The Social Shaping of a Technique for Environmental Assessment

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This article is about an evolving technique called environmental life cycle assessment (LCA) and about related programs and practices. Environmental product life cycle assessment[1] is a technique for evaluating the environmental impacts of products from "cradle-to-grave". LCA has been used to compare the environmental burdens of different products, for example plastic and paper bags, or biofuels and fossil fuels. It has also been used to identify the most important environmental impacts of a product, a system or an activity, for example in order to identify relevant criteria for environmental labeling or to prioritize environmental policy measures.

LCA has become increasingly popular both in business management and in public environmental policy. A professional community for LCA has emerged under the auspices of the Society for Environmental Toxicology and Chemistry (SETAC). International ISO standards for LCA are under development. Furthermore, the general life cycle framework is now frequently integrated into management and policy concepts such as 'integrated life cycle management', 'life cycle design' and 'total cost assessment'.

LCA is one of the many different approaches to environmental assessment, which include Environmental Impact Assessment (EIA) and Risk Assessment, among others. Each of these approaches has evolved out of its own historical context, and each has developed relatively independently of one another. The histories, social roles and development paths of such methods are interesting beyond their individual applications, because they provide a picture of how society's understanding of environmental problems and their solutions has developed. A close look at LCA from a social science perspective could also provide us with some ideas on where this development is leading.

Many members of the LCA community are sensitive to the social and political forces that shape the method. However, LCA has not yet been very systematically investigated from a social science perspective (although see Simmons, 1997). Nor will it be in this article. But I will try out some lines of thought from the social studies of science and technology (STS) tradition, and see how well they serve to conceptualize my own and others' practical experiences of the development and diffusion of LCA.

This article presents a number of views of the social shaping of LCA, each from a slightly different perspective. I will first look at LCA as a scientific method and then at LCA as a management tool. I will also look briefly at the employment of LCA in social controversies, and at the internal politics of LCA. I will then present LCA in the light of actor-network theory, and will argue that actor-network theory is a relatively solid representation of LCA that integrates many of the concerns that other conceptualizations raise. Finally, I will reflect on the potential value of these different views in understanding the social shaping of knowledge on human-environment interactions.

LCA as Science

Life cycle assessment (LCA) is currently defined (see SETAC, 1993) as a process to evaluate the environmental burdens associated with a product, process or activity. The evaluation should encompass all stages in the product life cycle: the extraction and processing of raw materials; manufacturing, transportation and distribution; use, reuse maintenance, recycling and final disposal. The energy and materials used and waste released to the environment in all these stages are identified and quantified. Furthermore, the impact of those energy and material uses and releases to the environment are assessed, and possibilities for improvements identified.

Current mainstream definitions of LCA emphasize the scientific aspects of LCA, and the existence of a standard method for conducting such studies (e.g., de Haes *et al.*, 1994, my italics):

> - LCA is a *comprehensive* tool, aiming at an analysis of all relevant types of environmental impact during the whole life- cycle
> - LCA is a *systems modeling* approach, employing *formalized analysis*, using well-developed *mathematical tools*
> - LCA is primarily a *quantitative analysis*
> - LCA is a *scientific* tool, as objective and transparent as possible
> - LCA must follow a strict procedure to ensure the quality of the study.
>
> The last point includes the reliability, accuracy, source of verification and representativeness of the data and the *sound application of the principles of LCA methodology.*

However, it was not always so. The origins of LCA-studies are usually located in the fuel cycle studies and energy analyses that became popular in the late 1960s and early 1970s. These were among the first studies that attempted to evaluate the total energy requirements of finished products by analyzing energy use at each stage in the production-consumption chain. Other precursors include mass-balance accounting in chemical engineering, and input-output analysis in materials balance economics (e.g., Kneese *et al.*, 1970; Ayres 1978). It is said that the first actual LCA-like study was an unpublished study conducted by the Midwest Research Institute in 1969 for the Coca Cola company on the resource and emission profile of alternative soft drink containers (Assies, 1992).

The first studies were followed by a number of resource and environmental profile studies in the US and energy analyses on packaging and other products in Europe (e.g., Lidgren, 1982). These studies were based on an analysis or accounting of the physical inputs and outputs of industrial processes. The novelty in the life cycle or resource and environmental profile analyses was the linking of multiple processes – from raw materials production to product disposal – and the calculation of system inputs and outputs per "functional unit", i.e. per one unit of the desired performance of the system (i.e., one wash of laundry, one ton-kilometer of freight, one m³ of space heated). However, comparisons on the basis of input-output data were (and remain) difficult, as different material flows vary greatly in environmental relevance, and the data are difficult to interpret.

Largely independently from the above-mentioned studies, interest in evaluations called "product-life-analysis" (PLA) and "Eco- balances" developed especially in German-speaking countries (see eg., Pedersen & Christiansen, 1992; Rubik 1995). Product-life- analysis was developed by a German research institute, and attempts to address social and economic, as well as environmental aspects (e.g., Osnowski & Rubik, 1987). Qualitative analyses addressing environmental and occupational health and safety risks of products and substances along the product life cycle were also initiated (e.g. Christiansen *et al.*, 1990). The starting-points and methods used in these studies varied considerably, and the boundaries toward other evaluation techniques (e.g., risk assessment, technology assessment, environmental impact assessment, materials accounting) were indistinct.

Until the 1980s, LCA-type studies remained relatively isolated and did not gain much public attention. A sudden interest in LCA-activities in the mid-1980s is attributed to various factors. Assies (1992) mentions a study by the Swiss Federal Laboratories for Materials Testing and Research (EMPA). The study presented a reasonable method for aggregating various emission using critical units of air and water, i.e. the necessary amount of the medium needed to dilute the emissions below the limits set by health standards. EMPA also published a database for packaging materials that was widely used. Another reason for the increased interest in LCA was public and legislative pressure on packaging waste (Virtanen, 1994). This gave rise to a spurt of LCA activities on packaging in various European countries, which was augmented by rising popular interest and environmentalist pressure on packaging and various consumer products.

However, criticism toward the methods used in LCA studies rose. In the US, this criticism was especially directed at the environmental claims made by industry and at the weaknesses of individual LCA studies (see, e.g., EAF, 1990). Some critiques were more of a scientific nature, and aimed at improving the methods used in LCA studies (Christiansen, 1991).

Starting in 1990, the Society of Environmental Toxicology and Chemistry

(SETAC) took the lead in LCA development. A very strong motivation for this effort was to salvage the credibility of LCA in the face of growing criticism and cynicism, largely due to conflicting findings of different studies, and claims that LCA findings are biased in favor of study sponsors' products. The lack of a systematic, transparent and reproducible methodology was identified as the key problem (see e.g., Assies, 1992; Poremski, 1992).

SETAC started to develop the LCA methodology by organizing numerous conferences, workshops and seminars on LCA methodology and case studies. These meetings brought together corporate, state and academic environmental scientists and engineers, and sought to forge a consensus on how LCA studies should be conducted. LCA articles also began to appear in scientific and professional journals (e.g. *Journal of Cleaner Production, Resources, Conservation and Recycling, Journal of Environmental Management*). In 1995, a peer-reviewed *Journal of Life Cycle Assessment* was announced. Thus, the science of life cycle assessment was born.

SETAC's development of LCA methodology reached one culmination point in the publication of the SETAC (1993) *Guidelines for Life- Cycle Assessment: A 'Code of Practice'* outlining a systematic framework for LCA studies. LCA was divided into the stages of ' goal definition and scoping', 'inventory analysis', ' characterization' and 'valuation'. This division aimed to make the LCA process more transparent as to the decisions made at the various stages (i.e. boundaries of the product system, allocation of inputs and outputs to products). It also clearly separated the input-output analysis (inventory) from the environmental assessment of the various inputs and outputs, and this, again, from the subjective valuation of the significance of the various environmental problems that they contribute to. Furthermore, the 'Code of Practice' included guidelines for reporting, publication and critical review. SETAC certainly deserves to be congratulated: largely thanks to its efforts, LCA studies have become more transparent and systematic and better documented.

Another result of the 'scientification' of LCA is that life cycle assessments have become increasingly complex and time-consuming to conduct (e.g. Schaltegger, 1997). Most of the published articles on LCA (even quite a few in the SETAC case study symposium reports) focus not on results, but on different kinds of methodological problems. These include, e.g., the difficulty of determining how far back in the product life cycle it is necessary to extend the study (e.g. Pedersen Weidema, 1994), and how different methods for the impact assessment and valuation of the different environmental burdens lead to different conclusions (e.g., REFORSK, 1992). And despite the great strides in better reporting discipline and better data quality, the methods used are still widely divergent, and the findings still tentative and inconclusive (Guinee *et al.*, 1993). Users of LCA findings frequently illustrate their experience with the saying: *"still confused, but on a higher level."*

SETAC's work has also strongly influenced the international standardization of LCA, e.g., within the International Standards Organization's (ISO) committee working on standards for environmental management. The ISO standards will probably be adopted as European standards, and will thus carry quite a lot of weight in Europe. LCA is a curious standardization item, as it is certainly not a test-method, and unequivocal procedures or interpretation rules can simply not be set out. It is part of a new trend in standards, system standards, that set out general guidelines for the development of systems to 'build in' and maintain the quality of a system (cf. the ISO quality standards series). Thus, the standardization procedure is moving LCA out of the domain of scientific methods, and in to the world of environmental management tools.

LCA as Environmental Management

The view of LCA as a management tool is not a new one. However, it has gained momentum over the past five years. Today, almost all the – incredibly numerous – textbooks on environmental business management include at least one chapter on LCA. Some even raise the life cycle perspective to the level of a guiding principle for environmental business management (Linnanen *et al.*, 1994; Niskala & Mätäsaho, 1996). For example, Richard Welford's textbook (1995: 12) presents LCA in the following way[2]:

> Life cycle assessment is an under-used, under-researched and under- rated tool of analysis. By forcing us to track a particular product (or service) from cradle to grave it forces us to widen our environmental dimensions. It is central to approaches that go beyond traditional environmental management techniques and in its purest form it will begin to evaluate wider ecological impacts and other issues consistent with the attainment of sustainability.

With this elevating thought in mind, it is encouraging to look at statistics from the recent Nordic Environmental Business Barometer (Lovio & Kuusisto, 1996). Almost half of the Finnish large industrial companies in the sample report that they perform LCAs on their products. The sample also included a group of SMEs. Even in this group, one-fifth report that they are conducting LCAs. Finland is no exception: similar findings have been obtained in the other Nordic countries, as well as in large corporations in the rest of Europe, the US and Japan (Ryding 1994; Karlsson 1995).

Various surveys of what firms are using or expecting to use LCA for (Finnveden & Lindfors, 1992; de Raad, 1993; Ryding, 1994) usually report the following applications:

- product improvement, product development, product analysis in general
- strategic decision-making
- marketing, public information
- supplier evaluation
- dealings with authorities,

although the main emphasis varies from one survey to another. Increasingly, product and process development are put forth as the most important application.

With this background, I was somewhat surprised at my own and colleagues' findings on the use of LCA in seven large Finnish firms (Heiskanen *et al.* 1995). Only one of the firms, a paints and coatings manufacturer, had plans for using their LCA results in product development. On the basis of life cycle considerations, product development was now considering ways to reduce the use of substances that are not harmful as such, but cause large environmental burdens at the production phase (e.g.,

TiO_2). The other firms reported that their LCA studies had mainly served to verify their previous conceptions, or that they conducted LCAs mainly for the purpose of submitting the data to their clients. No concrete product or process improvements were directly attributed to LCA findings. And on the other hand, the case studies conducted by my colleague with two manufacturers of electronic appliances reported that they had developed concrete product improvement guidelines in spite of not having conducted quantitative LCAs.

The findings can be reflected on using the framework of knowledge utilization, originally developed by Weiss (1979), and elaborated on by many authors, also in the context of environmental issues (see, e.g., Michaels, 1993). It seems that the original, simple view of knowledge utilization, called the knowledge-driven model by Weiss (1979), is not the most prevalent way of using LCA studies in environmental management.

Instead, the most frequent kind of LCA utilization that people we interviewed mentioned was more of a 'conceptual' or 'enlightening' nature (cf. Weiss, 1979). People stated that they had used LCA in "orienting themselves toward environmental problems related to products" and "viewed things in a new way". Especially, the significance of various non-process-related and non-point source issues, such as distribution, were mentioned. LCA was also reported as enhancing the importance of quality management. In addition, the use of LCA had influenced the firms' supplier relationships. As suppliers were asked for LCA data, they were also indirectly informed that their environmental performance was being monitored. Many informants also believed that simply collecting the data asked for would be educating for their suppliers (Heiskanen *et al.*, 1995).

More generally, there are, of course, some reports of very concrete, knowledge-driven applications of LCA in product development (e.g., PROMISE, 1994). An increasing supply of LCA software-tools and databases are making LCA studies easier to conduct. PC-based software tools bring to the product developer's fingertips the whole of the product life-cycle on a computer screen. However, the figures gained through the use of ready-made LCA packages are still not conclusive: the different packages hold different data and use varying methods (e.g., Sweatman, 1996). Furthermore, it has been recently argued that this kind of LCA use may be misleading: the databases containing aggregated, industry-average data have little connection with a specific firm's suppliers' environmental performance (Schaltegger, 1997). The uncertainty and lack of precision of the data used leads to the situation that the "total error of an LCA can easily become larger than the calculated differences of ecological impacts between products" (Pohl *et al.*, 1996).

Thus, it seems justified to listen to the authors who claim that the most important use of LCA in environmental management is not direct, but diffuse. The results, themselves, remain contestable and inconclusive. However, the involvement in LCA provides managers with new perspectives on their products, and new forms of co-operation with other individuals and organizations. The process of conducting an LCA study is more educational than the result (e.g.

Baumann, 1995). In an article on LCA standardization, one of the environmental managers interviewed (Will Gibson of Cummins & Barnard, quoted in Business and the Environment, 1996: 2) puts it as follows:

> I think it is important to get a (draft international standard (document out, because one of the main strengths of LCA, at least initially, is as a pedagogic vehicle. The LCA process should bring to the table the various disciplines within the company (accountants, engineers, designers, environmental managers, top management) and really begin the process of integrating environmental costs into the fabric of business

The first two, 'mainstream', conceptualizations of LCA, 'LCA as a science' and 'LCA as a management tool' would seem at first sight well matched. It is easy to argue that management, especially environmental management, should be based on sound scientific principles. Yet there are conflicts between these two roles, these two faces of LCA.

The determined attempt to 'scientify' LCA has aimed at legitimizing its practice and results through the authority of science. At the same time, the attempt to construct a universal, de-contextualized methodology has emptied the technique of much of its local meaning and usefulness in decision-making (Schaltegger, 1996; Groenewegen, 1997). The 'standard methodology' and 'industry average data' produce figures that informative, but extremely abstract for a manager in a specific context. Because it has been believed that the appeal to science would provide legitimacy, local stake holders have been largely ignored. An extreme case is the attempt to construct universal 'valuation methods', i.e. techniques that assign weights to different environmental problems irrespectively of the decision-maker's location, context or own values.

According to the 'received view', science aims at universality, reproducibility and transparency. Findings should be based on comprehensive, reliable data; the work should be carried out by trained experts, and the value of research should be evaluated by the scientific community. New findings should continually correct earlier ones (e.g. Webster, 1991). However, the most valuable contributions that LCA seems to have made to environmental management to date seem totally unrelated, even contrary, to the scientific aspects of LCA. It is very educational for a firm's staff to collect environmental data in their own firm and from suppliers, and to search for solutions together with managers from other functions. It is a progressive step for product designers to consider what happens to products when they are disposed of, and try to prevent waste. The process of LCA is obviously enlightening and insightful. On the other hand, the original problem for which LCA was developed, and eventually, the scientific community involved – of finding robust and incontestable solutions to environmental problems – remains unsolved.

LCA in the Employment of Public Controversies

One of the original expectations of LCA was that it would help to solve public controversies about products (e.g. de Oude, 1992). Controversy management has also been one of the most visible corporate applications of LCA. Here, the consequences have often been successful (from the point of view of the initiator). However, the main consequence of the use of LCAs in controversies has not been the arrival at a generally accepted solution (cf., e.g., Nelkin, 1979; Wynne, 1982). Rather, LCA has been used to redefine the debate by setting it in a new technical or political context.

There are numerous examples of cases of LCA in the employment of environmental controversies about substances and products. Products such as disposable packaging and diapers, plastics, paper based on primary fibers and chemicals, such as phosphates, have been defended against bans, environmental taxes, recycling quotas and public loss of image in general. Increasingly, LCA is also called to the aid when environmental policy runs into unsolvable controversies. In the following, two examples of this role of LCA are recounted: the European phosphate controversy and the Finnish beverage packaging case.

The Phosphate Controversy

Phosphates in detergents have been the subject of environmental debate since the 1970s. The debate culminated in the late 1980s in bans on phosphates in laundry detergents in some European countries. The market also reacted to the intensification of the debate, which corresponded with the growing public awareness and green consumerism at that time. Very swiftly, phosphate-use in detergents decreased. Finally, environmental labeling criteria, such as those of the Nordic Environmental Labeling Scheme, were established and gained influence, and criteria for the EU-wide Ecolabel came under preparation. The first (1992) Nordic environmental labeling criteria for laundry detergents precluded the use of phosphates. Phosphate manufacturers were naturally not enthusiastic about these developments, as they were swiftly losing one line of business. Many kinds of arguments were employed in countering criticism toward phosphates. Among them, and increasingly importantly, comparative life cycle analyses of phosphates and alternative builders were used.

The Phosphate Report conducted by Landbank Environmental Research and Consultancy and commissioned by Albright & Wilson, Ltd is one example of this use of LCA. The objective of the study (Landbank, 1993) is stated as follows:

> It is a received truth that the use of phosphates as a builder in detergent formulations is damaging to the environment and that the damage caused by nutrient enrichment of the water environment – the phenomenon known as eutrophication – can be avoided by replacing phosphates with other compounds, notably zeolite A and its co-builder, polycarboxylic acid or PCA. This study has been undertaken to test the truth of the proposition that phosphate-free powders are "greener", or friendlier to the environment, than those containing phosphates when assessed over their complete life cycles.

The authors of *The Phosphate Report* compiled life cycle inventory data on the environmental loadings of two builder systems, sodium tripolyphosphate (STPP) and zeolite-A as well as of the co-builder PCA (polycarboxylic acid). Furthermore, they conducted a washing test determining that varying amounts of the co-builder PCA are required to reach the same soil removal performance, so a larger amount of PCA was need for the zeolite-A product. Impact assessment of the inventory data was carried out using a Delphi-panel of British scientists. As a result, weights were attached to the inventory parameters. Thus, a single score for the impact of both builder systems was obtained. The score for STPP was 107, while zeolite A/PCA scored at 110.

It was concluded that, when equivalence of performance is taken into account, there is no real difference between the environmental impacts of the two competing builder systems. In the improvement analysis, three issues were identified to be significant: (1) the discharge of phosphogypsum waste from the phosphoric acid plant in Morocco (2) CO_2-emissions from energy use throughout the life cycle and (3) the contribution made by detergent phosphates in waste waters to eutrophication in fresh waters. The report recommended a program for the recycling of phosphogypsum waste, a program of energy conservation and increased renewable energy use in the manufacture of STPP and the recovery and reuse of phosphate from waste waters by the means of new phosphate-stripping technologies.

The report was followed by a number of national studies, including the *Nordic Phosphate Study*, with Nordic data and experts. In the end, the defense was successful, at least in one sense. Phosphates were returned to grace by allowing a small amount of phosphates in the formulation of the revised (1995) Nordic environmental labeling criteria for detergents, as well as in the criteria for the EU Ecolabel.

The Finnish National Beverage Packaging LCA

European national beverage packaging studies (e.g., Sundström, 1990; Pommer & Suhr, 1993; BMU, 1993; Mälkki *et al.*, 1995) are another example of the use of LCAs in environmental controversies. The studies have their history in a long-standing debate and legislative history on beverage packaging in Europe. Many European countries have tried to combat the increasing amount of one-way beverage packaging, and ensuing waste, in many different ways. For example, in Finland, there has been a variable excise on beverages discouraging the use of disposable packaging. As a result, refillable packaging have held a major share of the beer and soft-drinks market.

In the early 1990s, the retail trade and the metal packaging industry started to protest against this system. It was considered an impediment to increased import of beer, and storage of returned bottles was considered an extra cost to the trade. It was suggested that the tax be removed from aluminum cans, for which a recycling system could consequently be developed. It was pointed out that in Sweden, the recycling of aluminum cans was well instituted with continually growing return rates. On the other side, environmentalists and the breweries spoke up for the existing, well functioning refillable bottle system. This discussion coincided with Finland's EU membership, including harmonization of product excises, break-up of the state alcohol monopoly and the adoption of the EU Packaging and packaging waste directive, so the Ministry of Environment had a lot on their hands.

As in many other European countries, a public policy LCA on beverage packaging was initiated. The study was commissioned to the Energy Unit of the national Technical Research Centre, VTT, in co-operation with the Association of Packaging Technology and Research. All the relevant industries as well as the Ministry of Environment were involved in the steering group of the study. Furthermore, a 'scientific follow-up group' including representatives of environmental research and interest was instituted for the study. The study took a year and a half, and was very comprehensive and thorough, including both inventory and impact analysis, as well as the demonstration of valuation of the impacts using seven different methods. The study did not result in a clear conclusion on the relative environmental merit of the systems:

> There is hardly a clear winner in the comparison between different packaging options ... the differences are usually relatively small and alternative from one emission category to another (Mälkki *et al.*, 1995: 54).

This did not impede the different involved parties from drawing conclusions. The press-release of the Finnish Federation of Brewing and Soft-Drinks Industry was titled: "Refillable packages are a good alternative", while the Federation of Finnish Trade and Commerce headlined its press release with: "The beverage can is a good alternative". In spite of these somewhat differing interpretations, a decision was finally reached. The problem was reformulated so as to compare the aluminum can, not with the refillable bottle, but with one-way bottles for imported beer. Here, the recyclable aluminum can was considered environmentally superior, and the packaging surcharge on cans was lowered, on the provision that a recycling system with adequate recovery rates is instituted.

Although the results of the study probably did not manage to change anyone's opinion, the study clearly served as such a momentous trial that it emptied everyone's ammunition reserves. Lindblom & Cohen (1985) have aptly described this type of use of research as an arbiter or judge. Often, political decision- making finds itself bogged down by fundamental disagreement on the status of the problem, i.e., conflicting interpretations and representations of the problem and of its factual basis. New research evidence is unable to convince the disagreeing parties. However, they may sometimes agree on the decision to allow research to serve as a judge: "let the one with the best numbers win." Science is used as the flip of a coin may be used to solve a disagreement.

The national European beverage packaging LCAs are one example of the political employment of LCA. Here, science is used to resolve a conflict according to a given set of rules. However, even the beverage packaging example does not prove that the authority of science is strong enough to solve disputes. Although LCA as science managed to serve as a judge in the beverage packaging case, the judge was not trusted to work alone. The fact that a sizable steering group and a 'scientific advisory group' (more of an interest group, actually) were instituted – and held altogether about thirty meetings – is one example of how closely the judge was watched.

The Inherent Politics of LCA

While the previous chapter looked at the external politics that LCA can be employed for, I would like to maintain that there are politics embedded in the method itself. Winner (1985) is one protagonist of an approach called the "politics of technology", which illustrates how technologies can embody – and as physical artifacts, perpetrate – specific forms of social relations. As an example, he presents the design of bridges in Long Island, New York, which were designed to prevent low-income, black people using public transit from visiting the island. He also maintains that there are inherently political technologies that require the creation and maintenance of a particular set of social relations, such as the organizational forms required by railways.

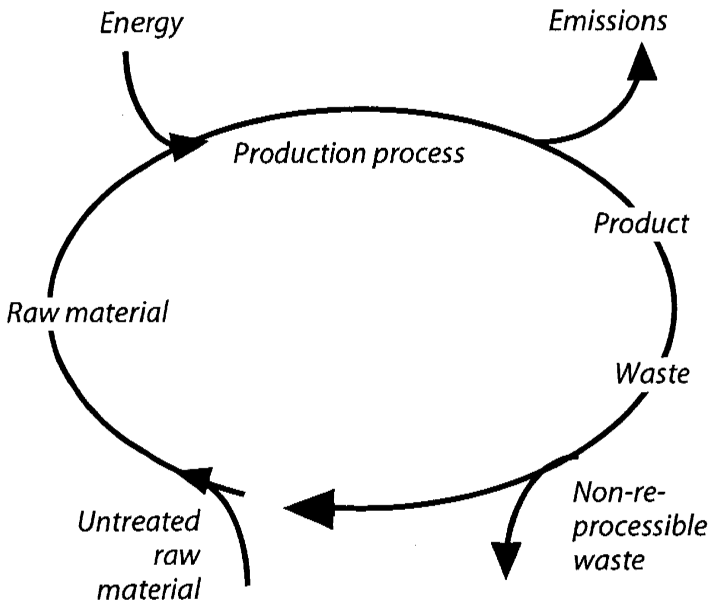
One of the 'politics' of LCA that provides much food for thought is how LCA affects the way we view responsibility for environmental problems. For example, Jamison (1992:149) has depicted the current global market economy as a place in which responsibility for environmental problems is so diffused among the different actors that: "Today, we face the possibility that the global environment may be destroyed, yet no one will be responsible". Life cycle thinking could be seen as an antidote for this diffusion of responsibility, as it shows the different actors the indirect consequences of their actions. Product designers learn that their choice of raw materials influences the environmental burdens of mining operations in South America as well as the emissions from landfills a hundred years from now. Consumers learn that their product choices have an impact on energy use in agriculture, industry and distribution.

The chain of responsible actors may turn out to be surprisingly long. For example, Essunger & Tell (1991) list 28 different actor groups that influence the environmental burdens of construction materials. These actors include everyone from the materials' producers and their chemical engineers, through janitors and residents to waste management operators and municipal authorities. This view of the product life cycle emphasizes the internal control of each actor group, co- operation among actors at each life cycle stage and the importance of continuity between the different stages. Following this line of thought, life cycle thinking has given rise to many co-operative and holistic concepts such as "life cycle management" (e.g., Hass and Groenewegen, 1996), "environmental co-makership" (Cramer & Schot, 1993), "integrated life cycle management" (Pesso, 1994) and "joint responsibility" (EAP, 1992), among others.

Thus, LCA seems to have a good mission. It tells us that we all are responsible. The basic life cycle model – starting with raw materials extraction and linking it with production, distribution, consumption and disposal – is intuitively simple and insightful (e.g., Figure 1). It is now frequently used in educational material, where it is used to teach people a more responsible attitude toward consumption and the use of products.

Yet the simplified model, however intuitive and insightful, is a construct that does not exist as such in the 'real world'. In reality, there is seldom a clear beginning or end to a product's life cycle. To extract coal, you need steel, and to make steel, you need coal. And there certainly

Figure 1. The simplified, pedagogical life cycle model (Finnish Ministry of Environment, 1995).



are no clear-cut boundaries between one product and another. Most industrial processes produce more than one type of product, products are not distributed individually, and there certainly isn't one separate landfill for each product. This leads to one of the central problems of life cycle assessment studies: the allocation of environmental burdens to products. Thousands of pages of LCA literature address this issue, to which there is no simple solution. How should resource use and emissions be divided between co-products: at the refinery, in distribution, at the landfill? How are the environmental burdens of primary materials production (e.g., aluminum) divided between primary and secondary (i.e. recycled) materials?

Often, the issue of allocation is discussed as a technical question within the LCA community, but an increasing number of authors are also addressing its social implications (Heijungs, 1994; Frischknecht, 1994; van Engelenburg & Nieuwelaar, 1994). One striking example is the extraction of precious metals. Two products are produced, the precious metal and stone and gravel for road construction. If the environmental burdens of this process are allocated on a mass basis, an overwhelmingly large share of the environmental burden goes to the gravel, making, e.g., gold or platinum very clean products (e.g., Maillerfer, 1996). Thus, decisions made in the LCA process may influence our views of what environmental burdens different products (and people) are responsible for.

LCA studies have also – at least until

very recently – been fairly selective in allocating responsibility to different life cycle stages. Until very recently, LCA comparisons of energy production alternatives have disregarded the environmental burdens of construction, maintenance and disposal of the production facilities (Miettinen *et al.*, 1995). The mining industry is one of the largest sources of environmental pollution and disruption in many countries, but the environmental burdens of mining are very often omitted on the basis of lacking data (e.g., Ayres, 1994). Other frequent blind spots in LCA studies include impacts on biodiversity, incidental emissions and spills, as well as emissions from landfills (e.g., Heikura, 1993). These issues are often discussed in the 'goal definition and scoping' section of LCA studies (which very few people read). The resulting environmental loadings do not appear in the 'results' section of LCA studies – which are, notwithstanding, seen as comprehensive representations of the environmental impacts of products.

Users also easily forget that, in LCA studies, the chain of responsibility for environmental impacts is constructed through material and energetic links. For example, a window-frame made of tropical wood is responsible for the environmental impacts of the processes that deliver materials of energy for the production, distribution, use or disposal of the window-frame (Guinee, 1992). One could envisage other kinds of links to the window-frame, as well. Felling the trees requires a road. The road opens up the forest for homesteaders, who cut more trees and clear more forest for farmland, which in turn leads to erosion. But such links are not part of the standard LCA methodology (see, e.g., Heikura, 1993).

Although the life cycle framework looks simple, it is still extremely complex, and often leads to inconclusive results. Depending on the location, on the boundary and allocation choices and on the valuation of different environmental problems, we get very different results. On the basis of such findings, it is difficult to present any clear prescriptions for action – in fact, the findings often challenge existing prescriptions, such as "prefer renewable energy sources" or " reduce, reuse, recycle". LCA results are often so inconclusive and conflicting that it is impossible to say – if you look at more than one study – that any single line of action, e.g., the recycling of glass containers, is always good for the environment (see, e.g., Boustead, 1989; Vertanen, 1993). Thus, LCA has contributed to the general trend of relativization of environmental issues and their solutions (cf. Yearley, 1991; Cholakov, 1994; Welford, 1997). From clear-cut black and white issues, we have shifted to a world that is shades of gray. It is increasingly difficult to classify materials, activities or products as environmentally harmful or environmentally clean.

Some aspects of this process may well serve to increase people's sense of responsibility. Nowadays, the environmental impact of a yogurt jar or of a university are taken as perfectly legitimate environmental issues. Pollution is not only due to heavy industries 'out there', but to everyday decisions of ordinary citizens. In other aspects, the blurring of environmental issues and their solutions may also lead to less feeling of responsibility. LCA has managed to contribute to that, as well. By distributing responsibility, it also allows responsibility to be shifted – sometimes long enough for it to dissolve and disappear. It is easy to locate the most significant environmental burdens at someone else's doorstep. For example, LCA studies on packaging often emphasize the environmental impact of transportation (e.g., Boustead, 1989). When we turn our attention to road-traffic, we learn that it already bears its external costs (Velhonoja, 1996). So, are we in the best of possible worlds?

As the politics of LCA are self-contradictory, it is difficult to envisage them simply as the result of the interests of one group or another. Actually, some aspects seem to be due to accidents. LCA has its background in chemical engineering and materials accounting. As the application of LCA has extended, their way of – unconsciously –construing environmental responsibility has remained embedded, and been transported far beyond the factory gates or the boundaries of energy analysis. Thus, CO_2 emissions and a firm's responsibility for its suppliers are highlighted in LCA studies, while impacts on biodiversity, or investors' responsibilities for how their money is used, are downplayed.

It seems to be fairly easy to find examples that demonstrate the socially constructed and political nature of LCA use. And if we believe what proponents of the "strong program" in STS studies are saying (e.g. Bloor, 1979), it seems that these elements cannot be exorcised from LCA, whatever efforts are made. Relativist approaches to science studies suggest that the project of scientific reform of LCA that SETAC is running will not succeed in solving all the problems in LCA. The record of current controversies in other environmental contexts points in the same direction (e.g., Salter 1988; Yearley, 1991; Väliverronen, 1996).

A number of people in the LCA and environmental management field are, in fact, currently suggesting that stake holders should be more closely involved in the planning and supervision of LCA studies (Welford, 1995) and that stake holder concerns should be addressed to a greater extent (Annema, 1992; Doig & Ellison, 1995). This is easy to argue for in the case of studies serving public policy. But there is no reason to limit the argument to public studies. Actually, there are even stronger reasons for individual firms to involve stake holders in their LCAs. It isn't even necessary to draw on moral or ethical arguments in this context. The more a company is seen as a profit-maximizer, the more important the stake holders are. Environmental pressures on a firm come from stake holders, e.g., authorities, consumers or environmentalists. The firm's solutions to environmental problems should be of the kind that stake holders accept them, preferably so that consumers are so impressed by them that they are prepared to pay extra for the improved products.

Although the social constructivist perspective of LCA use in controversies seems to provide a useful lesson for LCA practitioners and environmental managers, the findings are relatively old hat for science and technology studies. I think the analysis of the internal politics of LCA is more interesting from the point of view of understanding the social shaping of environmental assessment methods. Here, we have not one comprehensive interest (i.e., e.g., 'industry interests') but multiple, local, very partial interests – and maybe sometimes even just accidents – which continually shape the way we view human interaction with the environment. And there is no one direction in which LCA is taking us: some aspects extend our sense of responsibility, while others limit it. Many scholars speak of the path-dependence of the development of technologies (Arthur, 1989; David, 1989), and the development of LCA seems to be a case in point.

Another aspect that a look at the 'external' and the 'internal' politics of LCA reveals is the crucial role of problem formulation. The 'solutions' that LCA arrives at are not solutions in the traditional, rational-decision-making sense. Rather, they are reformulations of the problem, involving new combinations of actors and objects that are considered relevant. These reformulations are, of course, continually open to new reformulations. Thus, critique of the narrow scope of LCA, in a similar vein as presented in the previous chapter, has been recently voiced by environmental NGOs and some 'green business' representatives. For example, the lack of consideration for ethical issues in LCA, such as animal or worker welfare, has been challenged (Simmons, 1997). Thus, the 'peace' won through the use of a scientifically authoritative method such as LCA is continually an uneasy one.

LCA as an Actor-Network

On the basis of the previous examples, a number of issues seem to congeal that are relevant for the future of LCA, perhaps of environmental assessment in general. Obviously, the truths, solutions and insights that LCA produces are socially constructed. But they are constructed in a rather complex way. Mere reference to interests is insufficient (besides, interests are social constructs, too). The internal politics of LCA have their own role in the development, and these internal politics are self-contradictory, involving both environmentally "progressive" and "reactionary" elements. Many actors are involved – e.g., industry, environmental scientists, regulators and environmental organizations – but the development of LCA cannot be accounted for in terms of their power games. Both a simple, "in science we trust" realism, and a strong form of social constructivism seem too monolithic to account for the real-life experience.

One approach that looks promising in this context is actor-network theory, most visibly promoted by Latour (1987; 1988; 1993) and Callon (1987). This perspective takes a critical stance on both socially deterministic and technologically deterministic explanations. It goes as far as to claim that technology and society are inextricably interwoven, and have been so since the dawn of civilization (Latour, 1993).

Latour (1993: 4) illustrates this view of the relationship between technology and society with the use of an example concerning the debate on the free sale of guns in the US. The debate is very similar to the previous discussion on LCA (no offense meant to LCA by the analogy). "Guns kill people", say those who try to control the free sale of guns. "People kill people, not guns", say the members of the National Rifle Association. In the first type of account – to use Latour's very fluent words – "each artifact projects a script that can take a grip of any passer-by and force him to play a role in its story". In the NRA version, in contrast "the gun is such a neutral carrier of will that it adds nothing to the action, playing the same role as an electrical conductor, goodness or wickedness flowing through it effortlessly". Latour attempts to split this difference by exploring the different meanings of technological mediation.

The first meaning of technological mediation, according to Latour, is (1) *goal translation.* While technologies seldom totally determine the goals of human beings (e.g., suddenly make trigger-happy gunmen out of pacifists), technologies translate goals. In the gun example, and undefined desire to hurt becomes a more defined aim to shoot. And human users translate the goals and capabilities of technologies, making technologies-in-use different, much more potent, than technologies-by-themselves. Each person who uses the technology increases its power and shifts its domain of application (see Latour, 1988). In the LCA case, this first type of mediation could be illustrated by a case in which the general aim to improve the environmental profile of paper products – which could mean many things – is translated into the aim of reducing CO_2-emissions along the whole (physical) product life cycle (see, e.g., Virtanen & Ingman, 1993; Kärnä, 1993). Or the specific goal of reducing phosphates in detergents is replaced with the more general goal of improving the life cycle environmental performance of washing powders. And LCA is transformed, as it becomes – a little – more of a technique for pulp and paper industry or phosphate studies.

When a person takes into use a technology, this produces a new agent made by a fusion of the two. This is Latour's second definition of mediation: (2) *composition*: "the prime mover of the action becomes a new distributed and nested series of practices whose sum might be made, but only if we respect the mediating role of all the actants in the list" (Latour, 1993: 8). The new agent born through the co-operation of humans and technologies has capabilities beyond the sum of its constituent components. A human being, when part of such a network, is authorized by the others. Thus a person without an LCA, expressing a view on how environmental problems should be solved, is just expressing an opinion. When part of the LCA-community, consisting of people, databases, software tools and publications, the view expressed is much more than an opinion, it is a fact.

This brings us to Latour's third meaning of mediation, (3) *reversible black-boxing.* This form of mediation refers to the whole process in which individual components, such as humans and technologies, are first combined, then form a new goal, making the technology into a obligatory passage point for this goal. Subsequently, the components are aligned, the whole item is black-boxed, and finally punctualized. This sounds complex, but Latour's example is simple: the slide projector. It has become an (almost) obligatory part of a lecture, as the goal of speaking has been turned into the goal of presenting (speaking + showing). Competent lecturers know how to use the slide-projector, and the mechanics of the projector are so much of a black box that they are considered totally irrelevant to the lecture itself. Only when the projector breaks down, we go backwards along this sequence – sometimes far enough to give up the goal of presenting, and revert to speaking, if the projector cannot be repaired or replaced.

Needless to say, this is what is happening with LCA all the time. Users of LCA are trying to close the black box and use the technique as part of their larger program of action: product design, environmental policy or political lobbying. If someone is not happy with what they are doing, they may try to open the black box, ask things like "why are impacts on biodiversity excluded, why is only the physical life cycle considered, what is the reliability of your data?"

Latour's fourth category of mediation is called (4) *delegation.* It refers to the use of techniques and artifacts as actors representing humans. Latour's example is a road bumper, a 'sleeping policeman' that forces reckless drivers to slow down. Latour presents this as exemplifying the claim that technology is not only language, but matter: "nonhumans act too, and displace goals". I don't know if LCA can be considered as being 'inscribed in matter', but the examples presented in sections titled "LCA as an environmental management tool" and "LCA and controversies" certainly are illustrations of some kind of a delegation. In supplier relations, LCA serves as the buyer's aide, delving into the specific emissions of suppliers and reminding them that their environmental performance is continually being scrutinized. In public policy, it serves as the judge of how various kinds of packaging should be taxed, or of whether we should ban PVC.

From the perspective of actor-network theory, we could describe LCA as a nascent actor-network. Developers of LCA have taken bits and pieces, such as 'mass-balance', 'process analysis' and 'environmental science' and put them together into a method that spans time and space (cf. Latour, 1987: 'immutable and combinable mobiles'). Using LCA, a product designer can, by clicking some icons on his computer, see how a new design for a coffee-percolator would affect the global climate. Or the phosphate industry can summon new arguments, from far beyond the local fresh waters, and bring them to bear on the local debate on phosphates in detergents.

To make the method credible, a scientific, universal and reproducible process for conducting LCA is needed. This is the black box that the LCA community is attempting to close. At the same time, the LCA community has expanded: chemical engineers and energy analysts have been joined by environmental consultants, technical research institutes with specialized LCA departments, and by environmental scientists, corporate environmental managers and environmental authorities. Besides the community of LCA practitioners, the actor-network currently encompasses LCA users, such as third-party systems for environmental labeling, product designers, politicians, and environmental educators.

In spite of the success of the network-building up until this stage, the black box of LCA refuses to stay closed (cf. Callon, 1986). Critics are continually opening it and trying to push in things like biodiversity, working conditions, environmental burdens of mining operations or animal welfare. And the inconclusive findings (which are all the more cautious the more intricate the LCA methodology gets), themselves, keep the lid of the black box continually half off.

Undaunted by the gaping condition of the LCA black box, many people have been happily enrolled as LCA users, because LCA has managed to translate their – very different – interests into its own language. Corporate engineering specialists are happy, because they find a language for environmental debates which they consider rational and businesslike. A number of other industry representatives are happy, because LCA can be used to defend their products against environmental attacks. Environmental authorities are happy, because they see in LCA a way to involve business and the general public in environmental improvement, and in taking a broader responsibility for their actions.

However, for the final breakthrough, a much broader network needs to be enrolled. The network of LCA is far from being as complete as the network created by Pasteur in the *Pasteurization of France* (Latour, 1988). One missing link are consumers, the people who are supposed to buy the environmentally improved products and make environmental improvement profitable. LCA-based improvements are often invisible in the final product (e.g., the use of cleaner energy sources in production), and environmental aspects are thus credence characteristics of products. The buying public has become somewhat wary of environmental claims, even scientific ones (see e.g. Niva, *et al.* 1996). Environmental labeling, i.e., representing the environmental improvements on the product in the form of symbols of text, is becoming part of the LCA network, but the path is slow and conflict-ridden (see e.g., Heiskanen *et al.*, 1995; Simmons, 1997).

To complete the LCA network of power, actors and knowledge, work also remains to be done in re-embedding the disembedded knowledge that it produces (Schaltegger, 1996; Groenewegen, 1997). Producing knowledge requires the distancing of oneself from the object to be known, the creation of many orders of abstractions, each abstraction subtracting a large number of the details that make up the real-life context of the phenomenon. While much is gained, something is lost. For environmental management, while the process of conducting an LCA study is rewarding and educative, the 'truths' that it produces are of little use. The translation back from the universal to the local is as large a problem as the translation from the local to the universal (Latour, 1987: 247-257; 1988). In the development of LCA, this problem remains largely unaddressed, as yet.

Actor-network theory's solution to the re-embedding problem is the creation of a social organization that corresponds to the universal model to be applied (e.g., creating conditions on the farm that correspond to Pasteur's laboratory). This is exactly what is being attempted in the LCA case in programs titled 'product chain management', 'integrated life cycle management', etc. Some members of the LCA community have believed that such networks would emerge naturally as a by-product of life cycle thinking (e.g. Pesso, 1994), but in practice, it seems that quite a lot of active network-building is needed (Groenewegen *et al.*, 1996; Groenewegen, 1997; Heiskanen *et al.*, 1997).

LCA in public controversies attempts to solve problems by reformulating them, by translating the goals into new ones. However, because the black box remains ajar, many people are needed to sit on it to keep it even temporarily closed. These people are the stake holder panels, the Delphi panels of eminent scientists, the industry steering groups and the environmentalist critics. Sometimes their weight is enough to keep the lid on for long enough to reach a solution that is in the study initiator's interests (as in the phosphate case). At other times, relevant actors keep jumping off the lid, e.g., environmentalists decide to boycott a discussion forum on LCA use in eco-labeling (see Simmons, 1997). Thus, yet again, actor-network theory points to the need to extend and consolidate the network of actors. However, in the case of actor-network theory, this means more than political maneuvering or increased citizen access to LCA, as the actor-network consists of natural and man- made objects, as well as human beings. Besides "taming" the environmentalists and the business managers, the LCA community would also have to "tame" the mines and the forests, the factories and the shops that are the non-human actors in the product life cycle.

Concluding Reflections

In the previous account, I have tried to sketch some – by no means all – aspects of the social shaping of an environmental assessment method called LCA. It seems that social factors influence the content and interpretations of LCA, but LCA also influences our world-views and social and economic practices. To simply portray LCA as a science or as a management tool that is used to identify environmental priorities is naive. Even the managerial uses of LCA vary, and extend far beyond the rational model of decision making. LCA may be used as a conceptual framework or as a way of communicating between different organizations or organizational units. It may also be used tactically, to deflect criticism or to close debates.

The other extreme, to portray LCA only as a new battleground of economic and political interests seems a bit paranoiac. Many current accounts of the social construction of science, technology and professional practices show that the interests that shape these knowledge systems are often local and multiple (Bijker *et al.*, 1987). No single actor (or conflict) is able to determine the outcome, which is shaped also by the unintended consequences of action and by practical constraints (see, e.g. Leskinen, 1994). Thus, we could conclude that the development of LCA, too, is open-ended.

Actor-network theory seems to be a framework that manages to integrate quite a few of the observations rising from the various other perspectives. It is not a causal theory, and thus no final causes or consequences can be pointed out. However, actor-network theory allows for a relatively consistent description of what is happening in the LCA case. This description gives rise to some thoughts on the role of environmental science and environmental assessment techniques in environmental management and policy:

1. The issue of local versus universal knowledge seems is highlighted in the case of LCA. LCA emphasizes the fact that locally made decisions have broader, regional and global impacts. Thus, some form of knowledge transformation, combination and transfer is required. This is one rationale for LCA the science. Yet practical experiences of LCA

in management show that local and specific aspects of LCA are more relevant for management than the abstract, universal methods. The process of re-embedding and re-contextualizing the disembedded, abstract knowledge produced by LCA is as large a task as the original abstraction and disembedding. "Think globally, act locally" is not as easy as it sounds.

2. The socially constructed nature of knowledge about the environment is easy to demonstrate. Social constructivism presents a good argument in favor of more public involvement in environmental decision-making. But this is a two-edged sword: taking a very relativist approach to science in environmental issues does away with the specific features of environmental problems and reduces them to a run-of-the-mill of political conflict. Science is the basis of our awareness of environmental problems such as global warming, acidification and ozone depletion. If science is totally reduced to politics, the legitimacy of any claims about the environment is lost. Thus, public participation is not the panacea to all problems in environmental decision-making: a more intricate understanding of the specifics of the social shaping of environmental knowledge is needed.

3. A mere reference to interests is insufficient to account for the development and use of LCA. It seems that actor-network theory is applicable in this case: interests are not irrelevant, but they are transformed by the technique used. The development of techniques for environmental assessment – at least of LCA – are path-dependent. The only way to see where they are going is to "follow the actors, wherever they go" (Latour, 1987). In the case of LCA, the actor-network is still incomplete. To fully implement the improvements that LCA helps to identify, the social organization translating the LCA model into practice is lacking. Thus, experiments in "product chain management" and "value chain collaboration" are worth following, as are environmental labeling and extended producer responsibility. They are not merely new organizational forms. They are also embodiments of a new way of conceptualizing human-environmental interactions.

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Notes

1. In this context, the term life cycle refers to the physical life cycle of a product from raw materials to waste (not to the temporal life cycle of a product generation, as in economics or marketing).
2. To be fair and accurate, the quotation that I picked out continues with the following reservation: "However, in its most narrow form LCA may be used to mislead an already sceptical audience and therefore we need carefully to establish the scope and boundaries of any analysis."

References

Annema, J. A.
1992 "Methodology for the evaluation of potential action to reduce the environmental impact of chemical substances". In: Life cycle assessment. SETAC Leiden workshop report 2-3 December. Society for Environmental Toxicology and Chemistry, Brussels.
Arthur, B.
1989 Competing technologies, increasing returns, and lock-in by historical events. Economic Journal 99, (March): 116-131.
Assies, J. A.
1992 "State of the Art". In: Life Cycle Assessment. SETAC Europe Workshop Report, 2-3. December, Leiden, 1991. Society for Environmental Toxicology and Chemistry, Brussels.
Ayres, R. U.
1978 Resources, Environment and Economics. Applications of the Materials/Energy Balance Principle. New York: John Wiley and Sons.
Ayres, R. U.
1994 Life Cycle Analysis: A Critique. INSEAD R&D Working papers. Working papers 94/11/EPS.
Baumann, H.
1995 Decision-Making and Life Cycle Assessment. Chalmers University of Technology, Technical Environmental Planning. Report 1995: 4. Göteborg, Sweden.
Bijker, W., Hughes, T.P. and Pinch, T. (eds.)
1987 The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. Cambridge, Mass: MIT Press.
Bloor, D.
1979 Knowledge and Social Imagery. London: Routledge and Kegan Paul.
BMU
1993 Ökobilanz für Getränkeverpackungen. Umfassendes Zahlenmaterial für Frischmilch und Bier vorgelegt. Bundesministerium für Umweltschutz, Pressemitteilung 21.9.1993.
Boustead, I.
1989 Energy and Packaging: a Report for the Industry Council for Packaging and the Environment. Open University, East Grinstead, UK
Business and the Environment
1996 "LCA Standards Move Forward but Key Issues Remain". Business and the Environment VII (3), Supplement section on ISO 14 000 Update: 1-6.
Callon, M.
1987 "Society in the Making: the Study of Technology as a Tool for Sociological Analysis". In Bijker, W., Hughes, T. and Pinch, T. (eds.): The Social Construction of Technological Systems. New Directions in the Sociology and History of Technology. Cambridge, Mass: MIT Press.
Christiansen, K.
1991 "Possibilities and Limitations to life cycle analysis". In Packaging and the Environment - Policies, Strategies and Instruments. University of Lund: Department of Industrial Environmental Economics, Lund.
Christiansen, K., Grove, A., Hansen, L.E., Hoffman, L., Jensen, A.A., Pommer, K. and Schmidt, A.
1990 Miljøvurdering af PVC og udvalgte alternative materialer. (Environmental evaluation of PVC and selected other materials). København: Miljøstyrelsen, Miljøprojekt no. 54.
Cramer, J. and Schot, J.
1993 "Environmental Comakership Among Firms as a Cornerstone in the Striving for Sustainable Development". In. Fischer, K. and Schot, J. (eds.) Environmental Strategies for Industry. International Perspectives on Research Needs and Policy Implications. Washington, D.C.: Island Press.
de Haes, U., Bensahel, J.-F., Clift, R., Fussler, C.R., Griesshammer, R., Jensen, A.
1994 Guidelines for the Application of Life-Cycle Assessment in the European Union Ecolabelling Programme. Final report on the first phase by the Groupe des Sages set up by the European Comission. Leiden: Commission of the European Union.

de Oude, N.
1992 Life Cycle Assessment – The Regulatory Framework. In Life-Cycle Assessment. Workshop Report 25-26 June, 1992, Potsdam, Germany. Brussels: Society of Environmental Toxicology and Chemistry.
de Raad, I.
1993 Toepassingen van de levencyclusanalyse. (Applications of life cycle analysis). Centrum voor Milieukunde Rijksunivesiteit Leiden, CML notitie 13.
David, P.
1989 A paradigm for historical economics: path-dependence and predictability in dynamic systems with local network externalities. High Technology Impact Programme, Center for Economic Policy Research, Stanford University.
Doig, A. and Ellison, J.
1995 "Validating and Completing the Model: Integrating Social Science Data Collection Methods and Life Cycle Assessment". 5th SETAC-Europe Conference, Copenhagen.
EAP
1992 Commission of the European Union. Towards Sustainability – An Environmental Union Programme of Policy and Action in Relation to the Environment and Sustainable Development. Brussels: Commission of the European Union.
EAF
1990 Solid Waste Action Paper no. 1. Science or PR? Environmental Action Foundation, Washington, D. C.
Essunger, G. and Tell, W.
1991 "Bygvarors miljöpåverkan" (Environmental impact of construction materials). I: Sex studier av varornas miljöpåverkan. (Six studies on the environmental impact of products). Stockholm: Miljödepartamentet Ds 1991: 9.
Finnish Ministry of Environment
1995 National Environmental Policy Programme 2005. Helsinki: Ministry of Environment.
Finnveden, G. and Lindfors, L-G.
1992 "LCA in Different Applications - Demands and Expectations". In: Product Life Cycle Assessment - Principles and Methodology. Nordic Council of Ministers, Nord 1992: 9.
Frischknecht, R.
1994 "Allocation: an Issue of Valuation?" In Proceedings of the European Workshop on Allocation in LCA. Leiden, 24-25 February, 1994. Society for Environmental Toxicology and Chemistry, Brussels.
Groenewegen, P.
1997 "Technology and the Environment: The Management of Life Cycles". Presentation at Interdisciplinary Environmental Management Workshop, University of Tampere, April 25-26, 1997.
Groenewegen, P., Reijnen, E. and Goverse, T.
1996 Social Organisation of Crop Protection Technology for Sustainable Food Production Chains. Paper presented at the 5th International Research Conference of the Greening of Industry Network, November 24-27, 1996, Heidelberg, Germany.
Guinee, J.
1992 LCA of Window Frames. In Life-Cycle Assessment. Workshop Report 25-26 June, 1992, Potsdam, Germany. Brussels: Society of Environmental Toxicology and Chemistry.
Guinee, J., de Haes, U., Huppes, G.
1993 "Quantitative Life Cycle Assessment of Products: 1. Goal Definition and Inventory." Journal of Cleaner Production 1, 1: 3-13.
Hass, J. and Groenewegen, P.
1996 "Strategic Co-operation and Life Cycle Analysis", in Groenewegen, P., Fischer, K. F., Jenkins, E. G. and Schot, J. (eds.): The Greening of Industry Resource Guide and Bibliography. Washington, D. C.: Island Press.
Heijungs, R.
1994 "The Problem of Allocation: Some Complications". In. Proceedings of the European Workshop on Allocation in LCA. Leiden, 24-25 February, 1994. Brussels: Society for Environmental Toxicology and Chemistry.

Heikura, P.
1993 Elinkaarianalyysit. Metodologiaa ja kriittisiä kommentteja. (Life cycle analyses. methodology and critical comments) Suomen luonnonsuojeluliitto. Tutkimusraportteja 3/1993, Helsinki.
Heiskanen, E., Kärnä, A. and Lovio, R.
1995 Tuotelähtöinen ympäristönsuojelu. (Product-oriented environmental protection). Helsinki: SITRA 143.
Heiskanen, E., Kärnä, A., Munch af Rosenschöld, E., Pripp, L and Thidell, Å.
1997 "Environmental Product Improvement: Key Actors and Information Flows in the Product Chain." Paper presented at the 4th Nordic Business Environmental Management Network Conference, June 5-7, 1997 Tuohilampi, Finland.
Karlsson, R.
1995 LCA i Japan. (LCA in Japan). Stockholm: Avfallsforskingsrådet/Swedish Waste Research Council. AFR-Report 65.
Kneese, A. V., Ayres, R. U. and D' Arge, R. C.
1970 Economics and the Environment. A Materials Balance Approach. Baltimore and London: John Hopkins Press
Landbank
1994 The Phosphate Report. Landbank Environmental Research and Consulting, London.
Latour, B.
1987 Science in Action. How to Follow Scientists and Engineers Through Society. Bristol: Open University Press:.
1988 The Pasteurization of France. Harvard, MA. and London: Harvard University Press.
1993 "On Technical Mediation". The Messanger Lectures on the Evolution of Society. Cornell University, April 1993.
Leskinen, J.
1994 Tiede, teknologia ja kulutustutkimus. (Science, technology and consumer research). Helsinki: Kuluttajatutkimuskeskus, Julkaisuja 2/1994.
Lidgren, K. (ed.)
1982 Energy in Packaging and Waste. Wokingham: Van Nostrand, Reinhold.
Lindblom, C. and Cohen, D.
1985 Usable Knowledge. Social Science and Social Problem Solving. New Haven and London: Yale University Press.
Linnanen, L., Boström, T. and Miettinen, P.
1994 Ympäristöjohtaminen. Elinkaariajattelu yrityksen toiminnassa. (Environmental management. Life cycle thinking in business). Juva: Weiling+Göös.
Lovio, R. and Kuusisto, P.-C.
1996 "Studies of Environmental Competitiveness of of Finnish Companies in the mid 1990s." in Ulhoi, J. P. and Madsen, H. (eds.) Industry and the Environment. Practical Applications of Environmental Management Approaches in Business. Aarhus: The Aarhus School of Business.
Maillerfer, C.
1996 "Allocation of Environmental Interventions", in Schaltegger, S. (ed.): Life Cycle Assessment (LCA): Quo Vadis? Basel: Birkhäuser.
Mälkki, H., Hakala, S., Virtanen, Y. and Leppänen, A.
1995 Life Cycle Assessment of Environmental Impacts of Finnish Beverage Packaging Systems. Helsinki: Association of Packaging Technology and Research 43.
Michaels, S.
1993 "Weighing Science and Politics in Local Decision Making About Hazards". Knowledge and Policy 6, 2: 3-22.
Miettinen, P., Virtanen, Y. and Svensson, G.
1995 "Environmental Impacts of Renewal and Maintenance of Energy Production Facilities", in Virtanen, Y., Miettinen, P. and Junttila, V. (eds.) Energy Issues in Life Cycle Assessment. Helsinki: COMETT II UETP-EEE, TEK and VTT.
Nelkin, D.
1979 Controversy: Politics of Technical Decisions. New York: Sage.
Niskala, M.and Mätäsaho, R.
1996 Ympäristölaskentatoimi. (Environmental accounting). Porvoo and Helsinki : WSOY and Suomen Ekonomiliitto.

Niva, M., Heiskanen, E. and Timonen, P.
1996 Environmental Information in Consumer Decision-making. Helsinki: National Consumer Research Centre, Offprints 7/1996.
Osnowski, R. and Rubik, F. (eds.)
1987 Produktlinienanalyse. Bedürfnisse, Produkte und ihre Folgen. Köln: Kölner Volksblatt Verlag.
Pedersen Weidema, B.
1994 "Experiences from a Life Cycle Study of Two Food Products." SETAC 2nd Symposium for Case Studies. Programme and Abstract Book. Brussels: Society of Environmental Toxicology and Chemistry.
Pedersen, B. and Christiansen, K.
1992 "A Meta-review of Product Life Cycle Assessment." In Product Life Cycle Assessment --Principles and Methodology. Nordic Council of Ministers: Nord 1992: 9.
Pesso, C.
1994 An Overview of the Life Cycle Approach to Product/Process Environmental Analysis and Management. OECD: Paris.
Pohl, C., Ros, M., Waldeck, B. and Dinkel, F.
1996 Imprecision and Uncertainty in LCA. In: Schaltegger, S. (ed.): Life Cycle Assessment (LCA): Quo Vadis? Basel: Birkhäuser.
Pommer, K. and Suhr, M.
1993 Miljømaessig kortlaegning af emballager til øl. (Environmental review of packaging for beer). November 1993. RENDAN A/S, København.
Poremski, H.-J.
1992 "Draft Code of Practice." In: SETAC, Life Cycle Assment: Workshop Report 25-26 June 1992. Potsdam, Germany. Brussels: Society for Environmental Toxicology and Chemistry.
PROMISE
1994 Eco-design: acht voorbeelden. (Eco-design: eight examples). Delft: TNO Produktcentrum.
REFORSK
1992 Miljöbedömning af Förpackningsutredningens slutsatser. (Environmental evaluation of the conclusions of the Packaging Enquiry). Malmö: Stiftelsen REFORSK. FoU nr 71.
Rubik, F.
1995 "Produktbilanzen. Zwischen konzeptioneller Entwicklung und struktureller Herausforderung". In. Hellenbrandt, S. and Rubik, F. (Hrgs.). Produkt und Umwelt. Anforderungen, Instrumente und Ziele einer ökologischen Produktpolitik. Metropolis-Verlag, Marburg.
Ryding, S.-O.
1994 International Experiences of Environmentally-Sound Product Development Based on Life-Cycle Assessment. Avfallsforskningrådet/Swedish Waste Research Council. AFR-Report 36.
Schaltegger, S.
1997 "Economics of Life Cycle Assessment: Inefficiency of the Present Approach." Business Strategy and the Environment 6: 1-8.
SETAC
1993 Guidelines for Life Cycle Assessment. A 'Code of Practice'. Society for Environmental Toxicology and Chemistry, Brussels.
Simmons, P.
1997 "The Construction of Environmental Risks: Eco-Labelling in the European Union." Pp. 234-255 in Sulkunen, P., Holmwood, J., Radner, H. and Schulze, G. (eds.): Constructing the New Consumer Society. Houndsmill and London: Macmillan.
Sundström, G.
1990 Energiförbrukning och miljöbalstning för distributionssystem för öl och läsk I Sverige. (Energy consumption and environmental loading of distribution systems for beer and soft drinks in Sweden). Stockholm: Miljöbalans Gustav Sundström AB.
Sustainability
1993 The LCA Sourcebook. A European Guide to Life Cycle Assessment. London: Sustainability, SPOLD and Business in the Environment.
Sweatman, A.
1996 "Integrating Design for the Environment Tools into the Design Process." Paper presented at the 5th International Research Conference of the Greening of Industry Network,

November 24-27, 1996, Heidelberg, Germany.
Väliverronen, E.
1996 Ympäristöuhkan anatomia. Tiede, mediat ja metsän sairaskertomus. (The anatomy of an environmental threat. Science, the media and the case record of the forest). Jyväskylä: Vastapaino.
van Engelenburg, B. C.W. and Nieuwelaar, E.
1994 "A Framework for a Just Allocation Procedure.", in Proceedings of the European Workshop on Allocation in LCA. Leiden, 24-25 February, 1994. Brussels: Society of Environmental Toxicology and Chemistry.
Velhonoja, P.
1996 "Liikenteen ympäristöhaittojen arvottaminen." Esitelmä Suomen ympäristökeskuksen seminaarissa Ympäristövaikutusten arvottaminen ympäristöpoliittisessa päätöksenteossa 9.9.1996, Helsinki. ("Valuation of the environmental impacts of traffic." Presentation at Valuation of Environmental Impacts, hosted by the Finnish Environmental Agency, Sept. 9, 1996.)
Vertanen, S.
1993 Elinkaarianalyysi ja pakkaukset. (Life cycle analysis and packaging) Helsinki: Vesi- ja ympäristöhallituksen julkaisuja, sarja A: 154.
Virtanen, Y.
1994 "Elinkaariarviointi - tavoitteet, rajaukset ja hyväksytyt toteutustavat. Life-Cycle Assessment (LCA)." (Life cycle assessment - goals, limitations and approved procedures, presentation at seminar Life Cycle Assessment in Product Development 4.-5.5.1994, Neopolis, Lahti.)
1995 "Inherent Energy of Products.", in Virtanen, Y., Miettinen, P. and Junttila, V. (eds.) Energy Issues in Life Cycle Assessment. Helsinki: COMETT II UETP-EEE, TEK and VTT.
Virtanen, Y. and Nilsson, S.
1993 Environmental Impacts of Waste Paper Recycling. London: Earthscan.
Webster, A.
1991 Science, Technology and Society. Hampshire and London: Macmillan Education Ltd.
Weiss, C.H.
1979 "The Many Meanings of Research Utilization". Public Administration Review 29: 426-431.
Welford, R.
1995 Environmental Strategy and Sustainable Development. The Corporate Challenge for the 21st Century. London: Routledge.
1996 Hijacking Environmentalism. Corporate Responses to Sustainable Development. London: Earthscan.
Wynne, B.
1982 Rationality and Ritual: The Windscale Inquiry and Nuclear Decisions in Britain. Chafont St. Giles: British Society for the History of Science.
Yearley, S.
1991 The Green Case. A Sociology of Environmental Issues, Arguments and Politics. London and New York: Routledge.
Ziman, J.
1996 "Postacademic Science: Constructing Knowledge with Networks and Norms." Science Studies 9, 1: 67-80.

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