To be presented at the 10th international conference of the Greening of Industry Network

June 23-26, Göteborg, Sweden

Economists wanted in life cycle assessment

Tomas Ekvall, Dep. of Energy Conversion, Chalmers University of Technology, SE-412 96 Göteborg, Sweden; phone +46-31-772 1445; fax +46-31-772 3592; email tomas.ekvall@entek.chalmers.se

Abstract

The methodology and procedure for life cycle assessment (LCA) is, with a few exceptions, developed by engineers and natural scientists. As a result, LCA is crude in aspects relating to communication and market effects. Further developments could benefit greatly from involving management experts and macro economists. For example, two types of LCA have been distinguished, each generating a different type of information: one describes the environmental burdens of the product system investigated; the other describes how the environmental burdens are affected by changes that are made in the product system. The LCA community would benefit from a procedure to identify what information is relevant in a specific case. Second, it is simply assumed, in a typical LCA, that the increase in demand for a product by one customer results in the same increase in production. The actual effects on the market for this product are likely to be more complex. An analysis of these effects could be based on the concept of price elasticity, perhaps utilizing partial equilibrium models. It may also be possible to study economy-wide effects using general equilibrium models. Third, an input/output table is sometimes added to the life cycle model in an LCA to make the study more complete. These tables typically include average data only. To model consequences of changes, we would need an input/output table with data that reflect marginal effects in the different sectors of the economy. Fourth, in some cases the different types of environmental burdens are weighted into a single environmental index. This is a normative procedure and it is important that the weighting factors reflect relevant environmental considerations. A procedure to identify these considerations and quantify them in terms of weighting factors would be an important tool in this part of the LCA. Finally, an LCA typically does not generate objective and final answers, but has the potential to provide a good basis for discussion. To realise this potential, the most important aspects of the LCA have to be communicated in an efficient way to the relevant audience. These are all aspects where management experts or macro economists might provide expertise that is typically lacking among engineers and natural scientists.

Introduction

Environmental life cycle assessment (LCA) was developed from the idea of comprehensive environmental assessments of products, which was conceived in Europe and in the USA in the late 1960s and early 1970s (Hunt & Franklin 1996). The concept of LCA is here defined (based on ISO 1997) as the compilation and evaluation of the material and energy flows and of the potential environmental impacts of a product system. The product system is here defined as the system consisting of models of the technological activities used for the various stages of the product: from extraction of raw materials for the product and for ancillary materials and equipment, through the production and use of the product, to the disposal of the product and of ancillary materials and equipment, if any. In this context, the term *product* is broadly defined to include not only physical products but also services.

The methodology and procedure for LCA became an area of academic research around 1990. Since then, significant progress has been made in the methodology for modelling in the different phases of the LCA. However, the methodology and the procedure for LCA have, with a few exceptions, been developed by engineers and natural scientists. LCA practitioners are also typically engineers. For this reason, it is not surprising that, the modelling in LCA typically focuses on physical flows of energy and material rather than economic flows or the behaviour of people.

The life cycle inventory analysis (LCI) is the phase of an LCA where a model of the relevant part of the technological system is developed. The model is typically a static simulation model. The components in the model system represent technological activities such as production processes, transports, etc. The connections between the components represent physical flows of material or energy that constitute intermediate products. The components of the model system include primarily data regarding the relationship between the inflows and outflows of the physical flows into and out from the technological activity. These relationships are typically linear within the model component.

The aim of this paper is to discuss five different limitations in the LCI modelling and LCA procedure – limitations that might be alleviated through the cooperation with economists. These limitations concern the identification of what information the LCA should generate, the modelling of effects on supply and demand, the modelling of marginal effects, the trade-off between different environmental issues, and the reporting of the study.

Identifying information need

An interesting development during recent years is the distinction between two types of LCA: attributional and consequential LCA. An attributional LCA aims at describing the environmental properties of a life cycle and its subsystems. A consequential LCA aims at describing the effects of changes within the life cycle. Similar distinctions, but with different names, have been made by several LCA researchers (Ekvall 1999). The distinction between different types of LCA, each with a different purpose or application area, substantially reduces some of the persistent methodological problems in the life cycle inventory analysis

(LCI). These include the definition of system boundaries, so called allocation problems, and the decision to use average data or to model marginal effects.

The two types of LCA generate different kind of information. Different information might be relevant to the audience of the LCA depending on, for example, the decision situation. What information is relevant also depends on the prior knowledge and the normative point of departure of the audience (Ekvall 2000a, Ekvall *et al*. 2001). To decide which type of LCA to carry out, the LCA practitioner needs to know what type of information is relevant to the intended audience of the LCA. To my knowledge no procedure exists in the LCA community to identify what information is relevant to generate in a specific case study. Hence, we would benefit if such a procedure can be obtained from, or developed within, other research areas such as the management science.

Modelling markets

Although consequential LCA aims at describing effects of changes, it has, in fact, severe limitations in this context. Important limitations concern the completeness and accuracy when one is attempting to model the effects of changes. If the LCA practitioner aims at describing the full consequences, the LCA model will always include numerous data gaps and large uncertainties. Although, this incompleteness can be regarded as a serious limitation, it is one that is shared with other tools. A modeller can aim at describing as much as possible of the consequences of an action, but it is no use to aim at describing the full consequences. Decisions will always have to be made based on incomplete knowledge of their consequences.

The problem of accuracy is, in a sense, more noteworthy because it can probably be more effectively alleviated. The models generated in a consequential LCA include aspects that are not effects of changes. It is reasonable to expect that such unnecessary aspects can be eliminated from the models. For example, LCAs are typically based on the assumption that when the demand for a material increases in the life cycle investigated, the production of that material is increased by the same amount. But materials are typically bought on a market with other suppliers and purchasers. When more material is used in the product system investigated, less material of that type might be used in other product systems. As a result, the increase in total production can be much smaller than a consequential LCA indicates (Ekvall 1999). This is true not only for materials but also for other products in a broad sense, including energy, chemicals, components, services etc.

To accurately model the effects of an increased demand for a product in the life cycle investigated, it is necessary to account for effects on the market of this product. These effects depend on how sensitive the supply and demand are to changes in the price of the product. They also depend on how easily the product can be substituted for other products, and on what products are likely to be the substitutes. Such aspects are included in economic partial equilibrium models (Bouman *et al*. 2000). Hence, a solution might be to integrate partial equilibrium models into the LCI. Bouman *et al.* (2000) discuss this possibility but state that different types of models generate different and complimentary types of information. They suggest that an integration of different tools entails a risk that the specific advantages of the different tools are lost. But in this case, the integration of tools – LCA and partial equilibrium analysis – would be focussed upon creating a new tool with specific advantages with regards to modelling consequences of changes.

In general, the effects of changes in the life cycle depend on economic mechanisms. In fact, this was suggested in the LCA context as early as 1993 (Weidema 1993). Consequential LCAs only begin to model such mechanisms (Weidema *et al*. 1999, Ekvall 2000b). To describe more aspects of these consequences, it is necessary to integrate more of economic theory into the LCI.

A parallel development has already taken place in energy systems modelling. Dynamic optimising models are one result of the integration of knowledge on technology and economy in energy systems modelling. Such models can be relevant for an effect-oriented LCI. In particular, they can be used for generating information on marginal effects in dynamic production systems (Mattsson *et al*. 2002). In theory, at least, this information is more accurate than the information generated through static models.

So called rebound effects can occur, for example, when a cost-efficient change is made to make the use of resources more efficient. The savings in costs make it possible to increase the total economic activity. Such an increase results in a demand for the resource that – partly or completely – offsets the savings obtained through the original change. The increased economic activity is, of course, also likely to increase the demand for other resources. Current LCAs are far from modelling these effects, but valuable insights can be generated through a general equilibrium model (Ibenholt 2002). This is a macroeconomic model of a complete economy based on the assumption that all markets that make up the economy either are in or tend towards a state were the supply of each product equals the demand for that product.

A possible way to model rebound and similar effects in an LCA seems to be to link the process tree of the LCA to a general equilibrium model. The process tree is a bottom-up model in the sense that it starts from unit processes. Macroeconomic models are top-down models because they start from the perspective of the total economy. The pros and cons of bottom-up and top-down models have been debated in the field of energy economics (Wene 1996). To overcome some of the weaknesses and to utilize the advantages of both approaches, attempts have been made to link the two (Hoffman & Jorgenson 1974, Manne & Wene 1992).

Partial equilibrium models, dynamic optimising models, and general equilibrium models all seem to bring promising opportunities for developing a tool that is superior to current LCI in modelling market effects. These models include economic data – and often also technological data. Hence, economic as well as technological expertise is required to establish a solid basis for the models.

Marginal input/output tables

Another promising development in LCI methodology is to combine the process tree of the LCI with macroeconomic input/output tables (Lave *et al.* 1995). Such a table models the monetary transactions between the industrial sectors in an economy. For each unit of money that flows into an industrial sector, the table includes data on how much money flows from this sector to each of the other sectors. Before an input/output table is used in an LCI, environmental data have to be added that quantify the environmental burdens for each sector, per unit of money inflow to that sector. The monetary data as well as the environmental data are averages over the whole industrial sector. This makes the environmental data from an input/output table a poor substitute for ordinary LCI data, which are typically much more specific (Boustead 1996). However, the process tree of an LCI can generally not include the production of all inputs that are used in all processes in the process tree. Instead, the process tree is truncated, which causes a specific system-boundary problem: where should the cut be made? This methodological problem is essentially eliminated if an input/output table is applied at the truncation.

The fact that input/output tables to my knowledge include average data only has implications for the type of LCA for which they are applicable. Average data are relevant for describing systems, but they are typically not relevant for describing effects of changes – at least not effects far out in the branches of the process tree. This means that the input/output tables are applicable mainly in attributional LCAs. To be applicable in a consequential LCA, they should ideally include data that represent marginal effects. Such marginal input/output tables would probably be useful also outside of LCA. They would reflect the expected effects of a change in any industrial sector more accurately than the current input/output tables. The development of consequential LCA would benefit from the experience of economists trying to develop marginal input/output tables or equivalent tools for economic analysis.

Company-specific weighting

In some cases the different types of environmental burdens are weighted into a single environmental index. This is a normative procedure and it is important that the weighting factors reflect relevant environmental considerations. Several researchers have suggested different weighting methods each with a different set of weighting factors. These are often based on public values, as expressed by authorities, or the values of environmental researchers (Bengtsson 2000).

Private companies often have their own environmental priorities expressed, for example, in environmental policy statements. These priorities are not necessarily consistent with the factors of any existing weighting method. A procedure is required to ensure that the weighting factors that are used in LCAs within a company are consistent with the environmental considerations of that company. This procedure could include steps to investigate whether the environmental priorities are fairly reflected in an existing set of factors. It could also include steps to develop a company-specific set of weighting factors based on the environmental considerations of the company management. Natural scientists and engineers cannot be expected to have the expertise needed to develop such a procedure without the assistance of, for example, management experts.

Efficient reporting

The results from an LCA depend on methodological choices that are often subjective. Besides the weighting, if any, such choices include the definition of system boundaries, the choice of data and data sources, the approach to allocation problems, and the methods for modelling environmental impacts. Furthermore, the uncertainties in the LCA results are typically very large. For this reason, LCA results should, in general, not be interpreted as objective and final answers. In the face of these serious limitations, it is important to note that an LCA still generates much knowledge about the systems investigated and their environmental aspects. Such information can be relevant to many decisions. The quantitative and, possibly, qualitative description of the systems investigated can be a good basis for discussion on these decisions.

During the LCA, most of the knowledge is typically generated in the head of the LCA practitioner. The challenge is to transfer the relevant knowledge to the decision-makers. The most important aspects of the LCA must be efficiently communicated to the relevant audience. These aspects include information on the systems and their environmental impacts, but also information about the limitations of the LCA, i.e., the subjective methodological choices and the large uncertainties. These have to be presented in a balanced way. If the limitations are not sufficiently stressed, decision-makers might neglect them. If they are too strongly stressed, the decision-makers might reject the results completely, even when no better source of knowledge is available.

In too many cases, the LCA is presented in a thick report that includes a large amount of information but does not convey much knowledge because it is simply not read or not understood. To realise the potential of LCA studies to provide a good basis for discussion, the reporting procedure and technique need to be improved. Management experts might be able to provide insights that are valuable in this context.

Conclusion

Since the methodology and procedure for LCA is, so far, mainly developed by engineers and natural scientists, LCA is crude in aspects relating to communication and market effects. The LCA community could probably benefit greatly if different types of management experts and macro economists become involved in the continuing development of the LCA methodology and procedure.

References

Bengtsson M (2000) Environmental Valuation and Life Cycle Assessment. Lic.Eng. thesis. Gothenburg: Chalmers University of Technology.

Bouman M, Heijungs R, van der Voet E, van den Bergh JCJM, Huppes G (2000) Material flows and economic models: an analytical comparison of SFA, LCA and partial equilibrium models. *Ecological Economics* 32:195-216.

Boustead I (1996) LCA – How it Came About. *Int. J. LCA* 1(3):147-150.

Ekvall T (1999) System Expansion and Allocation in Life Cycle Assessment – With Implications for Wastepaper Management. PhD thesis. Gothenburg: Chalmers University of Technology.

Ekvall T (2000a) Moral philosophy, economics, and life cycle inventory analysis, *proc. Total Life Cycle Conference and Exposition - Land Sea & Air Mobility*, Detroit, USA: Society of Automative Engineers, 103-110.

Ekvall T (2000b) A Market-Based Approach to Allocation at Open-Loop Recycling, *Resources, Conservation and Recycling* 29(1-2):91-109

Ekvall T, Molander S, Tillman A-M (2001) Marginal or average data – ethical implications, *proc. 1st International Conference on Life Cycle Management*, Copenhagen, Denmark, 91-93.

Hoffman KC, Jorgenson DW (1974) *The Bell Journal of Economics* 5(2):444. Referred to by Wene C-O (1996).

Hunt RG, Franklin, WE (1996) LCA - How it Came About - Personal Reflections on the Origin and the Development of LCA in the USA. *Int. J. LCA*, 1(1): 4-7.

Ibenholt K (2002) Materials flow analysis and economic modelling, In: Ayres RU, Ayres LW, editors. *Handbook of Industrial Ecology*. Cheltenham: Edward Elgar, 177-184.

ISO (1997) Environmental Management - Life Cycle Assessment - Principles and Framework. EN ISO 14040:1997. European Committee for Standardization, Brussels, Belgium.

Lave L *et al.* (1995) Using input-output analysis to estimate economy-wide discharges. *Env. Sci. Techn.* 29(9):420ff. Referred to by Boustead I (1996).

Manne AS, Wene C-O (1992) MARKAL-MACRO: A linked model for energy-economy analysis. BNL-47161. Long Island, New York: Dep. Applied Science, Brookhaven National Laboratories. Referred to by Wene C-O (1996).

Mattsson N, Unger T, Ekvall T (2002) Effects of perturbations in a dynamic system – The case of Nordic power production. Manuscript in preparation.

Weidema BP (1993) Market aspects in production life cycle inventory methodology. *J. Cleaner Prod.* 1(3-4):161-166.

Weidema BP, Frees N, Nielsen A-M (1999) Marginal Production Technologies for Life Cycle Inventories. *Int. J. LCA* 4(1):48-56

Wene C-O (1996) Energy-Economy Analysis: Linking the Macroeconomic and Systems Engineering Approaches. *Energy* 21(9):809-824.