C above preindustrial levels to avoid the worst effects [1]. Robust approaches for the measurement and management of GHG emissions are required for target setting and assessing the success of climate change mitigation measures. 'Carbon footprints' are increasingly being recognized as a valuable indicator in the field of GHG and carbon emissions management [2].

The term carbon footprint has become a commonly recognized phrase, frequently used to describe the concept of relating a certain amount of GHG emissions to a certain activity, product or population. The term is also used interchangeably with other terms such as 'carbon accounting' or 'carbon inventory'. The use of the term has been driven largely by media, government, industry and nongovernmental organizations, captivating the interest of business, consumers and policy makers [2], although the term has only recently been adopted by the academic community, where effort has traditionally focused on **life cycle assessment** (LCA). As a result, previous authors suggest that there is confusion and little consensus over what the term actually means or what the process measures [2–5].

Prior to establishing a definition of a carbon footprint, a number of issues demand answers. First, what does the carbon footprint actually measure: is

[1]School of Civil Engineering & the Environment, University of Southampton, Highfield, Southampton, SO17 1BJ, UK
[†]Author for correspondence: Tel.: +44 2380 598 755; E-mail: I.D.Williams@soton.ac.uk

10.4155/CMT.10.39 ISSN 1758-3004

Key terms

Life cycle assessment: Provides a methodology for the measurement of the full range of environmental and social impacts associated with a process, product or activity from 'cradle-to-grave' (i.e., from raw materials through processing, distribution, use and disposal).

Ecological footprint: A measure of biologically productive land and sea area required to meet the needs of human consumption on the Earth. Using this assessment it is possible to estimate the total area or number of Earths required to meet human needs, estimated in 2006 as 1.4 Earths.

it a complete measure of climate change impact or an indicator of anthropogenic contributions to global GHG concentrations? How can the boundaries of the metric be reliably set to develop a comparable and reliable methodology? Finally, is the carbon footprint a 'new' indicator or simply an exercise in rebranding of traditional LCA techniques? Only once these issues have been addressed can a definition be established. The desired end use of the indicator will help inform the answers to these issues. Indeed, a number of accounting methodologies have been proposed, which depend wholly upon end use and subject. In addition, many emission-generating processes are, by nature, variable spatially and temporally, which increases the difficulty and uncertainties involved in the development of models and selection of input data. In some cases, processes are not fully understood and uncertainties may be high or not considered as an important emission source [6]. Even when these challenges are addressed, key questions remain; is the carbon footprint an appropriate, comparable, reliable, accurate, transferable and worthwhile measurement?

This article addresses these questions and seeks to develop a sound and pragmatic definition for a carbon footprint that could be universally adopted and utilized. The first section of the article critically reviews current definitions of the carbon footprint, identifying the key components and underlying theory. This critical review informs the investigation of carbon footprint accounting methodologies and approaches before discussing the potential use of a carbon footprint as a tool for the management of carbon and GHG emissions, at a variety of scales.

A clear, workable and universally accepted definition is fundamental to the development of national and international targets, legislation and standards. The final section of the article summarizes the definition issues, methodological challenges and possible uses. It is recognized that carbon footprints are a separate entity to existing impact categories in LCA. In addition, we recognize that carbon footprints must be kept free of complicated data requirements or high costs, to ensure widespread use and uptake, especially in the private sector. It is suggested that this is most easily achieved through the inclusion of CO_2 and CH_4 only, and this forms the basis of the definition of a carbon footprint. Consequently, a second, full impact indicator for the inclusion of all GHGs and adopting the term 'climate footprint' is proposed.

'Carbon footprint': a review of current definitions

What does the term carbon footprint actually mean? It appears to have been coined sometime around the year 2000 in a media article or similar; an exact origin in the scientific literature remains elusive [7]; the earliest (reasonably) authoritative etymologies we have been able to find are from 1999 [101]. As a consequence, development has been largely driven by corporate, governmental and NGO initiatives, and hence the depth and clarity of definitions varies widely. Previous authors identified numerous definitions for a carbon footprint, from which they concluded a baseline that all definitions in some way attempt to relate human activity to an emission of a certain suite of GHG emissions [2]. However, that is where the commonality ends. There is little consensus among existing definitions regarding the metrics, methods or life cycle perspective. Some definitions require a full LCA of all GHG emissions, while others consider only direct emissions of CO_2. It is possible that the language of the term carbon 'footprint' is rooted in the context of **ecological footprinting** [8], whereby the environmental impact of consumption is related to a land area required for its production. Indeed, the term carbon footprint is, when considered in ecological footprinting studies, considered to be synonymous with the category 'carbon uptake', which represents the biocapacity required to sequester CO_2 emissions from fossil fuel consumption [102]. However, in contrast to the ecological footprint, the likely key use of carbon footprinting is in the control/limiting of the use of fixed carbon fuels that release CO_2 (and other C-based gases), and convention suggests the carbon 'footprint' relates not to an area of land, but to a mass value representing emissions of CO_2 or a basket of identified GHGs.

Weidmann and Minx summarized the range of definitions for a carbon footprint in the 'gray literature' (i.e., non-peer reviewed) [2]. **Box 1** explores this range further; presenting a summary of gray literature definitions for a carbon footprint identified using the search term 'carbon footprint' in the popular internet search engine, Google. These are compared with definitions that have subsequently been published in peer-reviewed literature. In many cases, a carbon footprint is little more than a synonym for GHG emissions emitted by a particular process. The majority of definitions fail to adequately define the scope and boundaries of a carbon footprint. The term is currently used to mean anything from the direct emissions of CO_2 from the activities of an individual [103] to the amount of land required to sequester emissions from fossil fuel [102].

The UK Carbon Trust attempted to address the issue of ambiguity and proposed a detailed definition of a carbon footprint [103]. The definition clearly identifies

Box 1. Examples of definitions for a carbon footprint from the 'gray literature' and the academic literature.

Sample 'gray literature' definitions

- "a measure of the amount of CO_2 released into the atmosphere by a single endeavor or by a company, household, or individual through day-to-day activities over a given period" [101].
- "…a gauge of your CO_2 emissions or the impact your activities have on the environment measured in carbon emissions. Your carbon footprint is measured in units, tonnes or kg of CO_2" [103].
- "Your carbon footprint is the amount of CO_2 that enters the atmosphere because of the electricity and fuel you use. It's measured in tonnes of CO_2" [104].
- "A 'carbon footprint' measures the total GHG emissions caused directly and indirectly by a person, organization, event or product. The footprint considers all six of the Kyoto Protocol GHGs … A carbon footprint is measured in tonnes of CO_2 equivalent (tCO_2e). CO_2e is calculated by multiplying the emissions of each of the six GHGs by its 100 year global warming potential" [105].
- "...the total set of GHG emissions caused by an organization, event, product or person" [106].
- "A carbon footprint is a measure of the impact our activities have on the environment, and in particular climate change. It relates to the amount of GHGs produced in our day-to-day lives through burning fossil fuels for electricity, heating and transportation. The carbon footprint is a measurement of all GHGs we individually produce and has units of tonnes (or kg) of CO_2 equivalent" [107].
- "A measure of the GHGs that are produced by activities of a person, a family, a school or a business that involve burning fossil fuels" [108].

Scientific literature definitions

- "The carbon footprint is a measure of the exclusive total amount of CO_2 emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product" [2].
- "The total mass of GHGs directly and indirectly emitted by an individual, a company or throughout the lifecycle of a product" [17].
- "A carbon footprint analysis is the sum of the estimated CO_2 and other GHG emissions associated with a particular activity or industry" [10].
- "The 'carbon footprint' of a functional unit is the climate impact under a specified metric that considers all relevant emissions sources, sinks, and storage in both consumption and production within the specified spatial and temporal system boundary" [5].
- "The GHGs CO_2, CH_4, nitrous oxide and fluoride emitted in the production of goods and services used for final consumption and GHG emissions occurring during the consumption activities themselves" [25].
- "A carbon footprint is equal to the GHG emissions generated by a person, organization or product" [39].

the GHGs to be included – all six 'Kyoto Basket' gases – and the metric for presenting results ('CO_2 equivalents' [CO_2e] calculated using global warming potential [GWP]100), and outlines the subjects for which a carbon footprint can be used.

The definition explicitly states that the footprint can be used to account for emissions from "…a person, organization, event or product…"; this evidently excludes the use of a carbon footprint for applications such as national and international trade accounting, which have been developed and demonstrated [9]. This restriction is seen in a number of other definitions, either restricting the carbon footprint to a company, an individual's activities, a product or some combination of these.

The definition proposed by the UK Carbon Trust hints at a life cycle-orientated approach, stating the footprint should include all direct and indirect emissions related to the subject, represented CO_2e, calculated using GWP. The GWP facilitates the representation of a given GHG emission against a CO_2e. Presenting results as CO_2e using the GWP allows the inclusion of a range of GHGs in a carbon footprint. The GWP provides a simple, straightforward and widely recognized index for policy makers to rank GHG emissions in terms of equivalence [10].

A number of definitions in Box 1 include 'all' GHGs; this is evidently too vague as the influence of a number of GHGs on the global climate is still highly debated, and thus one cannot be certain what to include and what to exclude. Other definitions set the GHG inclusion boundary using legislatively controlled GHGs, such as the six Kyoto gases [11]. Although this sets a clearly defined boundary, reducing misinterpretation, it relies on accurate data being available for all cases to allow comparability, which may not always be true [2]. Weidmann and Minx propose a definition for a carbon footprint that considers the underlying life cycle approach, and which addresses the issue of GHG boundaries [2]. They suggest the carbon footprint should 'exclusively' measure CO_2. This approach is consistent with a number of previous definitions in Box 1 [2,12,104], and may appear logical since the carbon footprint is a carbon-based metric. As with others, they go on to suggest that further inclusion of GHG emissions should perhaps be termed a climate footprint [2,13].

Key terms

Kyoto Protocol: An international agreement linked to the United Nations Framework Convention on Climate Change. The Protocol sets legally binding targets for party nations for the reduction of GHG emissions.

European Emissions Trading Scheme: The European Union's multicountry, multisector, GHG emission trading system, the largest of its kind in the world, currently covering approximately 10,000 installations. Under the European Emissions Trading Scheme, large emitters of CO_2 must monitor and annually report their CO_2 emissions, for which they are required to purchase and surrender allowances.

Measuring the carbon footprint

The following sections consider the methodological issues that must be addressed prior to the proposal of a definition; for example, what GHGs should the carbon footprint include and how should it be presented? The answers to these issues are used to inform a discussion of the methodological processes available for the calculation of a carbon footprint.

Selection of GHGs

Different reporting mechanisms require the reporting of different GHGs. The **Kyoto Protocol** requires the reporting of six gases: CO_2, CH_4, N_2O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and SF_6, commonly referred to as the Kyoto basket [11]. The **European Emissions Trading Scheme** (EUETS) only requires the reporting of CO_2 emissions [14]. These reporting mechanisms only consider a limited selection of GHGs; there are many more emissions that affect climate (e.g., black carbon, SO_2, contrails, various aerosols or ozone precursors) [15]. A full LCA attempts address this issue by reporting the full suite of environmental impacts, including all climate impact emissions, to produce a holistic picture of the environmental impacts of a given system. These different reporting and accounting perspectives have generated confusion regarding the inclusion or exclusion of GHGs from the carbon footprint. Some definitions require a complete catalog of all GHGs arising from the studied process or activity [12,104], whilst some define the footprint as a measurement of only CO_2 [2,12]. Others require the accounting of legislatively controlled GHGs (e.g., the Kyoto Protocol gases [11,103]).

Weidmann and Minx suggest the carbon footprint should be an exclusive measure of CO_2 from the life cycle stages of the product or activity in question [2]. The use of the 'exclusive' term defines the carbon footprint as purely a CO_2-based assessment. They claim the benefit is twofold; the measurement of CO_2 is relatively straightforward compared with other GHGs and the term carbon footprint refers to a carbon metric. However, one must be aware of the dangers of oversimplification since reliance on the exclusive measurement of CO_2 can result in misleading outputs.

As an illustration of this issue, consider worldwide CH_4 emissions from the waste sector, which constituted approximately 14% of total global anthropogenic CH_4 emissions in 2004 [15]. Many developed countries have implemented technology for the capture and treatment of landfill CH_4 emissions, often combusted for the purpose of energy generation [16]. Applying the definition of a carbon footprint proposed by Weidmann and Minx, exclusive measurement of CO_2 would indicate a large carbon footprint since CH_4 combustion will generate CO_2. A likely policy conclusion from this output is that venting CH_4 is preferable to combustion; this would be an erroneous conclusion since the GWP of CH_4 is significantly higher than CO_2 (CO_2 = 1, CH_4 = 25) [15].

To overcome this potential problem, one could suggest that a carbon footprint be defined by carbon flows, whereby the footprint represents the mass or weight of carbon species emissions (e.g., CO, CO_2 or CH_4). This definition would address the issues identified with combustion of other carbon species, but it fails to capture other potentially important GHG emissions and incorporates carbon monoxide (CO),a relatively low impact GHG, but an important ozone precursor.

Moss *et al.* suggest that the issue of data complication cannot be used to justify exclusion of emissions, claiming that data availability for emissions monitoring will improve over time and a useful indicator must include all GHGs [17]. Even if one considers the carbon footprint as an indicator for all GHGs, its use in isolation may give a misleading picture of the overall impact(s) in certain cases. To be practically useful, a carbon footprint should be an indicator of the anthropogenic contribution of a named process/product/land area (e.g., city or country) to climate change. Utilized in isolation, it may fail to consider environmental impact categories such as land-use, resulting in 'burden shifting'; for example, biofuels are preferential to fossil fuels when considered in terms of climate impact, but this fails to consider the impacts on land. A carbon footprint is an indicator of the contribution made to climate change by a product, activity or population, rather than a full LCA, so it must be treated as such – as a decision-assisting tool, rather than a decision-making tool.

In the context of all GHGs, and including negative forcing, the global anthropogenic radiative forcing (RF) is estimated to be +1.6 W m^{-2}, (-1.0, +0.8, within 90% confidence intervals) [15]. **Figure 1** shows the total estimated global RF due to anthropogenic emissions of GHGs [1]. CO_2 is by far the most important GHG, with an estimated RF of +1.66 W/m^2, followed by CH_4 0.48 W/m^2, with the remaining anthropogenic GHGs contributing 0.497 W/m^2[15].

To only account for CO_2 emissions would capture approximately two-thirds of anthropogenic GHGs based on estimate global RF. However, the omission of CH_4 would result in the exclusion of almost a fifth of GHGs and a significant gap in their global management. One could argue that exclusion of the Montreal Protocol gases would have a similar effect. However, this represents the combined RF of a suite of gases (CFCs, HCFCs and chlorocarbons) for which, since 2003, total RF is decreasing owing to restricted use [15]. We suggest that as data collection for CO_2 and CH_4 emissions, when compared with other anthropogenic GHGs, is relatively straightforward, these two carbon-based gases should be used in the measurement of a carbon footprint. The effort required and uncertainties involved in the collection of data regarding the remaining suite of GHGs may not justify the outcome. Where the estimation of the full suite of GHGs is required, one could suggest this is merely slim-lined LCA, which, as has previously been suggested, could be termed a climate footprint [2,13]. This is especially true in countries where detailed national reporting is currently not practiced and data must be developed from first principles.

Metrics

The way that carbon footprints are presented to policy decision makers, businesses and consumers is an important issue. Presentation and representation of carbon footprints is a key issue in the development of a pragmatic and usable carbon footprint definition. The most common unit for results is CO_2e, calculated using the GWP. The GWP indicator is commonly used in LCA to indicate potential climate change impacts [18]. It is a measure of the extent to which a given GHG contributes to global warming, representing the integrated radiative forcing over a specified time period (e.g., 100 years) against a reference emission of CO_2; for example, CH_4 has a GWP of 25 (i.e., 25-times that of the reference CO_2). Therefore, a 1-ton emission of CH_4 is equivalent to 25 tons of CO_2 or 25 tons of CO_2e [15]. RF is used to describe the change in net irradiance at the atmospheric boundary between the troposphere and the stratosphere. Net irradiance is the difference between the incoming radiation energy and the outgoing radiation energy in a given climate system and is measured in W m^{-2} relative to a base period, usually the year 1750 (the commonly agreed start of the industrial era) [15]. More incoming energy (positive forcing) tends to warm the climate system, while more outgoing energy (negative forcing) tends to cool it. The requirement to represent GHG emissions in a way that enables the formation of targets requires a metric that accounts for different gases, with different RF and different atmospheric lifetimes. This accounts for the development of the GWP, a metric designed to weight gases in a manner that ensures 'equivalence' in climate impact within the chosen time frame [15].

Despite its widespread use and proliferation, the GWP is not without critics [10,19]; for example, perhaps misleadingly, a GWP does not purport to represent the impact of GHG emission on temperature [10]. The GWP relies on time-integrated RF and, owing to the differences in atmospheric lifetimes of GHGs, it cannot provide a true indication of emission on temperature [10]. A number of alternatives for the GWP do exist. Shine *et al.* propose an alternative climate change metric, the global temperature change potential (GTP) [10]. The GTP is defined as the ratio between global mean surface temperature change at a given future time horizon following an emission (pulse or sustained) of a compound *x* relative to a reference gas *r* (e.g., CO_2; for a full description of the GTP see Shine *et al.* [10]). The GTP could be used in a similar way to the GWP where a temperature change metric is required. However, despite the GTPs ability to more explicitly represent the temperature response due to a sustained emission, uptake has not been widespread among policy decision makers who tend to rely on the relatively well-established GWP.

However, other metrics also exist including: CO_2 per monetary unit; CO_2 emissions versus a reference unit; or CO_2 as C. Alternatively, should a carbon footprint be presented as a land area-based impact (e.g., in hectares) or – since the impact is climate change – is it more appropriate to consider a footprint as a quantification of the contribution to the impact (e.g., tonnes CO_2)? Conversion of the total emissions from physical mass (g, kg or t) to area unit (m^2, ha or km^2) would have to be based on a range of assumptions, increasing the uncertainty and errors contained within the metric [2]. Following the arguments of previous authors [2], unnecessary unit conversions should be avoided. Thus, a land-based metric is not appropriate, the carbon footprint should be measured in carbon equivalent mass units, reflecting the established metric of GWP.

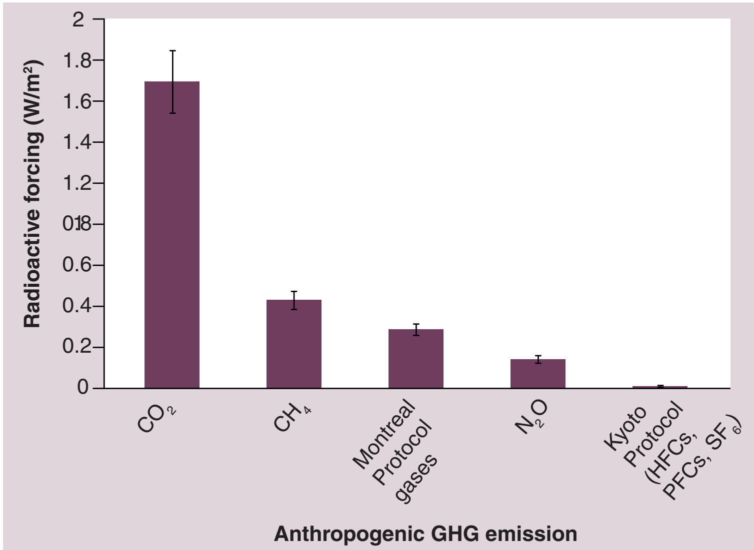

Figure 1. Positive radiative forcing of climate between 1750 and 2005 due to anthropogenic GHG emissions [15].
HFCs: Hydrofluorocarbons; PFCs: Perfluorocarbons.

Methodological processes

We have established that the carbon footprint is a life cycle-orientated indicator of a process, activity or population's contribution to climate change. There are three principal life cycle approaches to emissions inventories: environmental input–output analysis (EIOA); process analysis (PA), hybrid environmental input–output LCA (hybrid-EIO-LCA).

The EIOA uses national input–output tables as the basis for LCA. Input–output tables are designed for economic use and industries with very different environmental impacts are often aggregated into a single sector for reporting (e.g., paper production and publishing) and represented by average emissions intensities for the sector [7,20].

Top-down EIOA utilizes aggregate data at the meso level to attribute emissions based on economic flow. Input–output tables provide detailed accounts of all economic activities at the sector level. Combined with environmental accounting data, they can be used to calculate the carbon footprint, setting the economic system as the boundary [2]. EIOA is a top-down approach to LCA that uses national economic and environmental data such as fuel mix and technologies to estimate emissions caused by the activities of industry sectors within an economy [7,9]. EIOA is a method for tracking economic flows (inputs and outputs) between sectors within an economy and on to final consumer demand [9]. Tier 1 (activity data available to all countries) and 2 (technology specific) data collection methods are commonly used in EIOA [21]. Emission coefficients for units of activity of the different sectors are then used to generate emissions estimates [20,21].

Environmental input–output analysis is effective for LCA of upstream processes and associated emissions. Given that data on a whole economy are used, the footprint generated is a complete picture of upstream GHG emissions embodied in products and services used [9]. It is also less labor intensive than other methods of LCA since it requires no primary data collection [2]. One of the main disadvantages of this approach is that GHG emissions associated with delivery, use and end-of-life of products are not calculated [22]. Calculation of a complete carbon footprint would require additional data and methods to estimate emissions from these missing life cycle phases. There are also inherent uncertainties as material flows are derived from economic flows, introducing additional sources of error [23].

Environmental input–output analysis falls down when required to assess microsystems, such as an individual product, owing to the assumption of homogeneity at the sector level. PA is a bottom-up LCA approach to analyze the emissions associated with specific processes, leading to a greater level of accuracy than EIOA [20], but requires more time and resources [2,21]. The use of PA does raise the significant question of where to most effectively set the system boundary. System boundaries are normally set using expert judgment rather than a standard method as a more objective approach would require analysis of process emissions prior to setting the system boundary, making boundary selection redundant [23]. PA was originally developed for the environmental assessment of individual products and it excels when examining microsystems, providing the ability for assessment from cradle-to-grave. However, the bottom-up nature of PA can cause truncation errors, whereby only most first- and some second-order impacts are considered [20].

To overcome the shortfalls of EIOA and PA, hybrid-EIO-LCA is becoming widely accepted within the academic community as the best approach to carbon footprint calculation [2,21,22]. Hybrid-EIO-LCA is a combination of PA and EIOA approaches, where PA is carried out for specific processes and embedded within an EIOA [21]. This approach overcomes the issues of EIOA not being specific or detailed enough to monitor minor changes at an organizational or subnational scale and omitting use and end-of-life product life cycle phases and the issue of incompleteness and truncation errors in PA [21].

System boundary & scope

The majority of carbon footprint definitions and methodological structures consider emissions in terms of overarching 'scopes' that relate to the spatial boundary of the activity or process, including the World Resource Institute and the World Business Council for Sustainable Development (WBCSD) [24]. Scope 1 includes all emissions as a direct result of the defined system processes or activities (e.g., the emissions from a company owned vehicle). Scope 2 expands the boundary to consider the upstream emissions of electricity generation. Finally, scope 3 further expands the boundary to include other indirect emissions of the system [24]. This final scope is often cited as 'optional' with little guidance given as to the cut-off procedure for external upstream process emissions. None of the definitions reviewed previously offer any explanation or guidance regarding upstream and downstream cut-off.

Suh *et al.* outline a method of hybrid-EIO-LCA for estimating an industry sector carbon footprint [20]. The method uses PA to calculate GHG emissions for the main industrial processes undertaken within the sector as well as the main industrial processes in the immediate upstream supply chain. PA is also used to estimate GHG emissions from all downstream processes to the product end-of-life phase. EIOA is used for all upstream supply chain processes for which

PA is not performed. This has the benefit of being accurate and specific to the industry sector and would monitor carbon footprint variation owing to changes in controlled processes while also including complete upstream emissions embodied in goods.

The temporal boundary of the carbon footprint will generally depend on the subject and the desired end use of the carbon footprint. In applications such as product manufacture, the temporal boundary is largely defined by the time taken for manufacture completion. Conversely, for applications such as personal carbon footprints, a defined time period (e.g., 1 year) is required to facilitate boundary setting and effective measurement.

A tool for climate change management

The different reporting structures, procedures and methodologies of carbon footprinting and GHG inventorying can easily become confusing. The number of procedures originates from the high number of companies, individuals and organizations producing and developing methodologies, standards and protocols of varying complexity and technicalities and for a range of applications. The main difference between carbon footprinting at the various levels discussed is the definition of system boundaries. Whilst national accounting is structured around industrial sectors and large operational groups, the organizational procedures are structured using organizational and financial boundaries, and individual methodologies are structured on individual economic influences.

Carbon footprints of nations, regions & cities

Given the interest in the carbon footprint of products, and more recently organizations, there has been comparatively less interest in the carbon footprint of nations and subnational regions [7,9,25]. National GHG reporting was initiated by the Intergovernmental Panel on Climate Change in 1988 and is a requirement of the signatories of the UN Framework Directive on Climate Change [26]. Participating countries are required to submit an annual declaration of all GHG emissions associated with all activities in their boundaries.

Carbon footprints of nations are closely linked to debates regarding fairness in the allocation of emissions: should production or consumption be used as the basis for responsibility in national carbon footprint allocation? Production accounting may lead to large underestimates of carbon emissions from products and services as a large proportion of carbon emissions are from supply chain processes [20]. It often conceals issues of 'burden shifting', energy-intensive processes are exported to less developed countries, and imports of products then increase in consumer countries [22]. Consumption is the main driver of environmental degradation [27], so allocating full responsibility for emissions to producers and giving no responsibility to consumers seems inequitable. This is especially true when both producer and consumer countries have legally binding emissions reduction targets [25].

The widespread use of EIOA to the carbon footprint of nations has led to the development of national carbon (GHG) trade balances [9] where the influence of trade in producer/consumer nations is taken into account for the purposes of calculation, ensuring equitable allocation of emissions.

Carbon footprints can also be used at the subnational level – most importantly for cities. Cities are, by their very nature, areas of high consumption and population density, often blamed for a plethora of environmental problems. Arguably, per capita emissions in cities are reduced by high population densities; however, more than half the world's population now live in urban areas. Local and regional governments are responsible for many decisions that affect GHG emissions, such as transport and land-use planning, zoning and setting building standards as well as the management of their own activities [24,28]. The development of city carbon footprinting models is relatively new, but of potential importance in providing accurate data to allow for evidence-based strategic decisions.

Carbon footprints of sectors & organizations

Reporting of GHG emissions in an organizational context (e.g., business units or municipal organizations) is becoming increasingly important. A number of mandatory and voluntary schemes exist, the latter recognizing the important role of climate change management as a legitimate business concern. A number of voluntary codes of practice and standards have been developed by industry-led initiatives, sometimes supported by nongovernmental organizations. The most commonly accepted methodology is the GHG protocol, developed by the World Resource Institute and the World Business Council for Sustainable Development [24]. The protocol can be seen to form the basis of a number of prominent carbon footprint methodologies and calculators used in the organizational context.

The most common approach to organizational carbon footprints uses emissions factors. Emissions factors relate a certain activity to an amount of emission (e.g., the mass of CO_2 released through the combustion of 1 kWh of natural gas). These factors are often based on previous detailed studies of the particular aspect [17]. Rarely is it an efficient use of resources or possible to directly measure emissions; therefore, emissions factors are an essential component of the organizational footprint. As previously discussed, EIOA provides a viable alternative to bottom-up type emissions factors, the advantage being that the boundary can be set at the economy of the economic sector, reducing truncation errors. In reality, a hybrid approach is often taken combing bottom-up and top-down analysis.

Demand for an internationally recognized standard and consistency in the calculation of organizational GHG inventory reports has led to the creation of ISO14064 part I [29]. The ISO14064 standard provides a standardized framework methodology for the reporting of organizational GHG emissions; however, it does not provide an accounting or calculation methodology.

Carbon footprints of products & services

Life cycle assessment was initially developed for product environmental impact analysis in order to assess and compare different methods of production and provision, enabling environmentally sound decision making. It follows that the single impact indicator of carbon footprinting should have received attention regarding the potential assessment and labeling of products.

In the UK, the Carbon Trust worked with manufacturers and businesses to introduce a carbon footprint label in 2007, a direct result of the development of a British Publicly Available Specification (i.e., not a standard), PAS 2050 [30]. PAS 2050, "Specification for the assessment of the life cycle greenhouse gas emissions of goods and services", was jointly sponsored by the Carbon Trust and the UK Department for Environment, Food and Rural Affairs and was published by the British Standards Institution on 29 October 2008 [31]. The specification attempts to limit the variability in interpretation of the underlying LCA methodology required for the single impact indicator of a carbon footprint. These requirements, including goal-setting and life cycle inventory assessment, aspects of system boundary identification and temporal aspects of GHG emissions, clarify the approach to be taken by organizations implementing product carbon footprinting, and simplify the application of LCA procedures in relation to product carbon footprinting [31].

In principle, the ISO LCA standards 14040 and 14044 [32,33] provide a tool for the calculation of GHGs associated with a product [34]. However, the standards do not explicitly document the process or boundaries required to calculate a carbon footprint; in response, ISO14067 is currently being developed [35].

Personal carbon footprints

There is an increasing awareness of an individual's behavior or lifestyle as a source of GHG emissions [36]. Individual carbon footprint software (often in the form of a 'calculator') provides a tool that enables individuals to calculate their GHG emissions and link them to their lifestyle and activities. These tools play an important role in education and awareness, allowing individuals to relate more easily with climate change and mitigation. In addition, the individual is empowered by the ability to directly visualize the impact of lifestyle changes. Some calculators go so far as to include recommendations for mitigation or investment in 'carbon offsets'.

Carbon footprint calculators are now widely available on the internet for the calculation of household or individual carbon footprints. Most models calculate individual emissions based on energy consumed and use of transport; some models exclude various types of public transport such as air travel. Calculators are provided by a range of organizations including governments, NGOs and private companies [37]. Currently, there exist significant differences between these calculators and no standard model or practice exists. Previous studies have found that outputs from these calculators can vary by up to several metric tonnes [38]. Despite these inconstancies, individual carbon calculators may have an important role in promoting behavior change and increasing the focus of public pressure on policy officials. Agreement on the definition of a carbon footprint and a method for estimating a personal carbon footprint are essential, if any decision to pursue individual carbon credits or taxation is followed. Without a method of fair, equitable and accurate apportioning of emissions, trading or taxation on carbon emissions will be impossible.

A definition for a carbon footprint

A definitive and unilaterally agreed upon definition for a carbon footprint is vital for the development of national and international targets, legislative agreements and standards. Comparability, accuracy and transferability cannot be ensured until this agreement is reached. It has been established that the carbon footprint has a number of key criteria, from which a definition can be proposed. The carbon footprint builds on the principles established by LCA. The metric uses the concept of the GWP indicator to present anthropogenic climate change impacts. Whilst the GWP has been criticized, it remains widely used and accepted by policy makers. The GWP enables the representation of any number of GHGs in a consistent manner of CO_2 equivalence. Emissions of CO_2 account for greater than half of all anthropogenic emissions; however, one cannot ignore CH_4, the second most prominent GHG, owing to its direct relationship with CO_2 production. Data are usually readily available or easily gathered for these emissions, whereas complications arise in data acquisition for the remaining GHGs and uncertainties are increased with GWPs. In some cases, it is recognized that other GHGs (e.g., N_2O or SF_6) will be important; however, in specific environmental assessments, arguably LCA is preferable.

Taking these key components into consideration, the carbon footprint should act as a proxy indicator of the contributions to anthropogenic climate change made by a process, product, activity or population, accounting for the most prominent anthropogenic GHGs, CO_2 and CH_4. Further GHG inclusion should perhaps be termed, as a climate footprint conducted in the context of LCA. We propose the following definition for a carbon footprint:

"A measure of the total amount of CO_2 and CH_4 emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest. Calculated as CO_2e using the relevant 100-year global warming (GWP100)."

Thus, we define a carbon footprint as a measure of CO_2 and CH_4 emissions. This excludes other GHGs; CO_2 and CH_4 are by far the most prominent GHGs (see Figure 1). In addition, accurate measurements of other GHGs are not always available, thus comparability could not otherwise be insured.

The use of the term 'population or activity' ensures the definition does not exclude potential subjects from the methodology, the definition can be interpreted to include products, services, events, individuals, companies, sectors, processes, communities, cities and even nations. It must be realized that these scales are not additive owing to the issue of double counting and the different measurement perspective; for example, the summation of individuals cannot represent the emissions of a city, since this would not accurately or equitably assign emissions from transboundary sources such as transport. It is recognized that sources of emissions will not always be located within an easily defined geographic boundary (e.g., an organization's manufacturing site). A proportion of emissions could originate from process chain-related sources; for example, grid electricity generation or imported products. Whilst one must be aware of the issues of possible double counting inherent in LCAs, the definition can include all direct, upstream and downstream emissions, depending on the desired outcome and system boundary setting, acknowledging the life cycle perspective and origin of carbon footprinting. Finally, the footprint is presented in CO_2e using a 100-year GWP, ensuring consistent and comparable representation of results. Our definition potentially provides a clear, practical, cost-effective and universally applicable solution to the question of 'what is a carbon footprint?'

Conclusions

The term carbon footprint is widely used and discussed in gray literature and more recently in the academic community, but no commonly agreed definition has yet been established. The development of the carbon footprint can trace its origins to the concept of the ecological footprint and to the principles developed in LCA. This article has highlighted the myriad methodological and philosophical issues that need to be resolved before a universally accepted definition for the term carbon footprint can be realized.

There is debate regarding the choice of GHGs to be included in the carbon footprint. This depends heavily on the purpose of the measurement, whether it is to be another name for the climate impact category utilized in LCA or a separate indicator of anthropogenic GHG emissions. It has been demonstrated that a significant proportion of anthropogenic GHGs can be captured through measurement of CO_2 and CH_4. These two gases are relatively easy to monitor and data is readily available worldwide. This is not the case for other anthropogenic GHGs, for which uncertainty in data is often greater. Where further inclusion of GHGs is required, one should either refer to traditional LCA or consider reference to a climate footprint.

The carbon footprint has developed based on the concepts proposed by LCA and, consequently, the carbon footprint has been estimated via a number of different life cycle methodologies. The choice of methodology depends highly on the subject and desired outcome, although the concept of hybrid accounting is becoming the methodology of choice. However, it is not always abundantly clear where system boundaries are drawn or where cut-offs are created. These issues will need to be addressed on a case-by-case basis as the use of carbon footprints become more widespread. Carbon footprints can be used with a variety of cases and subjects and the methods used for calculation should reflect them.

By addressing the above issues, we propose a sound and pragmatic definition for the carbon footprint that we feel can be applied universally to a variety of cases and subjects. The definition is developed for the concept of the carbon footprint as an indicator of anthropogenic contribution to climate change, versus a full climate change impact 'tool', since this has been previously achieved with the development of LCA. Achieving true sustainability requires the evaluation and consideration of all relevant environmental impacts. By definition then, a carbon footprint should constitute a tool to aid in GHG mitigation policies and practice, at all levels from the individual to the nation. The carbon footprint must be recognized as a tool for assisting decision making, rather than a definitive answer. If decisions based on the carbon footprint indicator are correct the majority of the time, it is better than the alternative of no indicator and decision making with ignorance. Carbon footprinting is by no means the only aspect of the LCA process to be simplified for the purpose of communicating complex environmental issues, but uniquely has been able to catch the attention of the public, policy makers and the academic community. As such, the carbon footprint has the potential to stimulate improvement in GHG management and climate change mitigation.

Future perspective

Climate change is a global issue; however, mitigation and impacts are profoundly local; for example, the impacts of reduced rainfall and draught are felt at a regional level. Mitigation relies on community,

Executive summary

'Carbon footprint': a review of current definitions

- The carbon footprint' is increasingly being recognized as an important tool in the field of climate change management. The term carbon footprint has become an extremely popular phase for the practice of relating an amount of GHG emissions to a certain activity. The development of the carbon footprint has been driven largely by governments, NGOs and the media, with (to date) less interest in the academic community.
- There are a plethora of definitions for a carbon footprint. However, there is little consensus regarding life cycle perspective, methods and metrics.
- The underlying concept is similar to the global warming potential indicator used in life cycle assessment (LCA) to represent climate change impact(s).

Measuring the carbon footprint

- The CO_2 equivalent (CO_2e) enables the representation of a range of GHGs in a consistent and relatable manner. Whilst not without criticism, it is widely accepted and utilized by policy makers.
- The selection of GHGs to include in the carbon footprint is an important issue. Previous authors have suggested that the metric should only include measurements of CO_2. This does create a number of issues regarding misleading output and exclusion. Alternatively, the metric can include all GHG emissions. However, issues exist regarding data availability and accuracy. A significant proportion of emissions can be captured through measurement of the two most prominent anthropogenic GHGs, CO_2 and CH_4.
- There are three principal life cycle approaches to emissions inventories: environmental input–output analysis (EIOA); process analysis (PA), hybrid environmental input–output LCA (hybrid-EIO-LCA). EIOA is a top-down analysis that uses aggregate data at the sector level. PA is a bottom-up approach for assessing a specific process. Hybrid-EIO-LCA uses both EIOA and PA to assess processes at both the macro and micro levels.
- The boundary of the carbon footprint depends on the desired final use and expected outcome. The World Resource Institute/World Business Council for Sustainable Development define emissions in terms of scopes: scope 1, direct emissions; scope 2, emissions from electricity consumption; scope 3, indirect emissions. Scope 3 is often seen as optional and little guidance is available regarding cut-offs and inclusion.

A tool for climate change management

- The carbon footprint has been used for a range of activities including nations, cities, organizations, products and on the personal level. There has been less interest in the carbon footprint of nations and subnational regions. Carbon footprints of nations are closely linked to debates regarding fairness in the allocation of emissions. Production accounting may lead to underestimates and burden shifting, whilst consumption accounting removes the emphasis of emissions reduction from the producer. Carbon footprints can also be used at the subnational level – most importantly for cities.
- Reporting of GHG emissions in an organizational context is becoming increasingly important. The most common approach to organizational carbon footprints uses emissions factors. Emissions factors relate a certain activity to an amount of emission. Demand for an internationally recognized standard and consistency in the calculation of organizational GHG inventory reports has led to the creation of ISO14064 part I, which provides a standardized framework methodology.
- Life cycle assessment was initially developed for product environmental impact analysis. It follows that the single impact indicator of carbon footprinting should have received attention regarding the potential assessment and labeling of products. In principle, the ISO LCA standards 14040 and 14044 in principle provide a tool for the calculation of GHGs associated with a product. Following the structure of the ISO standard, the relevant GHGs can be accounted and presented as a carbon footprint.
- There is an increasing awareness of an individual's behavior or lifestyle as a source of GHG emissions. Individual carbon footprints provide a tool enabling individuals to calculate their GHG emissions and link them to their lifestyle and activities. These tools play an important role in education and awareness, allowing individuals to relate more easily with climate change and mitigation. Carbon footprint 'calculators' are now widely available on the internet for the calculation of household or individual carbon footprints. Most models calculate individual emissions based on energy consumed and use of transport, some models exclude various types of public transport such as air travel. Personal carbon footprints may play an important role in any future schemes for personal carbon credits/taxes.

A definition for a carbon footprint

- We propose a sound and pragmatic definition for the carbon footprint that we feel can be applied universally to a variety of cases and subjects: "A measure of the total amount of CO_2 and CH_4 emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest. Calculated as CO_2e using the relevant 100-year global warming potential (GWP100)."

organizational and individual action to reduce GHG emissions from products, services and processes. The need for decision support tools to assist policy and decision makers in climate decisions will become especially poignant as the impacts of climate change are realized.

Until relatively recently, the development of the carbon footprint has been largely driven by governments, industry and NGOs. It is likely that we will see greater interest developing in the academic community, as the carbon footprint is realized as a valuable tool for communicating complex scientific measures in the pursuit of promoting sustainable behaviour and climate change mitigation.

Acknowledgements

The authors wish to thank Helen Krzanowski, Bill Clarke, Loraine Brown and Matthew Dean (Southampton City Council) and Tony Bush (AEA Technology) for their advice and assistance. Thanks also go to all those organizations and individuals who have supplied data and assistance to the project.

Financial & competing interests disclosure

This study is funded by Southampton City Council, UK. The authors have no other relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript apart from those disclosed. No writing assistance was utilized in the production of this manuscript.

Bibliography

Papers of special note have been highlighted as:

- ■ of interest
- ■■ of considerable interest

1 Intergovernmental Panel on Climate Change. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Pachauri RK, Reisinger A (Eds). Cambridge University Press, Cambridge, UK 104 (2007).

2 Wiedmann T, Minx J. The definition of a carbon footprint. In: *Ecological Economics Research Trends.* Pertsova CC (Ed.). Nova Science Publishers, NY, USA 1–11 (2008).

■■ **Review of definitions for a 'carbon footprint' in the gray literature, with proposed new definition.**

3 Finkbeiner M. Carbon footprinting – opportunities and threats. *Int. J. LCA* 14(2), 91–94 (2009).

■■ **Editorial highlighting the challenges and research issues in carbon footprinting.**

4 Weidema BP, Thrane M, Christensen P, Schmidt J, Løkke S. Carbon footprint a catalyst for life cycle assessment? *J. Industrial Ecology* 12(1), 3–6 (2008).

■ **Discussion of the carbon footprint as a proxy indicator for life cycle assessments.**

5 Peters GP. Carbon footprints and embodied carbon at multiple scales. *Cur. Opin. Environmental Sustainability* 2, 245–250 (2010).

■■ **Review of the carbon footprint and possible applications at different scales.**

6 Rypdal K, Winiwarter W. Uncertainties in greenhouse gas emission inventories – evaluation, comparability and implications. *Environmental Sci. Policy* 4(2–3), 107–116 (2001).

7 Wiedmann T. Editorial: carbon footprint and input–output analysis – an introduction. *Economic Systems Research* 21(3), 175–186 (2009).

8 Wackernagel M, Rees WE. O*ur Ecological Footprint – Reducing Human Impact on the Earth.* New Society Publishers, British Columbia, Canada (1996).

9 Minx JC, Wiedmann T, Wood R *et al.* Input-output analysis and carbon footprinting: an overview of applications. *Economic Systems Research* 21(3), 187–216 (2009).

10 Shine KP, Fuglestvedt JS, Hailemariam K *et al.* Alternatives to the global warming potential for comparing climate impacts of emissions of greenhouse gases. *Climatic Change* 68, 281–302(2005).

11 United Nations. Kyoto protocol to the United Nations framework convention on climate change (1998).

12 Strutt J, Wilson S, Shorney-Darby H, Shaw A, Byers A. Assessing the carbon footprint of water production. *J. AWWA* 100(6), 80–91 (2008).

13 Hammond G, Time to give due weight to the 'carbon footprint' issue. *Nature* 445, 256 (2007).

14 Directive 2003/87/ec of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the community and amending council directive 96/61/ec (2003).

15 Intergovernmental Panel on Climate Change. *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 University Press, Cambridge, UK (2007).

16 Spokas K, Bogner J, Chanton JP *et al.* Methane mass balance at three landfill sites: what is the efficiency of capture by gas collection systems? *Waste Management* 26(5), 516–525 (2006).

17 Moss J, Lambert CG, Rennie AEW. SME application of LCA-based carbon footprints. *Int. J. Sustainable Eng.* 1(2), 132–141 (2008).

18 Bauman H, Tilman A. *The Hitchhiker's Guide to LCA*. Studentlitteratur AB, Sweden (2004).

19 Shine KP. The global warming potential – the need for an interdisciplinary retrial. *Climatic Change* 96, 467–472 (2009).

20 Suh S, Lenzen M, Treloar GJ *et al.* System boundary selection in life cycle inventories using hybrid approaches. *Environmental Sci. Technology* 38(3), 657–664 (2003).

21 Larsen HN, Hertwich EG. The case for consumption-based accounting of greenhouse gas emissions to promote local climate action. *Environmental Sci. Policy* 12(7), 791–798 (2009).

22 Matthews HS, Hendrickson CT, Weber CL. The importance of carbon footprint estimation boundaries. *Environmental Sci. Technology* 42(16), 5839–5842 (2008).

23 Hondo H, Sakai S. Consistent method for system boundary definition in LCA: an application of sensitivity analysis. *J. Advanced Sci.* 13(3), 491–494 (2001).

24 Greenhalgh S, Broekhoff D, Daviet F *et al. Project Accounting Protocol and Guidelines.* WRI/WBCSD, Washington DC, USA (2003).

25 Hertwich EG, Peters GP. Carbon footprint of nations: a global, trade-linked analysis. *Environmental Sci. Technology* 43(16), 6414–6420 (2009).

26 United Nations Framework Convention on Climate Change (1994).

27 Lenzen M, Murray J, Sack F, Wiedmann T. Shared producer and consumer responsibility – theory and practice. *Ecological Economics* 61(1), 27–42 (2007).

28 Salon D, Sperling D, Meier A, Murphy S, Gorham R, Barrett J. City carbon budgets: a proposal to align incentives for climate-friendly communities. *Energy Policy* 38, 2032–2041 (2010).

29 International Organization for Standardization. *Greenhouse Gases – Part 1: Specification with Guidance at the Organization Level for Quantification and Reporting of Greenhouse Gas Emissions and Removals.* ISO, 14064–14061 (2006).

30 Publicly Available Specification. *Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services.* PAS 2050 (2008).

31 Sinden G. The contribution of PAS 2050 to the evolution of international greenhouse gas emissions standards. *Int. J. Life Cycle Assess.* 14, 195–203 (2009).

32 International Organization for Standardization. *Environmental Management. Life Cycle Assessment. Principles and Framework.* ISO, 14040 (2006).

33 International Organization for Standardization. *Environmental Management. Life Cycle Assessment. Requirements and Guidelines.* ISO, 14044 (2006).

34 Schmidt H. Carbon footprinting, labeling and life cycle assessment. *Int. J. Life Cycle Assess.* 14(Suppl. 1), S6–S9 (2009).

35 International Organization for Standardization. *Carbon Footprint of Products – Part 1: Quantification.* ISO, 14067. (In Press).

36 Bin S, Dowlatabadi H. Consumer lifestyle approach to us energy use and the related CO_2 emissions. *Energy Policy* 33(2), 197–208 (2005).

37 Kenny T, Gray NF. Comparative performance of six carbon footprint models for use in Ireland. *Environmental Impact Assessment Review* 29(1), 1–6 (2009).

38 Padgett JP, Steinemann AC, Clarke JH, Vandenbergh MP. A comparison of carbon calculators. *Environmental Impact Assessment Review* 28(2–3), 106–115 (2008).

39 Johnson E. Disagreement over carbon footprints: a comparison of electric and LPG forklifts. *Energy Policy* 36, 1569–1573 (2008).

Websites

101 Collins English Dictionary – Complete & Unabridged 10th Edition, from Dictionary.com. http://dictionary.reference.com/browse/carbon footprint

102 Global Footprint Network. 'Ecological footprint glossary'. www.footprintnetwork.org/gfn sub.php?content=glossary

103 Carbon Footprint. www.carbonfootprint.org.uk/

104 The Energy Saving Trust. What is a carbon footprint? www.energysavingtrust.org.uk/Easy-ways-to-stop-wasting-energy/What-is-a-carbon-footprint

105 The Carbon Trust. carbon footprinting. www.carbontrust.co.uk/cut-carbon-reduce-costs/calculate/carbon-footprinting/pages/carbon-footprinting.aspx

106 Wikipedia. Carbon footprint. http://en.wikipedia.org/wiki/Carbon_footprint

107 Carbon Footprint. What is a carbon footprint www.carbonfootprint.com/carbonfootprint.html

108 US Environmental Protection Agency. Create a new climate for action. www.epa.gov/climateforaction/learn/glossary.htm