Int J Life Cycle Assess (2008) 13:432–439
DOI 10.1007/s11367-008-0015-y

LIFE CYCLE MANAGEMENT

Life cycle management of energy-consuming products in companies using IO-LCA

Seppo Junnila

Received: 13 June 2007 / Revised: 18 March 2008 / Published online: 6 May 2008

Abstract

Background, aim, and scope Today, the effective integration of life cycle thinking into existing business routines is argued to be the most critical step for more sustainable business models. The study tests the suitability of an input–output life cycle assessment (IO-LCA) approach in screening life cycle impacts of energy-using products in companies. It estimates the life cycle impacts of three products and assesses the suitability of such approach in a company environment.

Materials and methods The multiple case studies evaluate the suitability of an IO-LCA method in a company environment. A comprehensive life cycle cost and impact study of three product systems (building ventilation system, information and communication technology (ICT) network product, and welding machine) is conducted and the life cycle phases with highest economical and environmental contribution are determined. Scenario analysis is performed in order to assess the sensitivity of the results to major changes in the studied systems. Finally, the usability of the IO-LCA approach for environmental evaluations in companies is assessed by collecting data on workload and interviewing the participating workers and managers.

Results The results showed that the use phase with operating energy was environmentally important in all evaluated energy-using products. However, only in one case (ICT network product) the use was the single most significant life cycle phase. In two other cases, the sourcing was equally important. The results also indicated that the IO-LCA approach is much easier to adapt by current management of companies because it automatically links life cycle costs to environmental indicators and, by order of magnitude, reduces the workload in companies.

Discussion It appears that the IO-LCA approach can be used to screen environmentally significant life cycle phases of energy-using products in companies by utilizing readily available accounting or other documented data. The IO-LCA approach produced comparable results with the ones published in traditional process-based LCA literature. In addition to the main results, some practical benefits of using the IO-LCA could also be suggested: the approach was very fast to use and would thus allow an easier adoption of environmental evaluations in companies as well as wider environmental testing of products in early conceptual design phase.

Conclusions The results indicated that the IO-LCA approach could clearly offer added value to the environmental management of companies. The IO-LCA was found to provide a very fast access to the key life cycle characteristics of products. Similarly, it offered practical means to integrate life cycle thinking into existing business routines and to activate the decision makers in companies by giving them easily comprehendible results.

Recommendations and perspectives The results would suggest that similar environmental IO tables, besides the US ones used here, would have value and should be collected for other major geographical and economical regions. The tables would enable a much larger share of companies to manage their environmental issues. It also seems that, because the user profile is so dominant in the case of energy-using products, more studies, both theoretical (How to valuate the future behavior in environmental studies?) and empirical (What really creates value for users?), should focus on the behavior of users.

S. Junnila (✉)
Department of Civil and Environmental Engineering,
Helsinki University of Technology,
P.O. Box 9800, 02015 TKK Espoo, Finland
e-mail: seppo.junnila@tkk.fi

Keywords Companies · Energy-consuming products · ICT network · Input–output LCA · IO-LCA · LCC · Life cycle costing · Life cycle management · Ventilation system · Welding equipment

1 Background, aim, and scope

In recent years, an urgent need for implementation of the life cycle thinking into business processes has been highlighted (Hunkeler and Rebitzer 2005). Effective integration of life cycle thinking into existing business routines is considered as a critical success factor for more sustainable business models (Swarr 2006). A good example of legislative measures that try to take life cycle thinking into business processes is EuP directive (EuP 2005), which sets the eco-design requirements for the life cycle performance of energy-using products. Similarly, the life cycle assessment (LCA) community has taken initiative to focus increasingly on life cycle management (UNEP 2004).

At the same time, the challenges in environmental management grow as the business models move from traditional do-it-yourself approach to creating value through supply chains. As the number of outsourced functions and relationships with suppliers grows, more attention has to be paid to supply chain management (Håkansson and Gadde 1994; Cousins 1999). Especially in light and service industries, which have recently been noticed also environmentally to be significant industries, the majority of the environmental impacts occur in up- or downstream supply chain (Junnila 2007; Suh 2006).

The adoption of LCA practices has been suggested as an option to improve the quality of environmental design in companies. The traditional LCA is based on system models, where the product under study is described by unit processes and input–output flows (Consoli et al. 1993). The approach is called here a process-based LCA (Pro-LCA). However, there are still many practical problems before the traditional Pro-LCA can widely be used in environmental management of companies. Some of the major hindrances presented in literature are listed below (Hendrickson et al. 2006; Wong 2004; Suh et al. 2003; Junnila 2006). Firstly, the approach is very laborious, which is a significant drawback for organizations operating in a fast and cost-conscious business environment. Secondly, the system included in the LCA should be determined in terms of energy and mass units (i.e., by MJ, kWh, kg, etc.). In practice, most of the material and energy inputs and outputs are primarily collected and expressed in monetary terms in company records and not as energy and mass units. Finally, some other inputs, such as the purchased services and capital goods, are typically only expressed in monetary terms in the records.

Another interesting approach for conducting an environmental life cycle assessment is the so-called input–output life cycle assessment (IO-LCA). The IO-LCA approaches the environmental issues by using an input–output analysis (Hendrickson et al. 2006; Tucker et al. 2006). It is an economic discipline that concerns the inter-relationships between industries and households through producing and consuming commodities, and it makes use of ‘input–output’ tables produced by statistical agencies. These tables, in the form of matrices, describe production activities in terms of the purchases of each industrial sector from all other sectors. This information is linked to the environmental data of each sector and can then be used to calculate the environmental impacts of products covering the full production chain.

The IO-LCA could offer some clear benefits from the perspective of environmental management of companies. Firstly, the purchased materials, energy, and services need to be defined only in the terms of monetary value. Secondly, the approach is suggested to be very fast to use (Hendrickson et al. 2006); the practitioner does not need to collect information from all processes in the supply chain because the information is already included through the use of IO-LCA tables. Thirdly, the IO-LCA always provides a full inventory (e.g., there is no need to make cutoffs in the supply chain) for the production phase of the commodity or service that is taken into account. Fourthly, the environmental interventions of goods and services produced within the economy are always assessed consistently, and finally, the monetary information (life cycle costs) of the product is always available in parallel with environmental information. These are all important benefits especially in light and service industries in which a considerable amount of supply chain purchases are either minor amounts of materials or services from other companies and the share of small- and medium-size organizations is significant.

At the moment, the IO-LCA approach per se is thought to be less adequate for detailed LCA studies (Suh et al. 2003; Treloar et al. 2000). Thus, the IO-LCA is actively being developed as a part of so-called hybrid method (Udo de Haes et al. 2004). However, for some other purposes, the IO-LCA is perceived as even more suitable than process LCA (Hendrickson et al. 2006). For example, the European Commission’s Integrated Product Policy (IPP 2003), which is set to identify the products with the greatest potential for environmental improvement, has determined that the IO-LCA would be the most suitable approach. Interestingly, even inside EU, controversy on suitability of the two, Pro-LCA and IO-LCA, approaches exists. The Directorate-General for Energy and Transport has preferred Pro-LCA approach in the preparation of EuP directive to evaluate what energy-using products cause significant environmental impact within the Community (MEEup 2005), whereas the European Commission’s Environment Directorate-General has favored the IO-LCA approach for identifying the products that have the greatest environmental impact throughout their life cycles in Europe (Tucker et al. 2006).

Nevertheless, if the IO-LCA model could be used in companies to identify environmentally significant aspects, it could considerably reduce the resources needed for environmental evaluations in companies compared to traditional Pro-LCA. In addition, it would also considerably improve the exactness of environmental evaluations in companies compared with the present situation. The purpose of this study is to test the IO-LCA approach in screening life cycle impacts of energy-using products in companies. The study uses IO-LCA to estimate the life cycle impacts of three product systems and assesses the usability (workload and adoption) of such approach in a company environment.

2 Materials and methods

2.1 Research design

The study proceeded in the following main steps:

1. The first product system under study (building ventilation system) was defined and assessed by the researcher.
2. Primary accounting (monetary) data were collected for the life cycle cost calculation of the product system. Direct life cycle costs were presented without any discounting or depreciation of monetary values.
3. The life cycle impacts were assessed using IO-LCA and the life cycle phases with the highest environmental contribution were determined.
4. More detailed data were collected for the life cycle phases with the highest contributions.
5. The environmental impacts were recalculated by using the more specified data.
6. The life cycle phases and processes with the highest contribution were determined.
7. The environmental impacts were compared with life cycle costs.
8. The stages 1 to 7 were conducted to two other product systems (information and communication technology (ICT) network product and welding equipment). The LCA inventory of the products was done by the companies with the help of the researcher.
9. The data for usability, i.e., workload and easiness to adapt the IO-LCA method and results, were collected from the companies by interviewing persons involved in the projects.

2.2 The scope of the LCA

2.2.1 Cases

Building ventilation system The scope covers an estimated life cycle of 25 years of a new apartment-specific ventilation system in a dwelling house. The primary data were collected as monetary flows from a life cycle cost study of the system (Saari and Mäkelä 2000). The sourcing phase covers all manufacturing processes of fans, automation parts, air ducts, and structural supports. The production phase refers here to the assembly of the ventilation system at the construction site. The costs for the operating energy were calculated based on the energy demand of the product, and those for the maintenance and end-of-life phases were estimated based on similar products in use.

ICT network product The scope covers an estimated life cycle of 10 years of a new ICT network with both 2G and 3G elements. The primary data were collected as monetary flows from several data sources. The data for the product life cycle up to the use phase (sourcing, production, office work, and delivery) could be retrieved directly from the company accounting systems. The costs for the operating energy were calculated based on the energy demand of the product and those for the maintenance and end-of-life phases were estimated based on a similar product in use. The cost information of the product is not presented in the paper due to the sensitivity of the information.

Welding machine The scope covers an estimated life cycle of 10 years of new metal inert gas (MIG) welding equipment. The primary data were collected as monetary flows from several data sources. The data for the product life cycle up to the use phase (sourcing, production, office work, and delivery) could be retrieved directly from the company accounting systems. The costs for the operating energy were calculated based on the energy demand of the product at a sheet metal element-producing plant, and those for the maintenance and end-of-life phases were estimated based on a similar product in use. The cost information of the product life cycle is not presented in the paper due to the sensitivity of the information.

The secondary data, the IO-LCA environmental inventory, were retrieved from a US input–output database using the sectors best describing the materials, services, or energy used in the actual product system (SimaPro 7 2006). The environmental impacts were estimated up to the middle point impacts with eco-indicator 95 method using primary energy resources (PER), global warming potential (GWP), ozone depletion potential (ODP), acidification potential (AP), summer smog potential (SSP), eutrophication potential (EUP), and heavy metals (HM) categories. The selection of the impact assessment method was widely discussed with participating organizations. At the end, several practical (life cycle management) arguments led to selection of the ‘old’ methodology with midpoint indicator instead of more recent methods. The organizations felt that the selected method is most concretely linked to the actual environmental targets in the organizations. Similarly, many emission reduction

Table 1 Life cycle costs and impacts of a building ventilation system

Impact category	Unit	Total	Sourcing	Production	Delivery	Use	End-of-life
LCC	€	1,533	780	287	9	399	57
PER	MJ LHV	59,200	20,200	3,100	200	33,800	1,800
GWP	kg CO_2	5,650	1,590	290	20	3,620	130
ODP	kg CFC11	0.0039	0.0021	0.0006	0.0000	0.0008	0.0003
AP	kg SO_2	36	7	1	0	28	1
SSP	kg C_2H_4	3.1	1.8	0.4	0.0	0.6	0.2
EUP	kg PO_4	2.2	0.6	0.1	0.0	1.4	0.1
HM	kg Pb	0.017	0.012	0.002	0.000	0.003	0.001

LCC life cycle costs, *PER* primary energy resources, *GWP* global warming potential, *ODP* ozone depletion potential, *AP* acidification potential, *SSP* summer smog potential, *EP* eutrophication potential, *HM* heavy metals

policies and international agreements align better with midpoint indicators than endpoint ones. Finally, the selection of the approach facilitated the comparison of the results with the existing ones.

Finally, the usability data of the IO-LCA approach in companies were retrieved by interviewing the project managers of the LCA projects in companies. At the beginning of the study, all the project managers were familiar with Pro-LCA but not with IO-LCA approach. They also had a lot of experience in communicating environmental information and policies inside the companies. At the beginning, the project managers were asked to collect man-hours used for collecting and analyzing the LCA inventory and results in companies. In addition, they were asked to inquire how well the other workers perceived the IO-LCA approach for making environmental evaluations. The usability data were collected and discussed separately for both companies (LIHAS project 2006, 2007).

3 Results

3.1 Life cycle costs and impacts of a building ventilation system

The life cycle costs and impacts of the ventilation system are presented in absolute values in Table 1 and in relative contributions in Fig. 1. The life cycle costs of the product are dominated by the sourcing phase (around 50%) followed by the use and production phases (around 20–25%). Mostly life cycle impacts do not correlate with life cycle costs. Instead, the use phase contributes the most (60–75%) to all energy-related impacts, i.e., primary energy, climate warming, acidification, and eutrophication. The operating energy in the use phase is the single process having clearly the highest contributions, 55–75% of life cycle impacts, in the impact categories above. However, in ozone depletion, summer smog, and heavy metals categories, the use phase has only a minor contribution (15–20%) whereas the sourcing phase contributes the most 50–70%. The production phase has the third most impacts with 5–15% share followed by the end-of-life (2–8%) and delivery phases (0–2%).

3.2 Environmental impacts of ICT network product

Life cycle contribution of an ICT network product is presented in Fig. 2. The use phase dominates the results with 60–90% of the impacts. Only in heavy metals category the use contributes clearly less, around 25%. The operating energy alone produces around 70–80% of primary energy, climate warming, acidification, and eutrophication impacts. However, in heavy metal, summer smog, and ozone depletion categories, the operating energy contributes less, 10–20%, and the results in those categories are dominated by manufacturing process in the sourcing and the use phase

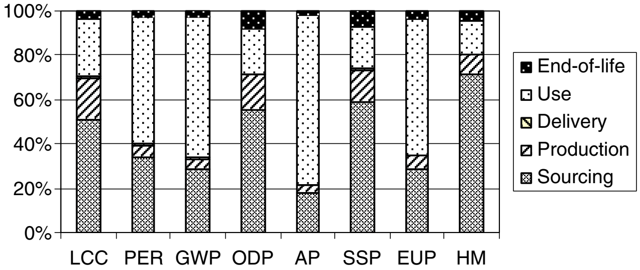

Fig. 1 Economical and environmental contribution of the main life cycle phases of a building ventilation system

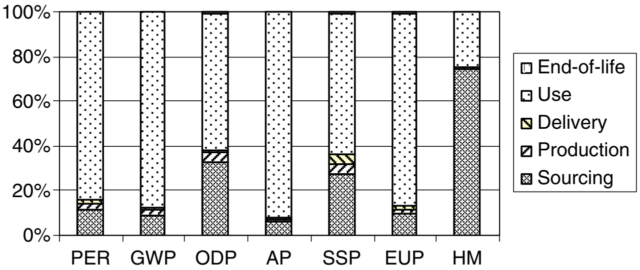

Fig. 2 Environmental contribution of the main life cycle phases of an ICT network product

of the product. All other life cycle phases have significantly lower, 0–4%, contributions.

3.3 Environmental impacts of welding equipment

Life cycle contribution of MIG welding equipment is presented in Fig. 3. The environmental profile of the welding equipment seems to be different from the other products because the sourcing phase contributes the most in majority of impact categories. It produces 50–90% of impacts in primary energy, ozone depletion, summer smog, eutrophication, and heavy metal categories. Only in climate warming and acidification categories the use phase has the highest impacts (50–60%), of which all is due to the operating energy of the equipment. All other life cycle phases have significantly lower, 1–7%, contributions.

3.4 Sensitivity analysis

Several sensitivity scenarios were tested for the assessed products. In the case of ventilation system, the enlarging of the system to include the heating of the exhausted air was the scenario that had the highest influence on the results. The inclusion of heat content of the exhausted air is a plausible scenario, since several similar ventilation systems include a heat recovery unit which specifically aims at recycling the heat in the exhausted air. If the heated air was included in the scope of the ventilation system, the contribution of the use phase would increase considerably from the current 15–75% range all the way up to the 55–95% range.

In the case of ICT network product, the operating energy had the greatest contribution on results. Thus, the sensitivity to the energy production mix was tested using several scenarios based on regional production mixes. Some extreme production mixes, such as the one in Norway (90% hydro and 10% wind), reduced energy consumption related impacts radically, over 95%. However, when production mixes of larger areas (Organisation for Economic Co-operation and Development (OECD) Europe, OECD non-Europe, and non-OECD countries) were tested, the contribution of the use phase changed only moderately from the base 25–92% range down to 20–89% in OECD Europe up to 22–96% range in non-OECD countries. However, here, the results of the sensitivity analysis should be interpreted cautiously because the energy profiles used for different scenarios were retrieved from several databases with some differences in data collection procedures (SimaPro 7 2006a,b,c).

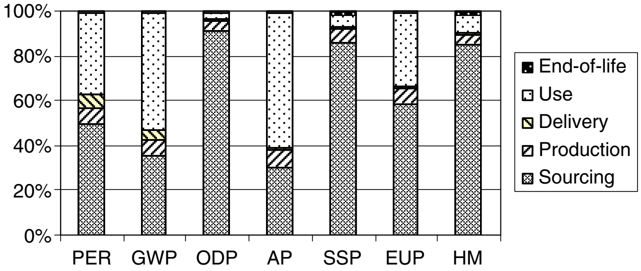

Fig. 3 Environmental contribution of the main life cycle phases of a MIG welding equipment

Two scenarios were found to influence the results of welding equipment noticeably. First, the selected user profile had a clear influence. The base case was based on the use at a sheet metal element plant, where the usage is less intense than in some other places, such as at a dockyard. With the dockyard user profile, the environmental contribution of the use phase increased from the current 2–50% range up to the 7–83% range. Even more radical change in results occurred when the system studied was expanded to include the welding wire. Welding wire could be argued to be part of the system because the MIG welding process requires an external wire. On the other hand, the welding equipment itself does not have an influence on the amount of the welding wire used in the welding process, and thus, the wire was excluded from the base case. Nevertheless, if the welding wire was included into the system, the current contribution range of the use phase (2–50%) would rise significantly up to the 32–97% range.

3.5 Usability assessment

The usability of the IO-LCA approach in a company environment was assessed similarly in both company cases, ICT network product and welding machine. The man-hours used were collected and the persons involved in LCA inventory and calculation were interviewed. The aggregated man-hours for the inventory and IO-LCA calculation were 75 h net for the first case and 90 h net for the other. However, the overall length of the projects was much longer, 2 and 5 months, due to much waiting time. The following reasons were stated for delays. All interviewed persons stated that the main reason for the difference between net and gross times was that the required information for the inventory is to some extent dispersed in the company systems and needs to be collected by several persons in the organization. At the same time, development projects such as this are almost always extra work for persons involved. On the other hand, difficulty of finding required information was never mentioned as a reason for the time waited.

When the project participants were asked to assess how fast and resource-intensive the IO-LCA approach is compared with a traditional Pro-LCA, all agreed IO-LCA to be both considerably faster and required less resources. Similarly, when they were asked whether the results gained through IO-LCA were easier to communicate to or adopt by managers, all agreed that to be the case. Reasons given for better communicability and adoption mostly evolved around the theme approach being able to link costs to impacts. When the approach can directly link the costs to environmental information, it can also link the 'familiar' thinking mode of management to less familiar environmental thinking and to facilitate people to get an overall picture of the situation. Also, the significantly reduced workload in IO-LCA seemed to be critical for adoption in companies. Because the workload required for environmental evaluation with IO-LCA is not "totally out of the realms of possibilities", the organizations seemed to start to seriously think about the possibilities of integrating environmental issues in their design processes.

4 Discussion

Today, the effective integration of life cycle thinking into existing business routines is argued to be the most critical step for more sustainable business models. The study tested the suitability of the IO-LCA approach in screening life cycle impacts of energy-using products in companies. It estimated life cycle impacts of three products and assesses the suitability of the approach in a company environment.

The results showed that the use phase with operating energy was environmentally always an important process in the case of energy-using products. However, interestingly, only in one case (ICT network product) out of three the use was the single most significant phase. In the other two cases, the sourcing was equally important. The results also indicated that the IO-LCA approach would be easier to adapt by current management processes of companies because it automatically links life cycle costs to environmental indicators and significantly reduces the workload of collecting data.

When the results of this study are compared with previous Pro-LCA studies, it seems that both approaches identify the same life cycle phases contributing the most to environmental impacts. The LCA results of two other ICT network products have produced consistent results with the ones here. Malmodin (2004) has reported that the operating energy in the use phase dominates the result of a 3G network system with around 80% contribution in the climate change impact, here 82%. Emmenegger et al. (2006) have reported that the use of a base station causes approximately 85% of its life cycle impacts, here 88%. Similarly, the results of another welding machine case study are consistent with the ones here (Valkama 2002). With the closest available user profile in the report, the dockyard, the Pro-LCA reported around 90% contribution for the use phase in the energy-related impact categories (GWP and AP), which is close to the results here, around 80%. However, in some other categories, such as ODP, the Pro-LCA has reported 90% contribution for the use, whereas the IO-LCA here found only around 10% contribution for the use phase.

The usability of different LCA approaches has not yet been compared and reported in a company environment. However, similar usability indicators for Pro-LCA project have been collected separately by several parties. For example, a major LCA of a generic American automobile has been stated to take 2 years and estimated to have cost almost 8 million dollars (Hendrickson et al. 2006). In construction and electronics industries, the net resources needed for process-based LCAs seem to range from around 4 man-months all the way up to 20 man-months, the typical size being around 6 man-months (Junnila 2003; Kommonen and Svan 2002). When the workloads above are compared with the ones collected here, it seems that the IO-LCA is significantly less laborious reducing the workload of an LCA from several months to a few weeks. The main reason for the reduced workload seems to be the more efficient inventory process due to readily available data in accounting systems and documents in the companies.

The results of the study are limited for several reasons. Firstly, being a case study, any generalization made based on the results is purely analytical, not statistical. Secondly, the secondary data (i.e., emissions) represented US conditions and may thus bias results to those conditions when applied to other regions. However, in the case of operating energy, which was found to be the single most significant process, the major economical regions were tested in scenario analysis and the variation seemed to be rather modest. Thirdly, the use phase of the energy-using products seems always to have considerable environmental contribution, but the prediction of the future use is, by necessity, quite limited. Especially with products that are not used constantly, the amount of operating hours could be expected to vary enormously, as was the case here with the welding machine. Finally, the usability assessment in companies was based on interviews and discussions with less than 15 people, which all were experts on environmental management in companies. Thus, the results of the usability assessment can only be interpreted as indicative.

Nevertheless, it appears that the IO-LCA approach can be used to identify the environmentally significant life cycle phases of energy-using products in companies by utilizing readily available accounting or otherwise documented data. The IO-LCA approach produced comparable results with the ones published in traditional Pro-LCA literature. The use of energy in the operating phase seems to be an environmentally highly significant process for all energy-using products, but the impact of some manufacturing activities in the supply chain can also be expected to be equally significant with some products.

In addition to the main result, some practical benefits of using IO-LCA could be suggested. The approach was very fast to use and would thus allow an easier adoption of environmental evaluations in companies as well as wider environmental testing of products in early conceptual design phase. Finally, as the approach combines monetary flows with environmental impacts, it seems that the managers get more interested in environmental issues being able to link new information to the existing one.

5 Conclusions

The implementation of life cycle thinking into business processes is highlighted as the challenge of the future for sustainable business. This study used multiple cases to evaluate the suitability of IO-LCA in companies. The result showed that the IO-LCA approach clearly offered added value to the environmental management of the companies. The IO-LCA was found to provide a very fast access to the key life cycle characteristics of products such as the system processes contributing the most to the life cycle impacts. Similarly, it offered practical means to integrate life cycle thinking into existing business routines and to activate the decision makers in companies by giving them easily comprehendible results.

6 Recommendations and perspectives

The results would suggest that similar environmental IO tables, besides the US ones used here, should be collected for other major geographical and economical regions. It would enable a much larger share of companies to enter into environmental management. It also seems that, as the user profile is so dominant in the case of energy-using products, more studies should focus on the behavior of users. Both methodological and practical studies are required to answer questions such as how to valuate future uncertainty and what really creates value for users. Finally, as the IO-LCA can successfully be combined with process-based LCA, the company applications should also be kept open for these ‘hybrid’ approaches.

Acknowledgements The author wishes to thank Tekes (National Technology Agency of Finland), Teknologiateollisuus (Technology Industries of Finland), and the participating companies Efore, Elcoteq, Idman, KCI group, Kemppi, Nokia, Retermia, and Tellabs for inspiring and funding the research.

References

Consoli F, Allen D, Boustead I, Fava J, Franklin W, Jensen A, de Oude N, Parrish R, Perriman R, Postlethwaite D, Quay B, Seguin J, Vigon B (1993) Guidelines for life-cycle assessment: a ‘code of practice’, 1st edn. SETAC, Brussels

Cousins PD (1999) Supply base rationalisation: myth or reality. Eur J Purch Supply Manag 5(3/4):143–155

Emmenegger M, Frischknecht R, Stutz M, Guggisberg M, Witschi R, Otto T (2006) Life cycle assessment of the mobile communication system UMTS. Int J LCA 11(4):265–276

EuP (2005) Directive 2005/32/EC of the European Parliament and of the Council establishing a framework for the setting of ecodesign requirements for energy-using products

Håkansson H, Gadde L-E (1994) The changing role of purchasing: reconsidering three strategic issues. Eur J Purch Supply Manag 1 (1):109–117

Hendrickson C, Lave L, Matthews S (2006) Environmental life cycle assessment of goods and services: an input–output approach. RFF, Washington

Hunkeler D, Rebitzer G (2005) The future of life cycle assessment. Int J LCA 10(5):305–308

IPP (2003) Communication from the Commission to the Council and the European Parliament, COM (2003), 302 final, http://europa.eu.int/comm/environment/ipp/ippcommunication.htm, accessed 1.8.2004

Junnila S (2003) Workload of commercial LCAs. Contracts of 9 commercial LCAs. Pöyry Consulting and Engineering, Helsinki

Junnila S (2006) Empirical comparison of process and economic input–output life cycle assessment in service industries. Environ Sci Technol 40(22):7070–7076

Junnila S (2007) Environmentally significant processes of consulting, banking and facility management companies in Finland and the U.S. Int J LCA 12(2):18–27

Kommonen F, Svan T (2002) The environmental aspects of Ambiotica. Senate Properties. Helsinki, Finland, Interviewed January 2002

LIHAS project (2006) 3rd steering group meeting, August 18, Helsinki, Finland

LIHAS project (2007) 4th steering group meeting, March 2, Helsinki, Finland

Malmodin J (2004) Summary of the study ‘Life cycle assessment of a third generation (3G) system at Ericsson’. Ericsson, Stockholm

MEEup Methodology report, final (28.11.2005), Methodology study eco-design of energy-using products. VHK for European Commission. Brussels, Belgium

Saari A, Mäkelä J (2000) Eco-economic valuation of building components. Helsinki University of Technology, Construction Economics and Management, Publication 192. Espoo, Finland

SimaPro 7 (2006) USA input output data base 98. PRé Consultants. Amersfoort, The Netherlands

SimaPro 7 (2006a) Ecoinvent data base. PRé Consultants. Amersfoort, The Netherlands

SimaPro 7 (2006b) Dutch input output data base 95. PRé Consultants. Amersfoort, The Netherlands

SimaPro 7 (2006c) DK input output data base 99. PRé Consultants. Amersfoort, The Netherlands

Suh S (2006) Are services better for climate change. Environ Sci Technol 40(21):6555–6560

Suh S, Lenzen M, Treloar G, Hondo H, Horvath A, Huppes G, Jolliet O, Klann U, Krewitt W, Moriguchi Y, Munksgaard J, Norris G (2003) System boundary selection in life-cycle inventories using hybrid approaches. Environ Sci Technol 38(3):657–664

Swarr T (2006) Life cycle management and life cycle thinking: putting a price on sustainability. Int J LCA 11(4):217–218

Treloar G, Love P, Faniran O, Iyer-Raniga U (2000) A hybrid life cycle assessment method for construction. Construct Manag Econ 18:5–9

Tucker A, Huppes G, van Oers L, Heijungs R (2006) Environmentally extended input–output tables and models for Europe. EUR 22194 EN. Joint Research Center (DG JRC), Institute for Prospective Technological Studies, European Commission, Brussels, Belgium

Udo de Haes HA, Heijungs R, Suh S, Huppes G (2004) Three strategies to overcome the limitations of life-cycle assessment. J Ind Ecol 8(3):19–32

UNEP (2004) Why take a life cycle approach? Life cycle initiative. United Nations Environment Programme, Division of Technology, Industry and Economics, Production and Consumption Branch, Paris, France

Valkama J (2002) The LCA of a TIG welding equipment (in Finnish). Department of Electronics, Tampere University of Technology, Tampere, Finland

Wong M (2004) Implementation of innovative product service systems in the consumer goods industry. Dissertation. University of Cambridge, Cambridge, UK