Science as Culture
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/csac20

It's Complicated: Corporate Sustainability and the Uneasiness of Life Cycle Assessment

Susanne Freidberg[a]
[a] Geography, Dartmouth College, Hanover, NH, USA
Published online: 18 Aug 2014.

To cite this article: Susanne Freidberg (2014): It's Complicated: Corporate Sustainability and the Uneasiness of Life Cycle Assessment, Science as Culture, DOI: 10.1080/09505431.2014.942622

To link to this article: http://dx.doi.org/10.1080/09505431.2014.942622

Science as Culture, 2014
http://dx.doi.org/10.1080/09505431.2014.942622

It's Complicated: Corporate Sustainability and the Uneasiness of Life Cycle Assessment

SUSANNE FREIDBERG

Geography, Dartmouth College, Hanover, NH, USA

ABSTRACT *Life cycle assessment (LCA) is a technique and field of expertise aimed at modeling the complete 'cradle-to-grave' life of goods and services, as well as their multiple impacts on environmental and human well-being. Although not new, in recent years LCA has become a central tool in corporate and government initiatives to improve overall product sustainability. These initiatives show how corporate supply chains have become increasingly important sites and objects of knowledge production. But the production process is not straightforward. LCA practitioners must navigate complicated relationships with corporations that serve as both clients and sources of vital information. The challenges of generating knowledge deemed both credible and useful are compounded by the complexity, diversity and contingency of product life cycles, as well as by ongoing debates about exactly how product sustainability should be modeled and assessed. While some of these challenges are unique to LCA, others reflect tensions common to many fields that assess corporate conduct in order to improve it.*

KEY WORDS: life cycle assessment, corporate science, sustainability, environment, complexity

Introduction

'One small step for Walmart, one giant leap for Planet Earth'. The *Harvard Business Review* blogger's quip joined many other breathless responses to the retailer's plan to rate the environmental performance of every product it sold (Kanter, 2009). Announced in July 2009, this 'sustainability index' would cover

Correspondence Address: Susanne Freidberg, Geography, Dartmouth College, Hanover, NH 03755, USA. Email: freidberg@dartmouth.edu

products' entire life cycles, from resource extraction through disposal. Revealing few details, Walmart said the index would both guide its own purchases and help shoppers make theirs. It would 'help their families, and the world, live better' (Sustainability Index, n.d.).

The most optimistic commentators predicted that Walmart's plan heralded a new age of 'radical transparency', empowering consumers and greening the economy more effectively than any government (Kanter, 2009; Goleman, 2010). Others described it as 'fiendishly complex', (Gunther, 2009) which Walmart itself did not deny. As a first step, the company planned to form a research consortium, based at the University of Arkansas but tapping a global pool of experts. The consortium would determine exactly how to collect and index data on tens of thousands of products and their multiple impacts on the earth's climate, natural resources and people. They would also determine how to turn these data into information useful to Walmart and its customers. The U of A professor chosen to lead what became known as the Sustainability Consortium agreed that what lay ahead would mean 'a lot of work for a lot of people' (Rosenbloom, 2009).

In particular, it would mean lot of work for practitioners of life cycle assessment (LCA), the modeling technique underlying Walmart's proposed index. This article examines what has been called the 'renaissance' of LCA, a once-obscure 'geeky system of accounting' that now guides major corporate and government initiatives to measure, disclose and improve products' cradle-to-grave environmental footprints (Makower, 2009). While most of these initiatives are recent, their reliance on LCA—understood here as a field of expertise, not just a technique—reflects the growing significance of the supply chain as both a site and an object of knowledge production.

What are the challenges involved in producing that knowledge, and assuring its credibility? In LCA, the practical, social and ethical challenges practitioners face must be understood in light of the field's historically complicated relationship to industry, broadly defined. In brief, practitioners depend on industry not only for financial support, but also for access to the data, sites and in-house knowledge needed to advance both their individual work and the field as a whole. To maintain this access as well as the field's broader credibility, LCA must demonstrate both bottom-line usefulness and scientific rigor. This has proven to be a difficult balancing act, not least because LCA's subject matter is itself extraordinarily complicated. The matter and energy flows that comprise a product's 'life' are diverse, variable, unstable, often proprietary and increasingly global in reach. Their many ecological and social impacts are closely coupled yet often highly uncertain (Fiksel, 2013). Rigor in this context does not come cheap or quickly, and does not guarantee results that clients can understand, much less use.

At the same time, LCA's heightened prominence in the business world has exposed and intensified the field's internal debates. At issue is not only which modeling methods most accurately capture a products' life cycle impacts, but

also which methods generate the most impactful knowledge—i.e. knowledge which helps assure those products are made, consumed and regulated in a more sustainable fashion. Ironically, insofar as these debates have slowed corporate and government efforts to apply LCA knowledge, they have undermined practitioners' widely shared goal of 'making a difference'.

To date, LCA has gone largely unnoticed by science and technology studies (STS).[1] A brief explanation of the technique and its applications thus precedes the empirical body of the paper, which examines LCA's relationship to industry both historically and in contemporary debates and professional practices. Informed by the literature and methods described in the next section, this analysis offers insights into LCA as well as the many other fields that assess corporate activity in order to make it more sustainable. It asks two related questions. First, how has the nature of the assessment relationship—in which the corporation serves simultaneously as knowledge source and customer—informed LCA practitioners' efforts to demonstrate both rigor and salience? And second, how are these efforts further complicated by the ecological and social complexity of corporate supply chains?

Supply Chains and Corporate Knowledge Production

In their call for greater STS engagement with corporate science, Penders *et al.* (2009) observe that this form of knowledge production encompasses much more than for-profit research and product development (see also Schleifer and Penders, 2011). Clearly corporate funding has transformed research priorities and outcomes in many fields over the past few decades (Lave *et al.*, 2010; Mirowski, 2011). But whether centered on gene therapies or granola bars, corporate R&D both informs and draws on a wide range of other knowledge-based activities, from advertising, branding and market research to logistics and management consulting (see, for instance, Greene, 2004). While some of these fields date back to the early days of corporate enterprise (Chandler, 1977), those specific to supply chains are relatively new and unexamined (Busch, 2007; Gibbon and Ponte, 2008).

One diverse and growing realm of corporate knowledge production centers on helping companies frame, assess, and demonstrate progress toward supply chain sustainability. The United Nations Global Compact defines this objective as 'the management of environmental, social and economic impacts . . . throughout the life cycles of goods and services' (Sisco *et al.*, 2010, p. 7). Its significance owes to specific historical developments. Over the past 40-some years, corporate practices of offshoring, subcontracting and transnational sourcing and marketing have pushed a growing proportion of global economic activity into supply chains, many effectively governed by high-profile manufacturers and retailers (Gereffi and Lee, 2012). As the sheer volume of goods and materials moving around the world has increased, so has their extraction, production and disposal in parts of

the world where these 'big brands' risk supply shocks or image-damaging scandals (Ernst and Young, 2013). Global or not, companies also face rising resource costs, growing pressures for transparency and new legislation (at least in Europe), requiring that they account for and steward material activities well beyond those they directly control (Seuring and Gold, 2013). Not least, major consumer goods companies such as Walmart see product 'greening' as a means to cut costs and liability, and thereby expand both domestic and global markets (Haanaes *et al*., 2011; Dauvergne and Lister, 2012). They have come to see their own sustained growth, in other words, as contingent on demonstrated care for the 'three Ps': people, planet and profits. The measure of companies' 'triple bottom line' performance has proven no simple matter (Slaper and Hall, 2011; Henriques and Richardson, 2013). But it has helped to turn supply chains into key sites and objects of corporate knowledge production.

LCA is hardly the only technoscientific field involved. From audits and specialized software to the consultancies hired to write annual sustainability reports, companies use varied tools and expertise to assess their supply chains (Livesey and Kearins, 2002; Loconto, 2010; Jere, 2011; O'Dwyer, 2011; Kanngieser, 2013). But as the next section discusses in greater depth, companies look to LCA in particular for quantitative indicators that can find them both their heaviest supply chain impacts (known as 'hotspots') and ways to measurably reduce them (Kaenzig *et al*., 2011; Fiksel, 2013; Wible *et al*., 2014). Comprehensive in scope yet covering only quantifiable material and energy flows, these indicators also indirectly serve companies' broader interest in framing sustainability itself as optimal eco-efficiency—as the minimizing of resource intensity, pollution and other environmental impacts per unit of economic value—rather than as reduced consumption or de-growth (Schneider *et al*., 2010; Dauvergne and Lister, 2012). Some LCA practitioners do advocate more radical change, as discussed later. But companies are understandably more interested in the technique's capacity to identify 'win–wins', such as energy savings that also save money, and to thereby help define sustainability as a goal compatible with continued growth (Freidberg, 2013, 2014).

More broadly, LCA counts among a growing number of fields devoted to what Thrift (2005) calls 'knowing capitalism': that is, they study corporate conduct in order to enlighten and improve it (Hughes, 2006). These fields assess managerial behavior; inter-firm relations; companies' adherence to industry codes, standards and norms of 'social responsibility' or, in the case of LCA, supply chain material and energy flows (Bryson, 2002; Hughes, 2007; Blowfield and Murray, 2011). Their membership tends to span and move between industry, consulting, academia and non-governmental organizations (NGOs). They may audit and certify as well as analyze and advise (Power, 1997; Owen, 2008), often employing 'science-based' rules and methods (Hatanaka, 2010). Whether or not they explicitly address sustainability, many of these knowledge-based activities aim to help companies manage increasing supply chain complexity, with its attendant

uncertainties and risks. In doing so, they have influenced corporate thinking about what constitutes 'sustainable' conduct, what competitive advantages it offers and what information and knowledge it requires (Sadler and Lloyd, 2009). But with this influence comes certain common concerns.

Chief among these are the tensions between credibility, salience and practitioners' own moral commitments. While scientific credibility in particular is one of the founding concerns of STS itself (Latour and Woolgar, 1979; Shapin, 1995), relatively little scholarship considers how it is produced and maintained by fields that exist to assess and improve industry. Companies engage in their own 'credibility engineering' via both scientific and commercial channels. They may publish in peer-reviewed journals, for instance, to build support for product claims, bolster overall brand image and portray themselves as 'science-minded' employers (Lehenkari, 2003; Penders and Nelis, 2011). But most of the scientific fields tapped for these purposes—nutrition and medicine, for example—do not intrinsically depend on industry, even if they now effectively depend on its funding (Mirowski, 2011; Sismondo, 2011; Scrinis, 2013). LCA, by contrast, does not just produce knowledge about products for companies. The field is itself a product of companies' need for a certain kind of credible scientific knowledge.

Companies look to LCA both to inform internal decisions—about, say, product design or the sourcing of raw materials—and to help justify those decisions within and beyond corporate walls. Its scientific credibility thus does not by itself assure its usefulness. Like science employed in the policy context, the salience of LCA findings also depends on their communicability, perceived certainty and relevance to the spatial and temporal scales of decision-makers' own jurisdiction (Cash *et al.*, 2002, 2003; Kinchy and Kleinman, 2003; McNie, 2007). Indeed, not unlike Knorr-Cetina's financial analysts (2010), retailers and manufacturers need current, quickly produced and, above all, *consumable* 'informational knowledge' about their supply chains—knowledge, in other words, that may be rendered obsolete by the changes it brings in how products are made, sold and consumed.

Companies also need this knowledge to generate a return on investment. It may seem like an obvious point, but obviousness is part of the problem. Companies' vested interest in LCA findings poses a chronic threat to the field's credibility, given that those findings typically derive from industry data and inherently unverifiable models (Oreskes *et al.*, 1994). Popular skepticism regarding corporate green claims frames the 'political situation' in which every metric invites controversy (Barry, 2012). Practitioners' insistence on methodological rigor may help defend LCA's credibility while also undermining the technique's usefulness to companies, partly by making their findings harder to interpret and profitably act upon. At the same time, rigor does not necessarily assuage practitioners' moral uneasiness about corporate pressures to supply lucrative knowledge. Again, at a certain level this is a familiar STS concern (Shapin, 2009). But this uneasiness

arguably takes on a particular weight in fields that, like LCA, consider industry not only a necessary sponsor but also the very object their work aims to transform.

The points raised here, like the following empirical analysis, draw on an ongoing ethnographic project. This project has involved more than 60 semi-structured interviews, participant observation at several international LCA conferences and online forums, coursework in LCA and an extensive review of the LCA journal literature. Most of the interviews were conducted with LCA practitioners working in academia, consulting or industry, usually either in Europe or in North America. Other interviewees included corporate sustainability managers, consultants, policymakers and representatives of NGOs that have either participated in or criticized LCA-based sustainability initiatives.

Revealing the 'World Behind the Product'

Shortly before Walmart announced its planned sustainability index, best-selling science writer Daniel Goleman predicted that LCA would 'change everything' about how the economy works. In *Ecological Intelligence* he described how practitioners could measure 'with near-surgical precision' the far-reaching environmental impacts of products' material lives. LCA practitioners themselves might clarify that they do not measure actual impacts; they model potential ones, using data on material and energy flows. They might add that these models aim for estimation and comparison, not precision. But most practitioners would probably not object to Goleman's characterization of LCA as a 'vanguard' field, offering a unique perspective on 'the world behind the product' (Leeuw, 2008; Goleman, 2010, p.14).

This perspective offers at least two types of insights. First, LCA often finds that products' hotspots occur in unexpected parts of their lives. In the case of many foodstuffs, for example, LCA shows that the farm, not transport or packaging, usually accounts for most of the emissions and resource use (Weber and Matthews, 2008). This information can help prioritize efforts to reduce impacts. Second, because LCA examines both entire life cycles and multiple environmental impacts—global warming, ozone depletion, ecotoxity, water and air quality, among others—it can highlight the tradeoffs of different materials and processes. Recyclable packaging may generate less waste but require more energy to manufacture and transport; biofuels may burn green but incur an immense footprint during production (Humbert *et al*., 2009; Plevin, 2009). Knowledge of such tradeoffs does not necessarily make them technically or politically easier to resolve. But especially when products and policies are still in the design stage, it can help avoid decisions that might later seem shortsighted (Heiskanen, 1999).

LCA has also become the basis for a number of initiatives to green entire industries, sectors and national and regional markets. The Walmart-backed Sustainability Consortium is just one of them. It now boasts more than 80 corporate members, runs offices on four continents and since late 2012 has worked with the much

larger Consumer Goods Forum to establish 'a globally harmonized science-based approach to measure and communicate product life cycles' (Sustainability Consortium, 2012; Dooley, 2014). As discussed later, this approach draws less directly on LCA than originally expected. But it is tapping the field's research to develop metrics of product sustainability that will, in principle, inform supply chain decisions of many of the world's biggest companies. Some of these companies, such as Unilever, already employ entire teams of LCA researchers. Elsewhere, the field's methods inform new international standards for carbon and water footprinting (Hoekstra *et al*., 2011; WBCSD/WRI, 2011), as well as an assortment of multi-stakeholder initiatives to measure and improve the footprint of beef and other food products.[2]

State procurement policies, carbon and energy taxes and new environmental disclosure policies have also pushed companies to assess their products' life cycle impacts (Berg, 2011; UNEP, 2012). The French government already conducted a yearlong 'product environmental footprint' (PEF) trial in 2011–12 in which some 270 companies volunteered to disclose their products' multiple life cycle environmental impacts on labels and websites. Although the trial made clear that it was not yet realistic to mandate such disclosures, the government indicated that it may eventually do so (Vergez, 2012). Meanwhile the European Commission has launched its own three-year PEF trial, also drawing on LCA, as part of a larger project to encourage the greening of industries and consumption across the entire European market (European Commission, 2013).

As a group of LCA practitioners wrote in 2011, 'we observe that LCA is booming' (Guinée *et al*., 2011). Consultancies offering LCA, which now include the 'Big Four' accounting firms (Deloitte, PwC, Ernst & Young, and KPMG) as well as more specialized agencies, reported 'torrid' demand (Green Research, 2011). The Swiss firm Quantis had expanded its workforce by 750% in three years; its Paris office is now crowded with 25-year-old analysts hired fresh from Swiss engineering schools. LCA conferences once dominated by academics attract increasing numbers of corporate presenters and sponsors.

Practitioners readily acknowledge that much of the current corporate interest in LCA reflects expectations rather than widespread evidence of its business utility.[3] In other words, they recognize that the boom might not last. This raises a question implicit in any reference to a 'renaissance:' what explains the prior dark age? In the case of LCA, the answer sheds light on practitioners' ongoing struggles to maintain both the credibility and usefulness of their work.

Invited into Industry

As an assessment technique focused on the material and energy flows comprising the 'industrial metabolism', LCA's intellectual lineage dates to mid-twentieth-century systems ecology and 'bioeconomics' (Ordway, 1953; Odum and Odum, 1959; Fischer-Kowalski, 1998; Cleveland, 1999). But LCA practitioners'

own historical accounts typically trace the technique's origins to a study commissioned by Coca Cola. In 1969 the company hired the Midwestern Research Institute (MRI) to compare the environmental 'profiles' of returnable glass bottles with new aluminum and plastic alternatives (Hunt and Franklin, 1996). Harry Teasley, the Coca Cola executive who initiated the study (and later the CEO), described Eugene Odum's systems ecology as 'a concept whose time has come' (Teasley, 1976). Companies such as Coca Cola, he said, needed environmental knowledge for both planning and public communication (though it never actually publicized the study's findings that returnable glass far outperformed aluminum[4]). 'What surprised everybody was how well plastics fared', one of the MRI analysts later said (Darnay, pers. comm. March 2, 2011). A material maligned as ugly litter was also efficient to produce and transport. Although Coca Cola did not switch to plastic bottles until many years later, the company 'gained a comfort with the idea' as a result of the study (Hunt and Franklin, 1996, p. 5).

Similarly, the Mobil Chemical Company commissioned MRI to determine whether its polystyrene supermarket meat tray was truly an 'environmental villain', as cardboard tray manufacturers claimed. 'The Mobil staff actually thought it was probably true, but wanted to know just how bad it really was', the MRI researchers later wrote. 'Much to their surprise, and ours, the plastic tray compared quite favorably' (Hunt and Franklin, 1996, p. 5). The potential to deliver surprising, even gratifying results became one of LCA's early trademarks. But whether these results improved anything beyond company morale was not always clear, even to the researchers who produced them. The MRI researchers sometimes suspected that their clients did not find much use for the dense mix of 'good news and bad news' they typically delivered (Hunt and Franklin, 1996, p. 7). As one later said, 'We used to joke that we could hear the backhoe cranking up behind the plant, getting ready to bury all the reports we'd given them' (Hunt, pers. comm, May 19, 2012).

The mixed and contingent nature of LCA studies made them especially unhelpful for marketing. The ecological virtues of Coca Cola's returnable glass bottle, for example, assumed it was returned at least 15 times before disposal, and with no extra consumer driving. Such qualifications did not make for good ad copy. Another early study, this one on European yogurt containers, found little difference between glass and polystyrene. But it had little effect on the marketing of glass as eco-friendly. 'This confirms', one of the study's authors later wrote, 'that complex systems discussed and explained from different view points are hardly … understood by the broad mass of the population' (Fink, 1997, p. 134). LCA practitioners today commonly express the same frustration.

Authors of early LCA studies also contended with the challenges of data collection, even when working on behalf of a major brand. 'We came wrapped in the mantle of Coke', recalled one of the MRI researchers, so its suppliers readily opened their doors and books. The problem, however, went beyond companies'

reluctance to disclose proprietary information. 'There are obviously commercial sensitivities involved', said a British practitioner, 'but these are usually less of a hindrance than the simple fact that the type of data needed [for LCA] is not the type ... needed to run a successful commercial enterprise' (Boustead, 1996, p. 149).

It helped that many industries in the 1970s saw energy efficiency and waste as competitive issues:

> ... Our involvement with different industries was never planned; it happened by accident. When plastic bottles began to compete with glass bottles, we were invited to work with the plastics industry. Then when aluminum cans were introduced in competition with steel cans, we were asked into the steel and aluminum industries ... When competition between plastics pipes and vitrified clay pipes became overheated, we were invited into the clay pipe industry and subsequently the building industry. Similarly because of involvement with the steel industry, we were invited into the car industry. (Boustead, 1996, pp. 147–148)

At first glance, Boustead's account suggests that LCA practitioners sold their services to any industry seeking to green its image. But this overlooks a basic reason why they needed such 'invitations': because industry was their field site, not just a client or a sponsor. They needed access, in other words, not only to do their job, but also to advance the technique as a whole. Boustead (a material science professor who, like many in the field, later started a consultancy) emphasized the value of such experience:

> Working with so wide a range of completely different industries gave us access to enormous quantities of primary industrial data but more importantly, from an academic viewpoint, was the exposure to widely different processes ... it helped to develop the analysis techniques, because methods that could be used in a relatively straightforward process such as glass melting were quite inadequate when applied to steel-making .... (p. 149)

The problem with these early techniques was not so much that they were developed under industry auspices, but that they varied widely. A product life cycle, after all, is a construct, and practitioners in different companies, research institutions and countries constructed it differently. This mattered little as long as companies only used the results internally. But in the late 1980s, stories of overflowing landfills reignited popular environmental concerns (Katz, 2002), and boosted demand for ostensibly eco-friendly goods (Luehr, 1991, pp. 313–314). For industries with a stake in this market, product claims based on LCA became irresistible.

In the United States, such claims proved especially controversial during the disposables versus cloth 'Diaper War'. The pro-cloth National Association of Diaper Services launched the first strike with an Earth Day 1990 report on disposables' sizeable contribution to the national waste stream (18 billion diapers per year, or about 2% of all solid waste). Procter & Gamble responded with a life cycle study claiming that the energy and water used to make and launder cloth diapers outweighed disposables' overall environmental burden (Little, 1990). The diaper launderers then challenged P & G assumptions about, among other things, the average baby's daily diaper needs (Lehrburge *et al.*, 1991). Environmental NGOs weighed in, generally favoring cloth; Dana Meadows, author of *The Limits to Growth*, observed that both sides had neglected important impacts and that, anyway, consumers' diaper choices mattered far less than their decision to have children in the first place (Holusha, 1990; Meadows, 1990).

Unresolved, the diaper debate led to the creation of a governmental task force to fight deceptive environmental advertising. A subsequent report listed the reasons to distrust life cycle-based claims:

> Problems include comparisons of information that technically cannot be compared; references to only the positive environmental aspects of one product and only the negative aspects of the competing product; and misuse of such assessments by third parties ... Moreover, the few product life cycle assessments that have been conducted by the business community have come out in favor of the manufacturer who paid for the assessment and against that manufacturer's 'target' competitor. (Attorney General Task Force, 1991, p. 12)

Until such assessments were standardized and guaranteed not to mislead, the report concluded that they 'should not be used to advertise or promote specific products' (p. 11).

From Tool to (Impossible) Profession

> A balance between aspirations and practicability must be found. A major question is, how to proceed in view of imperfections and demands for outcomes?
> 'How to get LCA in the right direction', (Krozer and Vis, 1998)

The greatest casualty of the Diaper War, then, was the authority of LCA itself, especially in the United States. But it did help spark international efforts to 'salvage the credibility' of the technique (Heiskanen, 2000, p. 29), partly through the development of a set of International Standards Organization (ISO) standards, documenting LCA's basic rules and procedures (ISO 2006a, 2006b). Their creation in turn helped to forge an expert community around LCA, with

its own associations, journals and conferences. But as the standards themselves reveal, LCA remains a field of conflicted ideals.

On the one hand, the ISO standards demand caution, modesty and transparency. 'ISO-compliant' life cycle studies must include certain steps to assure completeness and rigor. They must document assumptions, data sources, modeling choices, uncertainties and shortcomings. Although the standards never refer to LCA as a science, they do require 'scientifically valid' modeling (ISO 2006b, p. 19). Studies aimed at 'comparative assertions'—about which kind of diaper is greener than another—must undergo review by a panel of independent experts, a process that typically takes weeks if not months.

On the other hand, the standards also describe LCA as a technique that considers 'the *entire* life cycle of a product and . . . *all* attributes or aspects of natural environment, human health and resources' (ISO, 2006a, p. 7). Such breadth reflects practitioners' own aspirations to see the biggest possible picture. It also defines the field's market niche, allowing a company to claim a product that LCA has gotten at the 'whole story'. But such a story would never end. LCA, said Michael,[5] a Dutch practitioner interviewed for this study,

> tries to provide a recipe to model everything we do and then look at the impacts on everything we care for. And of course, you can't do it. Since LCA is in principle impossible, you can only come as close as possible to what you wanted.

Practitioners readily admit that their standards are unachievable. Even the title of the most popular LCA textbook: *The Hitchhiker's Guide to LCA* (Baumann and Tillman, 2004) alludes to the quixotic task of Deep Thought, the fictional supercomputer that spent seven and a half million years calculating the answer to the 'meaning of life, the universe and everything' (Adams, 1979). In lieu of everything, LCA practitioners learn early on that they must instead 'measure what matters', drawing on the best available data.

But determining what matters—and what is even feasible to measure—requires considerable time and trained judgment, especially for novel products with complex and far-reaching supply chains. A laptop computer, for instance, includes some 20 major parts (keyboard, battery, case, etc.) each containing multiple metals and chemicals sourced from multiple countries (Ciroth and Franze, 2011). The laptop's branded manufacturer may not know where certain raw materials or components come from. If suppliers can be located, they may either lack or refuse to share data on potentially significant impacts, such as toxic mining emissions. Often the only data available must be purchased from consultancies. All this means that ISO-compliant assessments still tend to be slow and costly. Despite ongoing advances in LCA software and databases, single product studies can easily take several months (before any expert review) and cost tens of thousands of dollars (Schatsky, 2012).

The dictum to measure what matters also means that not even ISO-compliant studies are performed according to a standardized method. Indeed, the standards themselves specify that no much method exists. This is partly because, as implied above, different measures matter for different types of products (i.e. laptops versus lettuce). They require different rules. It is also because LCA presumes that its practice should, up to a point, follow purpose. Exactly how one defines and assesses a product's ecological life depends on the 'intended application' of the results (ISO, 2006a, p. 9). Different clients and audiences need different information. But the ISO standards also do not prescribe a standardized method because their authors could not agree on one.[6] Their differences were relatively few, but fundamental. Ultimately they reached ISO-mandated consensus only by leaving certain parts of the final documents open to interpretation. Thus not only do the original disagreements persist, but also some of the concerns that made standards seem necessary in the first place. Put somewhat differently, seemingly arcane debates about problems of knowledge production are themselves a problem, threatening the credibility of both the knowledge itself and the field that produces it.

Mingling, up to a Point

Further discussion of LCA's methodological debates requires some context. Exactly what is 'uneasy' about this technique? Both meanings of the term apply, in that the work of assessing a product's life cycle is both difficult and a potential source of moral disquiet. Insofar as the latter type of uneasiness reflects the tension between commercial demands and practitioners' own political and ethical views, it is neither rare nor new in the world of corporate science (or beyond it) (Rasmussen, 2004; Jones, 2009). On the other hand, neither is it generic. LCA's uneasiness lies in the gap between the knowledge that corporations want about their products and what can credibly be supplied.

Although growing rapidly, the field of LCA remains small relative to most scientific and engineering disciplines. Its larger conferences still typically attract only several hundred people. Participants commonly refer to themselves as 'LCA people' and the 'LCA community'. And despite growing interest in LCA in Latin America and Asia (especially China), this community is still concentrated in northern Europe and North America. Many of the most active practitioners received degrees from the same graduate programs, whether in engineering, industrial ecology or one of the environmental sciences.

Yet despite its small size, the field of LCA has always included practitioners in diverse and often ambiguous professional positions. Many graduates from the top LCA programs enter consulting or industry. Many with academic positions also do corporate-sponsored research at least occasionally, especially if their salaries are soft-funded. Many consultants, meanwhile, keep a foothold in academia, which can help burnish their expert credentials. Like some industry-based LCA

practitioners, consultants regularly publish in the field's peer-reviewed publications, and present at its conferences.

Indeed, consulting or working for a large company can still provide unparalleled access to the sites, data and other resources needed to advance the field's methods, as well as an individual career. For example, a great deal of current LCA methodological development focuses on the specific challenges posed by agriculture and other 'bio-based' systems. Researchers employed by multinational food and forest product companies such as Unilever count among the major contributors (Canals *et al.*, 2011). Antonio, an Italian university-based consultant, described any purely academic research project as a likely 'non-starter, because most of the time it's virtually impossible to get good data if you don't have part of the industry on your side'. This is one reason why many university-based practitioners often collaborate or at least fraternize with their private sector peers. As Sofia, a Swedish academic explained, 'you often need a good rapport with companies, utilities, and authorities, so academics tend to mingle with industry and consultants quite a lot'.

Such mingling occurs at conferences, where the social programs are festive and well attended, and also in the online forums where practitioners exchange advice, opinions and sometimes data. But it does not overcome the different priorities that come with different professional roles. 'Lovely people', said Annika, a Swedish industry-based LCA practitioner about her academic peers,

> and of course they are better than me on LCA as such. But sometimes I say, 'OK, guys', but you're not in a company ... [and] it's my company that makes things happen in the world, not what you're doing in calculations.

Michael, a veteran Dutch consultant, spoke equally fondly of his university-based friends and co-authors, but noted that a typical academic assessment resulted in 'an unreadable thick report with a lot of options, and the final conclusion is the famous sentence: "it depends" ... somehow that doesn't really work for companies'.

The academics do want LCA to work for companies. Many say they chose to specialize in LCA precisely because it seemed the best way not only to think about industry's many environmental impacts—that is, scientifically, systemically and holistically—but also to address them. They would like to see more companies use LCA in decisions about product design, sourcing and marketing. But they also realize how companies' uses of LCA could, once again, threaten its own scientific authority. At an international LCA conference in 2011 one speaker, himself an industry practitioner-turned-academic, applauded the record number of industry participants. It showed that LCA's influence was finally spreading through the corporate world. Academics in the audience, meanwhile, grumbled that the conference had become 'too commercial'. In ostensibly scientific paper sessions, they said, too many talks amounted to little more than corporate public relations (or what one academic called 'industry crap').

Practitioners' ambivalence about the industry presence at conferences mirrors the pressures that LCA consultants, at least, face from industry clients. Once companies have invested time and money in studies, said Antonio,

> They will invariably try to push you toward some kind of conclusions . . . It can be a little tough to be impartial. Sometimes it's even hard to get the message across that it's not even possible to give a clear-cut answer. Typically that's not a message they want to hear. But we strive to do our best, to stay independent and credible. Because in the long term if you don't stay credible . . . then that backfires . . . because, paradoxically enough, industry wants to have this façade of credibility; [they say] 'we're commissioning this study because we want an independent point of view.' Then they'll go out of their way to try and make it partial. But through the backdoor . . . so that's the difficulty. But it's part of our job.

Pressures for partiality take two forms. First is the pressure to produce findings favoring a specific industry client. As Antonio observed, succumbing can backfire if greenwash accusations end up tarnishing the reputations of client and practitioners alike. But practitioners also face pressure to be partial to the demands of industry in general for quick and clear-cut answers. Here practitioners express more varied and ambivalent views. Michael, quoted earlier, shared companies' frustration with the 'it depends' conclusion. He was tired of writing reports that went unread. His consultancy had thus shifted toward interpreting LCA findings—what he called 'adding knowledge'—so that clients could understand and use them. But adding knowledge means, among other things, subtracting information that might overwhelm or confuse. It requires more judgment calls and translation than some practitioners find acceptable. 'So we are criticized', Michael acknowledged, because, 'we are playing a little on the edge of what science can do. But I think we need to; otherwise people can't make decisions'.

Antonio, though, responded to a comment about LCA's complicated findings by quoting Oscar Wilde: 'The truth is never pure and rarely simple'. It was 'the duty of the good practitioner', he said, to convey to clients that too much simplification was meaningless. 'We're all for simplified tools, but simplification doesn't have to mean the lack of a multifaceted answer'. In other words, for questions about which energy source, raw material or manufacturing process is environmentally superior to another, often the only honest answer really is 'it depends'.

While hardly new, concerns about industry pressures on LCA heated up with Walmart's founding of the Sustainability Consortium (TSC). TSC staff began appearing at LCA conferences to present their plans. They explained that the corporate membership needed a 'system' for measuring product sustainability that covered more than traditional LCA (i.e. social impacts) yet demanded much less time, money and expertise. It needed to be based on 'sound scientific methods', yet 'scalable' so that tens of thousands of product life cycles could

be assessed quickly and, given rapid innovation, repeatedly. TSC staff made clear that they needed help with this project. They organized special sessions to collect audience advice. They hobnobbed with the field's most prominent researchers.[7]

Practitioners' responses were mixed. Some found the whole idea ludicrous. As one said after hearing a consortium presentation, 'Take home message? TSC's in trouble!' Others saw it as Walmart's attempt to reinvent LCA to suit its own purposes. Yet amid these criticisms TSC recruited more than a few LCA practitioners. Several consultancies became dues-paying members, while academics agreed to review specific TSC-sponsored studies. Eventually entire departments signed on as 'university partners'. 'Everyone flocks there', said Johan, a German academic/consultant, who noted that his salary came entirely from soft funding; 'everyone sees it as a brokerage'.

Everyone includes practitioners who, in private conversations, criticize the typical corporate vision of sustainability as product eco-efficiency. They call for stronger government actions, such as higher energy taxes. These are views one might expect to hear from northern European practitioners whose own governments have traditionally prioritized environmental protection. But such views are also informed by research in LCA and related fields that warns of the possible 'rebound' effects of eco-efficiency improvements (Hertwich, 2005; Arvesen *et al.*, 2011; Druckman *et al.*, 2011). Carl, a Danish academic/consultant involved in TSC, saw the greening of corporate supply chains as entirely inadequate. However well intended, it 'will only change a tiny corner of the world'. His own research indicated the need for more radical measures, such as a government-enforced quota on global meat production. 'Until politicians start using their tools we won't really have big changes'. In the meantime, many LCA practitioners depended on corporate greening activities. 'That's where the money is', he added. 'Until there is money in working for governments, we work for industry'.

At least initially, TSC appeared an exciting place to do that work. Many of its member companies were big, influential and motivated. Individually they might offer LCA consultancies enormous business; collectively they could make LCA a standard tool for assessing and managing the environmental impacts of global supply chains. Via TSC, in short, LCA practitioners might really make a difference. That was the hope, anyway. After a few months of meetings and conference calls, Carl was impressed by the engagement of Walmart and other member companies. 'They have a lot of ambitions and they're really very open at the moment'. They had agreed, for instance, to sponsor several complete product LCAs, so that members unfamiliar with the technique could better understand what it entailed. Michael, the Dutch consultant, also saw TSC as a boon for the field. 'It has always been a supply-side market where [LCA] experts told industry, 'it's good for you, you should use it', he said. 'Now industry says, "come on, we need the tool". And that's what we were waiting for, for 20 years'.

In the Mud Pit

> For many professionals working in the sustainable development field, LCAs . . . are either seen as the vital DNA of sound sustainability decision-making, or a mud pit where techno-geeks wrestle it out—often inconclusively—over whose model better measures the real environmental footprint . . .
> —'The coming of age of life cycle assessment?' (Hohnen, 2012)

Within two years, TSC's enthusiasm for LCA had begun to fade. Jim, an American practitioner, admitted that many corporate members found it 'too complicated'. The sponsored studies (performed on relatively simple goods, such as orange juice and laundry detergent) had each taken months, indicating that full-scale LCA was impractical for companies with tens of thousands of products. Already the green business media was commenting on the consortium's slow progress (Makower, 2011).

The TSC's member companies, said Jim, also found LCA 'too fraught with conflict and dispute'. Some of the disputes witnessed by corporate members occurred between rival consultancies, who challenged each other's data reliability. But others revealed that basic methodological questions divided the field as a whole. For example, one of the oldest debates in LCA centers on the 'allocation problem': that is, how to assess the products of systems that make or process more than one thing (Heijungs and Frischknecht, 1998). Milk, for instance, may come from cows fed on soybean meal (a co-product of soybean oil), dairy farms that sell off bull calves and culled cows as meat and dairy processors that turn its cream into butter or cheese. An LCA of a liter of milk must determine how much of the environmental impacts incurred at each life cycle stage owe to the milk itself, rather than its co-products.

One common approach allocates the impacts according to physical properties, such as the mass or kilocalories of a dairy farm's output of milk versus meat. Another allocates them by economic value. The most complicated approach, known as system expansion, assesses all the co-products' impacts in relation to each other (Cederberg and Stadig, 2003). The different methods can reach dramatically different conclusions.

Twenty years ago, the authors of the ISO standards for LCA argued at length about allocation. Then as now, practitioners divided around questions of practicality as well as scientific validity. A common criticism of system expansion, for example, is that clients cannot understand, much less use, the results (Wardenaar *et al*., 2012). Yet ultimately the standards' authors designated this allocation method as preferable and the other two as permissible. While this diversity of approaches matters relatively little for academic or in-house industry studies, it poses an obvious problem when the aim is to 'footprint' many different goods. After all, most products of contemporary supply chains have co-products; even a simple apple may come from an orchard that also sells juicing fruits. Any

initiative aspiring to make the footprints of different apples comparable (much less those of apples and oranges!) must therefore address the allocation question.

Equally contentious is the related debate over 'attributional' versus 'consequential' LCA. The first and traditionally more common method estimates a product's current life cycle environmental impacts using average industry data. The second approach, by contrast, models possible consequences of a change in demand for that product, using marginal data (Thomassen *et al.*, 2008; Earles and Halog, 2011). These consequences could include shifts in energy sources, raw materials or production sites—all of which could improve or worsen a product's overall impact. Because it requires assumptions about market behavior, the consequential approach generates sizeable uncertainties. But applied to commodities such as beef, vegetable oil and corn ethanol, it has highlighted the potentially enormous emission increases caused by tropical deforestation in regions where production is increasing (Schmidt and Weidema, 2008; Plevin 2009; Cederberg *et al.*, 2011). The fact that consequential and attributional LCA can yield very different results means that, once again, a seemingly arcane debate is for many companies not a trivial one.

Consequential LCA has become more popular in recent years, at least among academics and a few consultancies (Zamagni *et al.*, 2012). Even those who never use consequential LCA agree that it asks important questions. But whether it can generate useful answers is another matter. Proponents argue that it is irresponsible to disregard a decision's potential consequences just because they are uncertain (Plevin *et al.*, 2014). Skeptics say it is irresponsible to deliver results based on assumptions that decision-makers cannot themselves assess (Suh and Yang, 2014). Consultants commonly express this view. 'If I was a university professor searching for the whole truth, I would go for consequential', said Erik, a Swedish food industry LCA consultant, 'But working in the context I actually work in, where I am supposed to give decision-makers the possibility to make decisions roughly in the right direction, I go for attributional. Because it works in that context'. Especially with smaller companies, he added, 'You can't have a global market model in your explanation. Because they will kick you out and won't listen to you at all'.

LCA is hardly the only field faced with the question of how much uncertainty and complexity to reveal. Climate science is another (Edwards, 2010). What is perhaps unique about LCA is how its commitment to completeness, as codified in the ISO standards, has pushed practitioners' model-building research into realms where their knowledge about products' cradle-to-grave impacts, they readily admit, is highly *in*complete. These include (among others) biodiversity, soil quality, landscape, nutrition and—especially contentious—social well-being.[8] Highly localized and in some cases not easily quantified, these impacts do not lend themselves to LCA's aggregative modeling. But for at least some practitioners, the goal of a 'deepened and broadened LCA' (Weidema *et al.*, 2009)

represents both an intellectual challenge and an ethical mandate; it recognizes that their models do not yet measure enough of what matters.

This goal also reflects LCA practitioners' efforts to keep up with the corporate world's own framing of supply chain sustainability in increasingly broad yet data-intensive terms. Companies can no longer simply report, say, a shrinking carbon footprint. They now want to know not only about their many potential supply chain risks but also, ideally, about whatever they might claim as positive environmental and societal impacts. And as always, companies want that knowledge to come in a quick, clear and easily communicable form. They want 'to be able to push a button', said Johan, the German consultant, and get numbers useful for corporate reporting, marketing and internal decision-making. All this increases the pressure on LCA practitioners, said Johan, 'to put something out there'—even in rough form. A journal article on newly developed guidelines for 'social LCA' captured this urgency with its subtitle 'just in time!' (Benoit *et al*., 2010).

When practitioners do present new methods, whether to make LCA more comprehensive, rigorous or 'streamlined', they provoke the kind of debate that in more purely academic settings would be considered unproblematic and indeed necessary for scientific progress (Gieryn, 1999). Within LCA it is also considered necessary, up to a point. 'There must be debate about these things', said Michael, the Dutch consultant. Unlike the more opaque (albeit more skillfully marketed) assessment methods offered by 'guru' consultancies, he said, in the LCA community 'you can shout at each other and try to improve'.[9]

But too much shouting could, of course, undermine LCA's scientific authority and broader adoption. For ultimately what companies and policymakers want from a scientific assessment tool such as LCA are 'plain facts', not debate (Arratia, 2011). Or more precisely, they want the experts to agree on how facts—in this case regarding products' lifelong environmental impacts—will be generated. Companies need such agreement to justify decisions and claims made about their products and suppliers, and to protect against accusations of greenwash. This was one of the lessons of the Diaper War. Since then, despite the ISO standards and the many ways LCA has been institutionalized and 'scientized' (Heiskanen, 1997), the basic problem has not changed, nor has the consequent danger. 'If we're down in the mud', as one American consultant put it, 'no one will listen to us'.

After three years, the Sustainability Consortium was indeed listening less intently to LCA debates. Instead it began developing more synoptic 'sustainability profiles' for different categories of products, from bread to bicycles. These describe the products' known hotspots, such as dairy farm emissions for milk; they also list the 'key performance indicators' by which Walmart and other retailer members can assess their suppliers' progress in addressing those hotspots (TSC Product Sustainability Toolkit™, n.d.). As a TSC staff member emphasized, the profiles still reference LCA studies. They still employ a life cycle perspective. But the priority was to 'make the information practical' for the corporate

members, not to make LCA itself the standard tool for assessing product sustainability. Some LCA practitioners, according to the TSC staff member, were pleased with this use of their work. But Carl, quoted earlier, had hoped that TSC would actively promote LCA research, not just reference it. This no longer appeared likely. 'It's a great disappointment', he said.

The consortium's change of course hardly spells the end of the LCA renaissance. Although not discussed in any detail here, governments also increasingly sponsor and draw on the field's research (Hellweg and Milà i Canals, 2014). European Union regulations now require lawmakers to employ 'life cycle thinking' (a less quantitative version of LCA) to justify waste management decisions (Lazarevic *et al.*, 2012). European governments have looked to LCA to guide policies covering everything from recycling and public transport to 'climate smart' food labeling (Richert, 2009; Fullana-i-Palmer *et al.*, 2011; Kliucininkas *et al.*, 2012). In the United States, both federal and California biofuel standards draw (albeit contentiously) on LCA (Plevin, 2009), as do waste and greenhouse gas emission reduction initiatives in other states. And in China, Chile and New Zealand, among other places, governments are backing LCA research and database development in order to assure that important export industries can, if required, report their products' environmental footprints (McLaren and Archer, 2011; Wang, 2011).

Especially in Europe, many practitioners see governments' interest in LCA as more significant than corporate initiatives such as TSC. Ultimately they see policy measures as the ones that matter, not consumers' or even retailers' efforts to buy greener goods. Policy settings sometimes offer greater opportunity for practitioners to explain complex and contingent ('it depends') findings (Fullana-i-Palmer *et al.*, 2011). Alongside the ongoing support of multilateral institutions such as the United Nations Environmental Program, government interest in LCA has bolstered not only research but also, arguably, the field's overall scientific stature. The top-ranked journal *Science*, for instance, gave unprecedented coverage to LCA in a June 2014 special issue on the sustainability of global supply chains (itself an unprecedented topic in *Science*) (Wible *et al.*, 2014). But even LCA research conducted under government auspices usually requires industry's input. Practitioners still need its data. For novel or rapidly changing products—biofuels, mobile electronics and nanotechnologies—they also need industries' own experts to help them understand and model product life cycles, which often stretch beyond the purview of any government.

Conclusions

Whatever the future of the LCA 'renaissance', supply chains are likely to remain a focus of corporate knowledge production. Companies' demand for the knowledge needed to demonstrate measurable progress toward supply chain sustainability is also unlikely to wane, if only because this broad goal subsumes the multiple risks

and uncertainties they must now manage. But producing this knowledge can be complicated on at least two levels. First, and as the history of LCA has demonstrated, it is expected to be scientific and objective, yet depend on the cooperation of companies with vested commercial interests—long term if not immediate—in the results. These interests may threaten the credibility of both the knowledge itself and the experts who produce it; they may also clash with the experts' own views about how that knowledge should be used. Exactly what these views are, where they come from and how they fit into broader ethical frameworks are, of course, empirical questions, and at a certain level familiar ones for STS ethnographers (Fortun and Fortun, 2005). This article has suggested that the very work of assessing global supply chains could foster skepticism and moral uneasiness about the types of incremental eco-efficiency improvements typically touted as progress toward sustainability.

Second, corporate knowledge production about global supply chains is complicated because so too is the subject matter. Even the supply chains of basic raw materials have complex, far-reaching and not easily measured impacts. Expert debates about how best to assess these impacts may try the patience of corporate clients, but they are not trivial. As supply chains account for a growing proportion of global economic activity, so do they affect the well-being of more people and places, for both better and worse. At the same time, as supply chains connect diverse buyers, suppliers and workforces (Tsing, 2009), they have also become the objects of research and measurement activities occurring in diverse sites and fields of expertise, many of them beyond company walls (Penders *et al*., 2009). How and how much these ways of 'knowing capitalism' (Thrift, 2005) actually change how capitalism works is, again, an empirical question. But as at least some of these fields gain recognition for contributing to 'the science of sustainable supply chains' (O'Rourke, 2014), more sustained attention from STS seems overdue.

Notes

[1]The work of Heiskanen (1997, 1999) is a notable exception.

[2]These include the industry-backed Global Roundtable for Sustainable Beef, the FAO's Livestock Partnership and the European Food Sustainable Production and Consumption Roundtable, comprising governments and trade groups.

[3]A 2012 survey of executives whose companies use LCA found that 'even the most fervent advocates' of the technique could not specify many ways it had changed, much less benefited, their business practices (Schatsky, 2012; on expectations, see Borup *et al*., 2006).

[4]The American Center for Life Cycle Assessment posted a PDF version on its web site for a few months in 2011, and then took it down at the request of the company. The report found that aluminum cans would be the best option only at a recycling rate of 87% or more; at the time the rate was only 5% (Darnay and Nuss, 1971, pp. 20, 48).

[5]All names are changed.

[6]Multiple interviewees who participated in the standards-setting process mentioned the persistent disagreements but acknowledged that the final document, as one Dutch practitioner put it, was 'better than nothing'.

[7]These quotations and events occurred during the LCA XI conference in Chicago, IL, on October 4–6.

[8]Social LCA aims to measure products' cradle-to-grave impacts on 'stakeholders' ranging from workers and local communities to consumers and 'society (national and global)' (Benoit *et al*., 2010, p. 161).

[9]The common example is the cradle-to-cradle approach developed and trademarked by the enterprising designer William McDonough (declared a 'Hero of the Planet' by *Time Magazine* in 1999) and chemist Michael Braungart. It differs from cradle-to-grave analysis in that the aim is to create entirely closed-loop, no waste systems at the company level and higher. Nike is a major client. LCA practitioners question the scientific premises of cradle-to-cradle but concede that McDonough and Braungart have marketed it well.

References

Adams, D. (1979) *The Hitchhiker's Guide to the Galaxy* (New York: Harmony Books).

Arratia, R. (2011) How life cycle assessment can align your stars. *Cut the Fluff*. Available at: http://www.slideshare.net/RamonArratia/how-life-cycle-assessment-can-align-your-stars (accessed 20 July 2014).

Arvesen, A., Bright, R. M. and Hertwich, E. G. (2011) Considering only first-order effects? How simplifications lead to unrealistic technology optimism in climate change mitigation, *Energy Policy*, 39(11), pp. 7448–7454.

Attorney General Task Force. (1991) *The Green Report II: Recommendations for Responsible Environmental Advertising* (Saint Paul, MN: Minnesota Attorney General's Office).

Barry, A. (2012) Political situations: Knowledge controversies in transnational governance, *Critical Policy Studies*, 6(3), pp. 324–336.

Baumann, H. and Tillman, A.-M. (2004) *The Hitchhiker's Guide to LCA* (Lund: Studentlitteratur).

Benoit, C., Norris, G., Valdivia, S., Ciroth, A., Moberg, A., Bos, U., Prakash, S., Ugaya, C. and Beck, T. (2010) The guidelines for social life cycle assessment of products: Just in time!, *International Journal of Life Cycle Assessment*, 15(2), pp. 156–163.

Berg, A. (2011) Not roadmaps but toolboxes: Analysing pioneering national programmes for sustainable consumption and production, *Journal of Consumer Policy*, 34(1), pp. 9–23.

Blowfield, M. and Murray, A. (2011) *Corporate Responsibility* (Oxford: Oxford University Press).

Borup, M., Brown, N., Konrad, K. and Van Lente, H. (2006) The sociology of expectations in science and technology. *Technology Analysis & Strategic Management*, 18(3–4), pp. 285–298.

Boustead, I. (1996) LCA—How it came about, *The International Journal of Life Cycle Assessment*, 1(3), pp. 147–150.

Bryson, J. (2002) Spreading the message: Management consultants and the shaping of economic geographies in time and space, in: J. Bryson, P. Daniels, N. Henry and J. Pollard (Eds) *Knowledge, Space, Economy*, pp. 157–175 (New York: Routledge).

Busch, L. (2007) Performing the economy, performing science: From neoclassical to supply chain models in the agrifood sector, *Economy and Society*, 36(3), pp. 437–466.

Canals, L. M. I., Azapagic, A., Doka, G., Jefferies, D., King, H., Mutel, C., Nemeccek, T., Roches, A., Sim, S., Stichnothe, H., Thoma, G. and Williams, A. (2011) Approaches for addressing life cycle assessment data gaps for bio-based products, *Journal of Industrial Ecology*, 15(5), pp. 707–725.

Cash, D., Clark, W. C., Alcock, F., Dickson, N., Eckley, N. and Jäger, J. (2002) Salience, credibility, legitimacy and boundaries: Linking research, assessment and decision making, KSG Working Papers Series, RWP02-046.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Jäger, J. and Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences*, 100(14), pp. 8086–8091.

Cederberg, C. and Stadig, M. (2003) System expansion and allocation in life cycle assessment of milk and beef production, *The International Journal of Life Cycle Assessment*, 8(6), pp. 350–356.

Cederberg, C., Persson, U. M., Neovius, K., Molander, S. and Clift, R. (2011) Including carbon emissions from deforestation in the carbon footprint of Brazilian beef, *Environmental Science & Technology*, 45(5), pp. 1773–1779.

Chandler, A. D. (1977) *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, MA: Harvard University Press).

Ciroth, A. and Franze, J. (2011) *LCA of an Ecolabeled Notebook: Consideration of Social and Environmental Impacts along the Entire Life Cycle* (Berlin: GreenDelta).

Cleveland, C. (1999) Biophysical economics: From physiocracy to ecological economics and industrial ecology, in: J. Gowdy and K. Mayumi (Eds) *Bioeconomics and Sustainability: Essays in Honor of Nicholas Georgescu-Roegen*, pp. 25–154 (Cheltenham: Edward Elgar).

Darnay, A. and Nuss, G. (1971) *Environmental Impacts of Coca-Cola Beverage Containers, Volume 1* (Kansas City, MI: Midwest Research Institute).

Dauvergne, P. and Lister, J. (2012) Big brand sustainability: Governance prospects and environmental limits, *Global Environmental Change*, 22(1), pp. 36–45.

Dooley, K. J. (2014) The whole chain, *Science*, 344(6188), p. 1108.

Druckman, A., Chitnis, M., Sorrell, S. and Jackson, T. (2011) Missing carbon reductions? Exploring rebound and backfire effects in UK households, *Energy Policy*, 39(6), pp. 3572–3581.

Earles, J. M. and Halog, A. (2011) Consequential life cycle assessment: A review, *The International Journal of Life Cycle Assessment*, 16(5), pp. 445–453.

Edwards, P. N. (2010) *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge, MA: MIT Press).

Ernst and Young. (2013) *Six Growing Trends in Corporate Sustainability*. Available at http://www.ey.com (accessed 24 July 2014).

European Commission (2013) *Product Environmental Footprint News*. Available at http://ec.europa.eu/environment/eussd/product_footprint.htm (accessed 14 June 2013).

Fiksel, J. (2013) Meeting the challenge of sustainable supply chain management, in: I. S. Jawahir, S. K. Sikdar and Y. Huang (Eds) *Treatise on Sustainability Science and Engineering*, pp. 269–89. (Dordrecht: Springer Netherlands).

Fink, P. (1997) The roots of LCA in Switzerland: Continuous learning by doing, *The International Journal of Life Cycle Assessment*, 2(3), pp. 131–134.

Fischer-Kowalski, M. (1998) Society's metabolism: The intellectual history of materials flow analysis, Part I, 1860–1970, *Journal of Industrial Ecology*, 2(1), pp. 61–78.

Fortun, K. and Fortun, M. (2005) Scientific imaginaries and ethical plateaus in contemporary US toxicology, *American Anthropologist*, 107(1), pp. 43–54.

Freidberg, S. (2013) Calculating sustainability in supply chain capitalism, *Economy and Society*, 42(4), pp. 571–596.

Freidberg, S. (2014) Footprint technopolitics, *Geoforum*, 55, pp. 178–189.

Fullana i Palmer, P., Puig, R., Bala, A., Baquero, G., Riba, J. and Raugei, M. (2011) From life cycle assessment to life cycle management, *Journal of Industrial Ecology*, 15(3), pp. 458–475.

Gereffi, G. and Lee, J. (2012) Why the world suddenly cares about global supply chains, *Journal of Supply Chain Management*, 48(3), pp. 24–32.

Gibbon, P. and Ponte, S. (2008) Global value chains: From governance to governmentality? *Economy and Society*, 37(3), pp. 365–392.

Gieryn, T. F. (1999) *Cultural Boundaries of Science: Credibility on the Line* (Chicago, IL: University of Chicago Press).

Goleman, D. (2010) *Ecological Intelligence: The Hidden Impacts of What we Buy* (New York: Broadway Books).

Greene, J. A. (2004) Attention to 'Details': Etiquette and the pharmaceutical salesman in postwar American, *Social Studies of Science*, 34(2), pp. 271–292.
Green Research. (2011, May 12) *New Research Finds torrid Growth in Life Cycle Assessment* [Press release]. Available at http://www.justmeans.com (accessed 14 June 2013).
Guinée, J., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T. and Rydberg, T. (2011) Life cycle assessment: Past, present, and future, *Environmental Science & Technology*, 45(1), pp. 90–96.
Gunther, M. (2009, July 13) Walmart to become green umpire, *The Big Money*. Available at http://005a5a4.netsolhost.com/articles/view/wal-mart-to-become-green-umpire (accessed 16 June 2013).
Haanaes, K., Balagopal, B., Kong, M. T., Velken, I., Arthur, D., Hopkins, M. S. and Kruschwitz, N. (2011) New sustainability study: The 'embracers' seize advantage, *MIT Sloan Management Review*, 52(3), pp. 23–35.
Hatanaka, M. (2010) Assessing rule-based governance mechanisms in an era of scientism, *Journal of Rural Social Sciences*, 25(3), pp. 141–159.
Heijungs, R. and Frischknecht, R. (1998) A special view on the nature of the allocation problem. *The International Journal of Life Cycle Assessment*, 3(6), pp. 321–332.
Heiskanen, E. (1997) The social shaping of a technique for environmental assessment, *Science Studies*, 11(1), pp. 27–51.
Heiskanen, E. (1999) Every product casts a shadow: But can we see it, and can we act on it? *Environmental Science and Policy*, 2(1), pp. 61–74.
Heiskanen, E. (2000) Translations of an environmental technique: Institutionalization of the life cycle approach in business, policy and research network. PhD Thesis, Helsinki School of Economics and Business Administration.
Hellweg, S. and Milà i Canals, L. (2014) Emerging approaches, challenges and opportunities in life cycle assessment, *Science*, 344(6188), pp. 1109–1113.
Henriques, A. and Richardson, J. (Eds) (2013) *The Triple Bottom Line: Does It All Add Up?* (New York: Routledge).
Hertwich, E. G. (2005) Consumption and the rebound effect: An industrial ecology perspective, *Journal of Industrial Ecology*, 9(1–2), pp. 85–98.
Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M. and Mekonnen, M. M. (2011) *The Water Footprint Assessment Manual: Setting the Global Standard* (Oxford: Earthscan).
Hohnen, J. (2012) The coming of age of life cycle assessment? *Guardian Sustainable Business*. Available at http://www.guardian.co.uk/sustainable-business/blog/ (accessed 14 June 2013).
Holusha, J. (1990, July 14) Diaper debate: Cloth or disposable? *New York Times*. Available at http://www.nytimes.com/ (accessed 14 June 2013).
Hughes, A. (2006) Learning to trade ethically: Knowledgeable capitalism, retailers and contested commodity chains, *Geoforum*, 37(6), pp. 1008–1020.
Hughes, A. (2007) Geographies of exchange and circulation: Flows and networks of knowledgeable capitalism, *Progress in Human Geography*, 31(4), pp. 527–535.
Humbert, S., Rossi, V., Margni, M., Jolliet, O. and Loerincik, Y. (2009) Life cycle assessment of two baby food packaging alternatives: Glass jars vs. plastic pots, *The International Journal of Life Cycle Assessment*, 14(2), pp. 95–106.
Hunt, R. G. and Franklin, W. E. (1996) LCA—How it came about, *The International Journal of Life Cycle Assessment*, 1, pp. 4–7.
ISO. (2006a) *ISO 14040: Environmental management — Life cycle assessment — Principles and framework* (Geneva: International Standards Organization).
ISO. (2006b) *ISO 14044: Environmental management — Life cycle assessment — Requirements and guidelines* (Geneva: International Standards Organization).
Jere, F. (2011) Auditing without borders, *Accounting, Organizations and Society*, 36(4–5), pp. 318–323.

Jones, P. (2009) Entrepreneurial science: The rules of the game, *Social Studies of Science*, 39(6), pp. 821–851.
Kaenzig, J., Friot, D., Saadé, M., Margni, M. and Jolliet, O. (2011) Using life cycle approaches to enhance the value of corporate environmental disclosures, *Business Strategy and the Environment*, 20(1), pp. 38–54.
Kanngieser, A. (2013) Tracking and tracing: Geographies of logistical governance and labouring bodies, *Environment and Planning D: Society and Space*, 31(4), pp. 594–610.
Kanter, R. M. (2009) *Wal-Mart's Environmental Game-Changer*. Available at blogs.hbr.org/kanter/2009/07/walmarts-environmental-gamecha.html (accessed June 16).
Katz, J. (2002) What a waste, *Regional Review*, Q1, pp. 22–30.
Kinchy, A. J. and Kleinman, D. L. (2003) Organizing credibility: Discursive and organizational orthodoxy on the borders of ecology and politics, *Social Studies of Science*, 33(6), pp. 869–896.
Kliucininkas, L., Matulevicius, J. and Martuzevicius, D. (2012) The life cycle assessment of alternative fuel chains for urban buses and trolleybuses, *Journal of Environmental Management*, 99, pp. 98–103.
Knorr-Cetina, K. D. (2010) The epistemics of information: A consumption model, *Journal of Consumer Culture*, 10(2), pp. 171–201.
Krozer, J. and Vis, J. C. (1998) How to get LCA in the right direction? *Journal of Cleaner Production*, 6(1), pp. 53–61.
Latour, B. and Woolgar, S. (1979) *Laboratory Life: The Construction of Scientific Facts* (Princeton, NJ: Princeton University Press).
Lave, R., Mirowski, P. and Randalls, S. (2010) Introduction: STS and neoliberal science, *Social Studies of Science*, 40(5), pp. 659–675.
Lazarevic, D., Buclet, N. and Brandt, N. (2012) The application of life cycle thinking in the context of European waste policy, *Journal of Cleaner Production*, 29–30, pp. 199–207.
Leeuw, B. (2008) The world behind the product, *Journal of Industrial Ecology*, 9(1–2), pp. 7–10.
Lehenkari, J. (2003) On the borderline of food and drug: Constructing credibility and markets for a functional food product, *Science As Culture*, 12(4), pp. 499–525.
Lehrburge, C., Mullen, J. and Jones, C. (1991) *Diapers: Environmental Impacts and Lifecycle Analysis. Report to the National Association of Diaper Services* (Philadelphia, PA: C. Lehrburger).
Little, A. D. (1990) *Disposable and Reusable Diapers: A Life-Cycle Analysis* (Cambridge, MA: Arthur D. Little Consultants).
Livesey, S. M. and Kearins, K. (2002) Transparent and caring corporations? A study of sustainability reports by the body shop and Royal Dutch/Shell, *Organization & Environment*, 15(3), pp. 233–258.
Loconto, A. (2010) Sustainably performed: Reconciling global value chain governance and performativity, *Journal of Rural Social Sciences*, 25(3), pp. 193–225.
Luehr, P. H. (1991) Guiding the green revolution: The role of the Federal Trade Commission in regulating environmental advertising. *UCLA Journal of Environmental Law & Policy*, 10(2), pp. 311–336.
Makower, J. (2009, August 10). The renaissance of life cycle thinking, *GreenBiz.com*. Available at http://www.greenbiz.com (accessed 14 June 2013).
Makower, J. (2011, September 10) The sustainability consortium: A status report, *Greenbiz*. Available at http://www.greenbiz.com/blog/2011/08/29/sustainability-consortium-status-report (accessed 16 June 2013).
McLaren, S. and Archer, R. (2011) Life cycle management for New Zealand food companies: a new way of doing business, *Food New Zealand*, December, pp. 20–23.
McNie, E. C. (2007) Reconciling the supply of scientific information with user demands: An analysis of the problem and review of the literature, *Environmental Science & Policy*, 10(1), pp. 17–38.

Meadows, D. (1990) The great disposable diaper debate, *Donella Meadows Archives*. Available at http://www.sustainabilityinstitute.org/ (accessed 14 June 2013).
Mirowski, P. (2011) *Science-Mart: Privatizing American science* (Cambridge, MA: Harvard University Press).
Odum, E. P. and Odum, H. T. (1959) *Fundamentals of Ecology*, 2nd ed. (Philadelphia, PA: Saunders).
O'Dwyer, B. (2011) The case of sustainability assurance: Constructing a new assurance service, *Contemporary Accounting Research*, 28(4), pp. 1230–1266.
Ordway, S. H. (1953) *Resources and the American Dream: Including a Theory of the Limit of Growth* (New York: Ronald Press Co).
Oreskes, N., Shrader-Frechette, K. and Belitz, K. (1994) Verification, validation, and confirmation of numerical models in the earth sciences, *Science*, 263(5147), pp. 641–646.
O'Rourke, D. (2014) The science of sustainable supply chains, *Science*, 344(6188), pp. 1124–1127.
Owen, D. (2008) Chronicles of wasted time?: A personal reflection on the current state of, and future prospects for, social and environmental accounting research, *Accounting, Auditing & Accountability Journal*, 21(2), pp. 240–267.
Penders, B. and Nelis, A. P. (2011) Credibility engineering in the food industry: Linking science, regulation, and marketing in a corporate context, *Science in Context*, 24(4), pp. 487–515.
Penders, B., Verbakel, J. M. A. and Nelis, A. (2009) The social study of corporate science: A research manifesto, *Bulletin of Science, Technology & Society*, 29(6), pp. 439–446.
Plevin, R. J. (2009) Modeling corn ethanol and climate, *Journal of Industrial Ecology*, 13(4), pp. 495–507.
Plevin, R. J., Delucchi, M. A. and Creutzig, F. (2014) Using attributional life cycle assessment to estimate climate-change mitigation benefits misleads policy makers, *Journal of Industrial Ecology*, 18(1), pp. 73–83.
Power, M. (1997) Expertise and the construction of relevance: Accountants and environmental audit, *Accounting, Organizations and Society*, 22(2), pp. 123–146.
Rasmussen, N. (2004) The moral economy of the drug company–medical scientist collaboration in interwar America. *Social Studies of Science*, 34(2), pp. 161–185.
Richert, A. (2009) Climate certification for the food chain: Launch of a Swedish initiative, Climate Smart Food Conference, Lund, Sweden, 23–24 November.
Rosenbloom, S. (2009, July 16) At Wal-Mart, labels to reflect green intent, *New York Times*. Available at www.nytimes.com (accessed 13 June 2013).
Sadler, D. and Lloyd, S. (2009) Neo-liberalising corporate social responsibility: A political economy of corporate citizenship, *Geoforum*, 40(4), pp. 613–622.
Schatsky, D. (2012) Life cycle assessment: A guide for sustainability and strategy executives, *2degrees*. Available at http://www.2degreesnetwork.com (accessed 14 June 2013).
Schleifer, D. and Penders, B. (2011) Food, drugs, and TV: The social study of corporate science, *Bulletin of Science, Technology & Society*, 31(6), pp. 431–434.
Schmidt, J. H. and Weidema, B. P. (2008) Shift in the marginal supply of vegetable oil, *The International Journal of Life Cycle Assessment*, 13(3), pp. 235–239.
Schneider, F., Kallis, G. and Martinez-Alier, J. (2010) Crisis or opportunity? Economic degrowth for social equity and ecological sustainability, *Journal of Cleaner Production*, 18(6), pp. 511–518.
Scrinis, G. (2013) *Nutritionism: The Science and Politics of Dietary Advice* (New York: Columbia University Press).
Seuring, S. and Gold, S. (2013) Sustainability management beyond corporate boundaries: From stakeholders to performance, *Journal of Cleaner Production*, 56, pp. 1–6.
Shapin, S. (1995) Cordelia's love: Credibility and the social studies of science, *Perspectives on Science*, 3(3), pp. 255–275.
Shapin, S. (2009) *The Scientific Life: A Moral History of a Late Modern Vocation* (Chicago, IL: University of Chicago Press).

Sisco, C., Chorn, B. and Pruzen-Jorgensen, Peder Michael. (2010) *Supply Chain Sustainability—A practical Guide for Continuous Improvement* (New York: UN Global Compact).
Sismondo, S. (2011) Corporate disguises in medical Science: Dodging the interest repertoire, *Bulletin of Science, Technology & Society*, 31(6), pp. 482–492.
Slaper, T. F. and Hall, T. J. (2011) The triple bottom line: What is it and how does it work, *Indiana Business Review*, 86, pp. 4–8.
Suh, S. and Yang, Y. (2014) On the uncanny capabilities of consequential LCA, *The International Journal of Life Cycle Assessment*, 19(6), pp. 1179–1184.
Sustainability Consortium. (2012) The consumer goods forum and the sustainability consortium announce global partnership to harmonize sustainability measurement [Press release]. Available at http://www.sustainabilityconsortium.org/consortium-news/the-consumer-goods-forum-and-the-sustainability-consortium-announce-global-partnership-to-harmonize-sustainability-measurement/ (accessed 14 June 2013).
Sustainability Index. (n.d.) [Web page]. Available at http://walmartstores.com/sustainability/9292.aspx (accessed 14 June 2013).
Teasley, H. (1976) Testimony, in: *Technology Assessment Activities in the Industrial, Academic, and Governmental Communities*, pp. 105–116. (Washington, DC: U.S. Government Printing Office).
Thomassen, M., Dalgaard, R., Heijungs, R. and Boer, I. (2008) Attributional and consequential LCA of milk production, *The International Journal of Life Cycle Assessment*, 13(4), pp. 339–349.
Thrift, N. J. (2005) *Knowing Capitalism* (London: Sage Publications Ltd).
TSC Product Sustainability Toolkit™. (n.d.) [Web page] Available at June 18, 2014 from http://www.sustainabilityconsortium.org/our-products/ (accessed 18 June 2014).
Tsing, A. (2009) Supply chains and the human condition, *Rethinking Marxism*, 21(2), pp. 148–176.
UNEP. (2012) Global outlook on sustainable consumption and production policies—Taking Action Together. Avalilable at http://www.unep.fr/shared/publications/pdf/DTIx1498xPA-GlobalOutlookonSCPPolicies.pdf (accessed 14 June 2013).
Vergez, A. (2012) Display of the environmental footprint of products: French developments in the food sector, Department of the Commissioner-General for Sustainable Development. Available at June 14, 2013 from http://www.developpement-durable.gouv.fr/IMG/pdf/ED64EN.pdf (accessed 14 June 2013).
Wang, H. (2011, October 5) Progress of Chinese Life Cycle Database (CLCD). Presentation, LCA XI (Chicago, IL).
Wardenaar, T., Ruijven, T., Beltran, A. M., Vad, K., Guinée, J. and Heijungs, R. (2012) Differences between LCA for analysis and LCA for policy: A case study on the consequences of allocation choices in bio-energy policies, *The International Journal of Life Cycle Assessment*, 17(8), pp. 1059–1067.
WBCSD/WRI (2011) Product life cycle accounting and reporting standard. World Business Council for Sustainable Development (WBCSD) and World Resources Institute (WRI). Available at http://www.ghgprotocol.org/standards/product-standard (accessed 14 June 2013).
Weber, C. L. and Matthews, H. S. (2008) Food-miles and the relative climate impacts of food choices in the United States, *Environmental Science & Technol*ogy, 42(10), pp. 3508–3513.
Weidema, B. P., Ekvall, T. and Heijungs, R. (2009) Guidelines for application of deepened and broadened LCA CALCAS. Available at http://www.leidenuniv.nl/cml/ssp/publications/calcas_report_d18.pdf (accessed 14 June 2013).
Wible, B., Mervis, J. and Wigginton, N.S. (2014) Rethinking the global supply chain, *Science*, 344, pp. 1100–1103.
Zamagni, A., Guinée, J., Heijungs, R., Masoni, P. and Raggi, A. (2012) Lights and shadows in consequential LCA, *The International Journal of Life Cycle Assessment*, 17(7), pp. 904–918.