

# **Life Cycle Assessment (LCA)** **- a Sustainable Management Tool?**

**Lennart Karlson**



**KUNGL  
TEKNISKA  
HÖGSKOLAN**

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**Lennart Karlson**

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fulfilment of the degree of Licentiate of Technology

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*Lennart Karlson, May 2002*

## **Abstract**

Life Cycle Assessment (LCA) is a tool to study the potential environmental impacts of goods and services over their life cycles. The aim of this thesis is to analyse and discuss the relevance, efficiency and sustainability of the LCA tool in industrial organisations. Management control and accounting theories have been analysed to identify parallels and similarities between LCA and other management activities and tools.

Industrial users perceive LCA as a relevant but not enough cost efficient tool. The LCA tool do not seem to be enough integrated in operational activities or linked to other established management tools. Two major tasks have to be dealt with if LCA should become a sustainable tool in industry, first to improve the efficiency of the LCA tool and secondly to define the role of LCA from a management control perspective. The demand for ecological information in varying management control situations should be the point of departure irrespective of improvement actions taken. The efficiency of the LCA tool could be enhanced in different ways. One route is to “build away” the drawbacks, e.g. through further developing inventory databases making the resource demanding inventory analysis phase more efficient. It is however important to not underestimate the costs related to these databases. Another opposite route is to develop LCA into an easy to use and resource efficient tool aimed for coarse judgements with the option to conduct more complete assessments when necessary. These two alternatives are not necessarily in opposition to each other, and both could be explored in parallel. The role of LCA in management control is however the most critical aspect to elucidate and the large base of experiences from other management control ambitions, as e.g. management accounting could be used in this work.

A new application aimed to control the life cycle environmental impacts on inter firm level is suggested. The application is based on economic theory and provides business incentives that could serve as one driving force towards a more sustainable society.

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# 1 Introduction

## 1.1 Background

Utilisation of resources from the ecosystem has contributed to a powerful increase in welfare in the society during the latest century, especially in the Western world. In addition, however, the uses of natural resources have created environmental problems. The climate change caused, or at least worsened, by carbon dioxide emissions from the energy sector, industrial activities and transports may illustrate one commonly discussed environmental problem (IPCC, 1996).

The first wave of a broad public concern for the ecosystem degradation can be traced back to the 1960s already. Rachel Carson (1962) discussed various environmental problems created by human activities in the famous book *Silent Spring*. The authors of the report *Limits to Growth* (Meadows et al, 1972) discussed the limits of our worlds ecological system and the constraints it puts on human activities. Another early activity was the first United Nations Conference on the Human Environment held in Stockholm in 1972.

Since then many kinds of preventive actions have been taken to decrease the ecosystem degradation caused by human activities. The Western industrialized world is, on the one hand leader in accomplishing these measures, on the other hand it also utilises most of the natural resources per capita. Governments have, as one example, developed environmental policies and regulations. The large interest for environmental management in industry is another example (Welford, 1998). Various types of environmental management tools have been developed to increase the control of environmental burdens related to industrial activities. Environmental management systems, environmental audits, life cycle assessment and design for environment exemplify some commonly used environmental management tools (cf e.g. Schaltegger et al, 2000 and Gray et al, 1993). Despite the large amount of resources spent in preventive measures increased ecosystem degradation has been observed, at least for some critical environmental problems. There may be several reasons behind that: strong interests among polluting actors to continue with their traditional activities,

lack of knowledge and/or consensus on the magnitude of the problems, too weak and/or inefficient environmental policies are some examples. But we may also ask ourselves whether the environmental management tools themselves are efficient.

## **1.2 Research approach and methodology**

The goal for this thesis is to study the efficiency and relevance of the LCA tool and to judge its sustainability (long-term survival) in industrial organisations. LCA is a comprehensive concept and it is not possible to consider all potential aspects and details when conducting LCAs in practice. The term LCA tool is in this thesis used to describe the subset of the LCA technique (different for different applications) used in practical LCA studies. The term LCA tool should however not be interpreted as being any type of specific LCA software tool.

The methodology used in this thesis was, as a first step, to derive empirical experiences from two LCA studies (paper I and II) and from a survey study (paper III) aimed to map the perceived efficiency, relevance and sustainability of the LCA tool in an industrial organisation. A review of the LCA technique and its development process in section 2 of this cover essay represents the next step. The aim for this was twofold, first to reflect on the large base of experiences available in this field, secondly to validate the empirical material.

Another part of the methodology was to study LCA from a management perspective since LCA may be looked upon as a management tool and is usually identified as such in industry. The implementation of LCA in industry intends to increase management's control of resource utilisation and the environmental impact of (primarily) products and services delivered from industrial activities. Although the sustainability vision may be new, there are obvious parallels and similarities between the LCA-tool and other management tools aiming to increase the control of industrial activities. Management accounting and management control theories (section 3 of this cover essay) are used as objects of comparison to identify these parallels and similarities. Finally a theoretical discussion related to LCA has been conducted (paper IV), with the aim to suggest a new application of LCA.

Three issues were early identified in my research and hence in the same time define the scope for this thesis:

- The *sustainability* (long-term survival) of the LCA tool in industrial organisations.
- The *efficiency* of the LCA tool, i.e. the benefits related to the costs from using the tool.
- The *relevance* of the results from the LCA tool. Do the LCA tool result in more environmentally sound products and/or increased environmental awareness in the organisation?

### **1.3 Aims and structure of the thesis**

The thesis is aimed as a contribution to the body of knowledge related to LCA tool use in industrial organisations. The target groups for this thesis are persons working with LCA development and implementation and those who develop environmental policies related to products and services.

The thesis consists of a cover essay followed by four papers. In the cover essay this introductory section is followed in section 2 by a description of the LCA technique and its development, primarily during the latest decade. Management accounting and management control theories are discussed in section 3. Section 4 summarises the research and give some concluding remarks. Section 5 finally gives some comments and suggestions for future work.

The four papers described below follow the cover essay:

Paper I is of limited scientific value but is anyhow included since this empirical material could be difficult to retrieve otherwise. The LCA study presented in this paper was conducted by the line organisation in ABB Switchgear as part of a product development project. There are good reasons to believe that the statements presented

in the paper are valid since they are retrieved solely from the line organisation, presumably constituting no more interest for LCA than being a tool for assessment and improvement of the ecological performance of the product. This statement is however not validated in the paper. One finding is the extensive amount of work needed for conducting a LCA for the first time. The initial work seems to be a one-time investment since both data and knowledge could be reused in the next LCA conducted on the same type of product. The increased level of ecological competence and awareness in the organisation was reported as a positive outcome of the LCA study. The LCA tool was seen as a crucial and relevant tool to optimise the environmental performance of the product. The LCA tool was also judged to be a compulsory and integral part of future product development projects to keep competitiveness in the future.

The LCA study in paper II is a future oriented environmental assessment of a non-existent solar energy system. The uncertainties related to the system boundary definition and inventory data collection are here much larger than for the product studied in paper I. One finding is the problem to select environmental indicator/s for evaluation of the results, and to weight the results into useful conclusions. Another finding is the problem to define the system boundary for what to include in the study of a large technical system, this is especially true for emerging technologies. A question related to system boundary definition is the problem of validating input data gaps. Large systems must be limited somewhere and then there is an obvious risk that critical unit processes could be excluded by mistake and the results could then be of limited relevance.

The survey presented in paper III was based on a questionnaire sent to 84 persons (77% answer frequency) with different management roles in ABBs line organisation, e.g. in product development. Persons working with LCA tool development and centralised environmental staff functions were excluded from the survey. Although the questionnaire was sent to people who in one way or another have had contact with LCA the answers indicate that they, with some possible exceptions, do not constitute a full time professional group with its own LCA interests. As regards the representativeness of the answers, we therefore have reasons to believe that they are

not severely biased. On the one hand the technical, economic and environmental benefit from current use of the LCA tool are seen as modest. The LCA activities seemed neither to be integrated in normal operational activities. On the other hand a positive opinion about the relevance and future use of the LCA tool was reported.

Paper IV is a theoretical paper based on economic theories suggesting a model aimed to create business incentives towards a sustainable development through utilising the environmental life cycle perspective to set up an emission trading system. Critical issues discussed in this paper are the cost of transactions due to asymmetric information and the role of property rights. It is however not possible to validate the theoretical discussion against the empirical material since the LCA tool has not yet been used in these types of applications. It is anyhow of interest to bring up the application from a theoretical perspective since LCA presumably could be applied on an aggregated level, e.g. for a whole sector of industries or set of activities.

## 2 Life cycle assessment, LCA

### 2.1 The LCA technique and its applications

LCA is a technique for environmental systems analysis (e.g. Finnveden, 1998) aimed to assess the potential environmental impacts for a product over its life cycle. The system analytical character of the LCA technique is important to understand and handle since this is probably one reason behind the perceived complexity of the LCA tool. Therefore we in the concluding section 4 suggest a model for visualisation of the most critical elements of LCA that could be used as a tool to better understand the LCA technique (see fig. 2). Systems analysis has been applied in many different types of sciences and disciplines, ranging from biology and ecology over sociology to technology and infrastructure planning (Karlqvist, 1983). Even if systems analysis has been used as a common concept and tool in mathematically dominated sciences there has been a debate about its applicability in other disciplines, like ecology and sociology. That discussion falls outside the scope of this thesis however.

Forrester's work on systems dynamics exemplifies one early input to the development of systems analysis (Forrester, 1968). One result of his work was presented in *Limits to Growth* (Meadows et al, 1972). The global modelling approach used was aimed to give insight into the limits of our world's ecological system and the constraints it puts on human numbers and activities. von Bertalanffy (1975) is another example of an early actor involved in the development of systems analysis. His major contributions are the development of a kinetic theory of stationary open systems and the general system theory. He also emphasizes the similarity between different types of systems, e.g. economical and ecological systems.

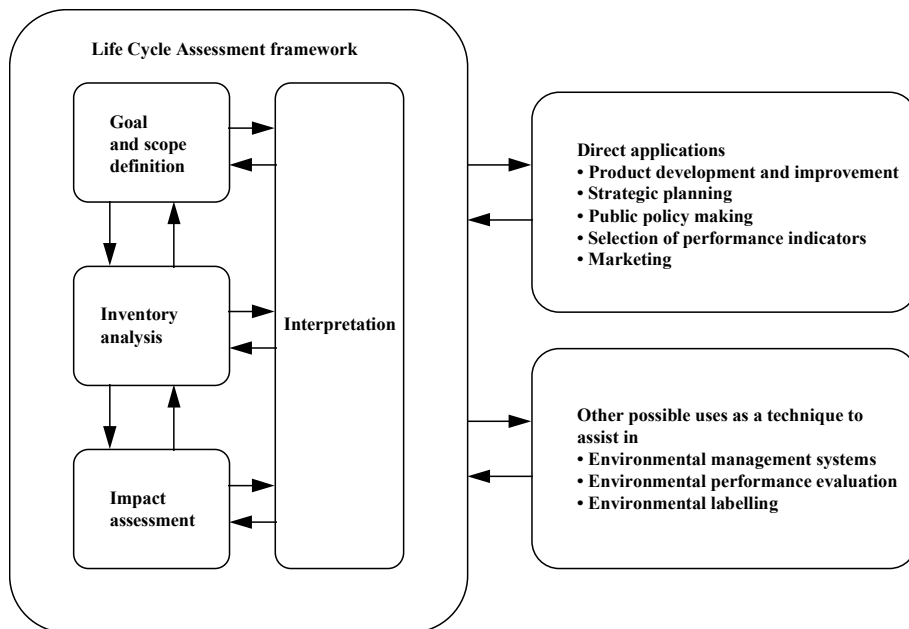
The correspondence between model and reality is a well-known problem within the philosophy of science (as well as among sailors with bad charts on shallow waters). When applying systems analytical tools there is a risk that the results are seen as the reality itself and not enough related to the model behind. In line with these thoughts Baumann (1998) suggests that the LCA process and the LCA model should be clearly

distinguished. The LCA model consists of the life cycle phases in the technical system (identified as relevant), like raw material extraction, raw material production, transports, manufacture of the product, use and scrapping of the product. The LCA model offers a base to allocate the environmental burdens, e.g. the pollutants and resource use, to the various parts of the life cycle of the studied technical system. The LCA process represents the practical working process used when conducting a LCA.

### The LCA technique

The framework for conducting and reporting LCA studies is defined by the internationally agreed standards ISO 14040 - 14043 developed by the International Organisation for Standardisations (ISO). The LCA process is divided into four iterative phases (ISO 14040, 1997): goal and scope definition, inventory analysis, impact assessment and interpretation, see fig 1.

**Fig 1. Phases of the LCA process according to ISO 14040 (source: ISO 14040, 1997).**



#### Goal and scope definition

”The goal and scope of a LCA study shall be clearly defined and consistent with the intended application”. ”The scope should be sufficiently well defined to ensure that

the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal. LCA is an iterative technique. Therefore, the scope of the study may need to be modified while the study is being conducted as additional information is collected” (ISO 14040, 1997). To define goal and scope is an important groundwork in the start phase of a LCA study. LCA studies can be conducted with many different types of goal and scope definitions. It is of importance how e.g. the technical system is identified, how the system boundary is defined and how the environmental burdens are allocated. Considerations related to inventory data, like level of detail and data quality are critical since they strongly influence the cost for the study. The system boundary has to be considered from different points of view, e.g. in relation to the time perspective and the geographical location. The function of the technical system should be as clearly specified as possible since this influences the choice of the functional unit to be used as an allocation basis for calculation of the environmental impacts. A proper definition of the functional unit is of special importance when comparing different types of technical systems (see e.g. paper II). One example of a functional unit for an electrical generator is per GWh output electricity, i.e. (GWh produced electricity)<sup>-1</sup>. This functional unit is then independent of the total lifetime. Furthermore allocation principles have to be considered, e.g. if more than one product is produced in the same production process.

### Inventory analysis

”Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system...”(ISO 14041, 1998). Inventory analysis is often referred as the most time consuming phase of a LCA, see e.g. paper I, and is thus critical in relation to the objectives of this thesis. Access to inventory databases containing data for various unit processes is one potential way to facilitate the inventory work. Input data to inventory analysis has to be collected for many different unit processes like:

- Manufacturing, e.g. amounts and types of materials and energy used.
- Transports, e.g. distances and modes of transports.
- Use of the product, e.g. energy use and amounts of maintenance materials.
- End of life, e.g. dismantling-, scrapping- and waste treatment processes.

## Impact assessment

In the first step of impact assessment, classification, the environmental impacts are assigned to different environmental impact categories, e.g. global warming or acidification (ISO 14042, 2000). There is no universally accepted set of impact categories to be used in the classification step. Lindfors (1995) suggests a set of 15 environmental impact categories. In the next step, characterisation, the total impact is calculated within each category by using characterisation factors. In the final weighting step, the values for all impact categories are aggregated to one single value, using weighting factors. Several different weighting methods have been developed. Some of them are based on national political goals for pollution reduction or on the willingness to pay for either impact on human health and ecological status or to restore/protect certain safeguard objects (Braunschweig et al 1996, Steen 2000). The epistemological problem related to the weighting step are many and also of great magnitude. The difficulties to create a common denominator with which to compare the impact of different kinds of emissions and to obtain additivity (i.e. make it possible to aggregate results) are obvious. In particular this is a problem when impact profiles differ between various emissions categories. To compare the impact of emissions with those of resource depletion (or activities like deforestation) adds to the methodological complexity as do the existence of synergies between emission categories and the fact that the localization of impact activities in space and time may be important. It could therefore be argued that the weighting step in impact assessment is moved to the interpretation phase. The impact assessment phase will then become a procedure based on natural sciences and weighting becomes a natural part of an already value based interpretation process. Impact assessment is further discussed in the concluding section 4.

## Interpretation

The interpretation phase is a systematic procedure to identify, qualify, check, evaluate and present the information from a LCA study in order to meet the requirements defined in the goal and scope of the study (ISO 14043, 2000). Interpretation includes communication of the result and serves as an important link between the LCA technique and its' applications. An issue to deal with in the interpretation phase is the comparability aspect, e.g. what system and system level with which to compare. The

interpretation phase and then especially the problems related to result presentation is further discussed in the concluding section 4.

### **LCA applications**

LCA applications are outside the scope of the LCA process according to ISO. In Christiansen et al (1995) four main applications of LCA are listed based on input from 38 LCA experts from Europe and US/Canada: LCA in strategic development of companies, in product development and improvement of product systems, in marketing and in development of governmental policies and regulations. Curran (1996) lists a number of applications and especially points out life cycle design, eco labelling and development of public policies. She also stresses that LCA is as much a concept as it is a tool, since there are many possible ways to conduct a LCA within the established framework. According to Finnveden and Lindfors (1992) the main application for LCA is in product and process development and for strategic decisions, with strategic decisions pointed out to be the most important. According to Baumann (1998) LCA has been used in a broad range of applications but more as a tool for learning than a tool for supporting single decisions. This last conclusion fits well to the findings presented in paper III where the concrete economical, technical and ecological benefits from the LCA tool was modest, but the organisational knowledge accumulation was seen as an important outcome.

### **2.2 The LCA development process**

Methods for analysing the environmental impacts over a products life cycle have been used since late 1960s. In connection to the oil crisis 1974 an increase in conducted LCA studies could be observed, then mostly limited to analyses of energy balances. At that time no commonly accepted standard defined how to conduct LCAs, which meant that a wide variety of environmental assessment techniques were developed, e.g.: ecobalance analysis, resource and energy profile analysis, product line analysis, integrated chain analysis, product life cycle assessment, life cycle analysis and life cycle assessment. Despite the variations in approaches there is a family resemblance between them since the scope for all of them is (more or less) the product life cycle. It was however in the end of 1980s that LCA became a more widely used tool. The

scientific organisation Society of Environmental Toxicology and Chemistry, SETAC, has been a major actor in the LCA development process during the 1990s (SETAC, 1990). Several LCA guidelines were published during this period, e.g. Heijungs (1992), Consoli (1993), EPA (1993) and Hansen (1995) indicating a demand for a harmonised LCA methodology.

In 1993 ISO, the International Standardisations Organisation, started a project for environmental standardisation within its technical committee *ISO TC 207 Environmental Management Standardisation*<sup>1</sup>. TC 207 was divided into five subcommittees (SC), which in turn were divided into a number of working groups. SC5 was set up to standardise the LCA methodology. The first LCA standard, ISO 14040, was published 1997 and the fourth, ISO 14043, during year 2000.

The LCA technique also became the subject for academic studies, and a selection of PhD projects are shortly presented below. The selection is made to exemplify the wide range of issues investigated, from technically and mathematically oriented issues to empirical studies of LCA applications and practice. Some of these PhD projects are of more relevance than others in relation to the scope of this thesis and are discussed further in the concluding section 4.

Weidema (1993) was an early researcher in this area and he gave suggestions regarding a broad panel of aspects related to the LCA technique, e.g. quality analysis, classification, weighting and applications within the food industry.

Rydberg (1994) studied the development of more environmentally sound products and used LCA as one suitable tool in this process. He also gave general contributions to the development of the LCA technique.

Guinée (1995) outlined a general framework for LCA. He pointed out that the problem oriented design of the classification and particularly the proposal for equivalency factors could be seen as an important contribution to development of the

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<sup>1</sup> <http://www.tc207.org>

LCA technique. His proposal for equivalency factors is fundamental for the LCA tool functionality since these factors form the basis for calculating environmental impact numbers in the impact assessment phase.

Baumann (1998) did not take a traditional departure in the barriers identified to prohibit proper LCA use, but instead she dealt with the practice of LCA. She used a multidisciplinary approach combining knowledge from both engineering sciences and social disciplines and then especially organisation theory. Two different types of LCA were identified, life cycle accounting and life cycle assessment. The former is based on a modelling strategy characterised as full and complete and the latter as relevance guided. According to Baumann LCA has been used in a broad range of applications but more as a tool for learning than a tool for supporting single decisions. This is in line with findings from paper III where the concrete benefits from the LCA tool was described as small. It is also in line with findings from paper I where the aspect of organisational learning is emphasised. She pointed out that the presence of a LCA entrepreneur is fundamental for things to happen, since both understanding of the LCA methodology and the problem to get commitment for conducting LCAs are common practical problems.

Finnveden (1998) discussed possibilities and limitations of LCA as a decision-supporting tool. He states that fundamental ethical and ideological valuations, perceptions and worldviews influence not only the weighting factors, but also the choice of weighting method. Another conclusion was the difficulty to show environmental preference for any of the different alternatives in the cases studied. The LCA results can anyhow give important guidance for decisions by helping identify aspects of the product that are of importance as well as of limited importance for the outcome. Finnveden concludes that policymakers and other decision makers must realise that LCA is a complex technique and that decisions have to be taken without complete information. Finnveden's conclusions are relevant in this thesis since he emphasises that it is not possible to assign 100% preference for one product in a comparative LCA. Even if the LCA study is conducted on a very detailed level there are always uncertainties and other inherent properties in the LCA technique that cannot be fully controlled. This means that there must be a trade off between cost and

benefits of the LCA results, the challenging and presumably very difficult issue is to find this trade off.

Business development, and its' relation to LCA, has been discussed by Karlsson (1998). He claims that the possibilities to develop eco-efficient products are not fully utilised depending upon a lack in alignment between business goals and environmental goals: "...it is difficult to bring the environmental viewpoints into concern with business concerns. There is a lack of conformity, or even an almost unexplored paradigmatic misfit, between different sciences. This may be observed as an incompatibility, for example between environmental ambitions and short-term profitability goals, between static and dynamic views... ". He identified a clear need for analytical techniques, like LCA, as one driver to implement environmental issues into the business process. Karlsson also identified the importance of a correct valuation of resources and suggests that firms and other actors must use and reuse resources much more efficient in the future to stay in business. He also pointed out that resistance to technological change, e.g. professional traditions could be a potential barrier in the development of eco-efficient technologies.

Hofstetter (1998) claimed that LCA is full of subjectivity and that these elements are not clearly distinguished from the objective elements. He suggests a modelling approach for the value sphere (weighting according to ISOs definition) comparable to modelling of the technical system. The problem of weighting different impacts is also raised in paper II.

Frischknecht (1998) introduced a disutility function to calculate the social cost, by combining private cost and environmental information into one formula. This makes it possible to judge marginal contributions of the technologies in the economic system by using an operational context and to visualise the consequences of decisions.

Ekvall (1999) described the importance of the choice of system boundary and allocation method. He points out that different choices in these parameters give very different results and conclusions. The question of defining the system boundary is one major issue raised in paper II and also takes us back to the complexity problem

discussed by Finnveden: a too wide system will probably be too costly and time consuming to handle and if defined too narrow the system will provide results without relevance.

Bras-Klapwijk (1999) identified a need for product assessment tools, like LCA, in public policy making. She observed that results from most LCAs are not conclusive due to the complexity and uncertainty of the LCA technique. One reason for this is the multi stakeholder perspective that must be considered in policy making. She suggests an alternative and slightly modified LCA methodology to be used in public policy making. This method is based on a shift of attention from attempts to enhance the objectivity of LCAs, to instead accept LCA with its uncertainties and basis in value choices. In line with Finnveden she concludes that decisions have to be taken even without complete information and this conclusion is very relevant in relation to the scope of this thesis.

Most of the findings retrieved from the empirical material in paper I to III are also discussed in the referred PhD projects. There is furthermore a good conformity between conclusions in the empirical material and the reviewed PhD projects. One issue not (completely) covered in these PhD projects is to view LCA from a management perspective and to use management control and management accounting theories as objects of comparison. The aim for this thesis is to fill that gap.

Another part of the LCA development process was conducted through various joint projects, involving industrial, governmental and scientific organisations. The common goal was to develop the LCA technique into an operative tool. Examples of joint projects are:

The Swedish *Product ecology project* engaged twelve Swedish companies, Chalmers Technical University, the Swedish Environmental Research Institute (IVL) and the Federation of Swedish Industries during 1993-95 (Ryding, 1995). The preconditions for this project can be traced back to Volvo who in 1989 developed a prototype to a LCA software tool named the EPS system together with IVL (Steen, 1994). This initiative obtained a substantial interest from other industries and Volvo together with

ABB, Electrolux, Akzo Nobel and STORA agreed to start the Product ecology project during 1993. The goal was to develop LCA into an operative environmental management tool based on Volvos experiences from the EPS system. The substantial interest for the project resulted in more than a doubling of participating companies, from five to twelve companies in a short time.

The *Nordic project for sustainable product development* started in 1994, with participants from the product ecology project and additional participants from Sweden, Norway and Finland. The project was focused on developing LCA database software and LCA applications. The project resulted in a methodology, sustainable product development, which combined LCA with cost issues through life cycle cost analysis and structuring of customer demands for ecological information through quality function deployment (Hansen et al, 1995). The LCA database structure SPINE (Steen et al, 1995) was developed in this project. Several public databases and commercial LCA software systems are today based on this database structure (see e.g. <http://www.globalspine.com>).

*CPM, Centre for environmental assessment of Product and Material systems*<sup>2</sup>, started 1996, and can be seen as a long-term continuation of the two projects described above. CPM is a joint project involving Chalmers Technical University, 12 Swedish companies and NUTEK, Swedish Board of Technical Development. The number of participating companies increased to 15 under 1998.

The short review above is only aimed to present some joint projects. Other LCA joint projects were also conducted in the same time, e.g.: the Dutch *Eco-indicator* project (Pré, 1993), the Danish *UMIP* project (Wentzel, 1996) and the Japanese project *concepts of inverse manufacturing for sustainable system* (Mooto).

The increased LCA tool use during the first half of 1990s and the (probably to large) expectations for easy to use and reliable LCA tools gave some bad reputations for LCA as an environmental assessment technique. From industrial point of view the

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<sup>2</sup> <http://www.cpm.chalmers.se>

results were often perceived as ambiguous and not generally applicable (Baumann, 1998). Viewed from the scientific community the LCA technique was seen as a to all-embracing and non-specific technique (Finnveden, 1998). From the middle of the 1990s the limitations connected to the LCA methodology were more commonly understood (Finnveden, 1998, Bras-Klapwijk, 1999). One reason was the harmonisation of LCA obtained by development of LCA ISO standards. Another reason was the base of user experiences built up in the first half of 1990s. The LCA development process can be described both as a learning process and a methodology development process (Baumann, 1998). The view of LCA as being a calculation tool during the first half of 1990s was completed with the view of LCA as a tool for education and competence build up.

Two very different perspectives and views on LCA can be identified:

- The first is LCA as a technique demanding further research and access to more input data to be operative.
- The second is LCA as a useful technique presumed that the user is well aware about the complexity and uncertainties of LCA when the results are applied.

Both perspectives can be found in the empirical material in this thesis. The first can be seen in e.g. paper III that requests a development through more efficient LCA tools. The second can be seen in e.g. paper I. These two perspectives create an important basis for the concluding discussion in section 4.

### **3 On management and control in industry**

LCA may- as mentioned earlier- be looked upon as a tool the application of which is intended to increase the control of environmental burdens originating in industrial activities in a wide sense and thus also to increase the control over the details of the industrial process itself. The word control can be understood in different ways, one example of a general definition is “purposive influence toward a predetermined goal” (Beniger, 1986). The rapid spread of this new controlling device during the 90s- mainly developed outside the context of other management thinking- may be analysed from many perspectives; there are similarities and parallels between the environmental management tool LCA and other control ambitions from the history of industrial transformation.

First of all the high ambitions to capture the details of industrial complexity may be analysed in relation to the general control problems facing the industrial society. In fact some scholars argue that the enormous demand for control data in this process create the foundation for the present information society (Beniger, 1986).

Secondly, on a somewhat lower level of aggregation this may be analysed as a variety of the problem of obtaining control over the industrial process (and the men involved in them), a phenomenon which is well known from the history of industrial transformation (cf. Laestadius, 1992). The modern history of management control originates in the experiences from control struggles and experiments around the shift between the 19th and 20th century (cf. Taylor and Ford) and the heritage from that phase is obvious in the literature on industrial management and plant production control from the first half of the last century (cf. Koepke, 1941).

Thirdly the modern growth of management accounting- i.e. how to control the cost of industrial activities- has its origin in the development of tools for solving the general management control problems and has for a long time been focused on how to obtain and transform information from the production system to comparable cost data and to analyse these data (Lind, 1996).

Fourthly we may also use a more cultural /anthropological perspective in our attempt to understand the control dimensions of the LCA tool. Levin states that control and technology have similar connotations and are nearly interchangeable, but adds that

engineers and managers today try to control large technical or socio-technical systems (Levin, 2000). Levin gives a more pessimistic picture of the possibility to control socio-technical systems in contrary to Koepkes “machine controlling perspective”. One reason is that Levin’s perspective see human beings and their (irrational) behaviour as part of the system, thus making it much more complex and less controllable. To what extent does the very high ambitions to obtain a centralised control of all the details of the material flows in the production process mirror some of the values of engineering culture? Is the LCA tool - which seems to be attractive within the engineering community- a necessary tool (although modified) or is it just one very control oriented tool among many possible solutions?

Although all these dimensions are worth a deeper analysis we - too stay within the format of a licentiate thesis- restrict ourselves to the second and third dimensions. Below we first discuss management control in general (3.1). Thereafter we focus on management accounting (3.2), which may be looked upon as narrowing the management control perspective to (one of) its core arena(s). Based on these theories some parallels and similarities are drawn as regards LCA in the concluding section 4.

### **3.1 Management control**

Even if management control was to some extent defined already by Taylor and Weber, we start by giving the core of Anthony’s classic definition of management control: “The process by which managers assure that resources are obtained and used effectively and efficiently in the accomplishment of the organisation’s objectives” (Anthony, 1965). He describes a hierarchical system where management control is seen as a technical tool to link strategic planning and operational control. He also sees management control as a planning and coordination function as well as a monitoring and feedback function. Anthony have been criticised by several authors, among them Otley et al (1995) for focusing too much on the accounting perspective and not considering the context where the management control system is used. These authors conclude that a result of this narrow perspective is that attention has been focused on exercise of power more than on the role of the control system as a means of organisational survival. Lowe (1971) gives a broader definition of management control also including the organisational context that Anthony’s theory was lacking.

This contingency-based, or situation based, research has been one dominant paradigm for management control research (Fisher, 1995). Fisher also describes different levels of contingent control analysis where the contingent factor correlates with a control system mechanism and relates this to the outcome.

Management control systems can also be seen as a broad set of control mechanisms to be used for self-regulation. Mary Parker Follett was an early researcher stressing these self-regulating and self-directing aspects (Parker, 1986). Otley et al (1995) include the ideas of information feedback and the implementation of corrective actions into the definition of management control. The self-regulation perspective is of interest in relation to the LCA tool since this could be one way to minimise the need for centralised LCA systems and databases, and thus to decrease the cost and increase the efficiency of the LCA tool. If e.g. a market mechanism is introduced each actor could be stimulated to take responsibility for its specific part of the environmental impact. Each actor could then take proper actions (since they know their own systems best) resulting in a cost-efficient system for minimisation of life cycle environmental impact from products. This idea is further discussed in paper IV.

Scott (1981) used organisation theory to explore management control, and he distinguishes between rational and natural systems models. Another way to classify management control is as closed or open system models. Some authors argue that it is not correct to talk about management control, since it is never possible to have control on all actions in a company. This is illustrated by the title *Illusion of control* in a paper by Dermer and Lucas (1986). They conclude that what is required to more effectively implement managerial control systems is a combination of task, behavioural and political perspectives. This is a challenging idea, but probably very relevant to consider in relation to LCA, since the acceptance of this fact could give a realistic picture of what could and should be controlled.

Management control is according to Merchant (1998) a critical function of management and he suggests a broad definition of the term management control. Merchant includes activities like human resource management, codes of conduct and supervision as parts of the management system even if these activities do not focus on

performance measurement. Management control can be both reactive and pro-active and it is seldom possible to find a perfect or single best alternative of a management control system. This is relevant in relation to the LCA tool since this could give a realistic picture of what type of information that could and should be requested from this tool viewed from a management control situation. In each management decision situation very different types of information have to be weighted together into one conclusion. It could then be enough to have a relevant but not too detailed picture of the environmental impact over the life cycle of the product. The environmental information does not necessarily need to be weighted together into one single score since management are trained to handle large amounts of information in processing of a decision. Aggregation of LCA results should therefore be done with this in mind and not done for its own sake.

Pro-active actions are often seen as the preferred types of actions in management control. The primary function of management control according to Merchant is to influence behaviour and stimulate all types of actions leading to desirable results. This is a sharp contrast to the cybernetic and technical view on management control, often compared with a single feedback “thermostat” loop system. Merchant describes three types of potential control problems that should be considered when developing and implementing management control systems: lack of direction, motivational problems and personal limitations. From an ecological point of view the “lack of direction” problem is critical but difficult to handle in practice. Even if the goal on a highly aggregated level is sustainable development, it is far from easy to translate this goal into operative goals on firm and/or product level. Without specific goals it is also difficult to know what actions to take on an individual basis giving a risk for contra productivity and sub optimisation. An important but challenging task for management should therefore be to define ecological goals and targets on different organisational levels. The motivational problem is closely related to the direction problem since it is difficult to find motivation without clearly defined goals. The problem with personal limitations should also be considered since ecological issues are relatively new components in management control decisions, and education is necessary. The role for the LCA tool as an educational tool for engineers and other decision makers in industry should therefore not be underestimated.

Merchant furthermore describes three different control alternatives: action control, result control and cultural control. In action control it is important to have a clear understanding of what actions that lead to what results.

Action control is of some interest in relation to environmental management since the commonly used environmental management system ISO 14001 can be seen as an action control methodology. ISO 14001 is built on procedures and instructions aimed to stimulate concrete actions expected to result in continuous environmental improvements. A general problem with action control tools is how to make them enough flexible to fit into the dynamic and complex reality of most firms' daily business life. If these tools are wrongly designed there could be a risk that they hamper innovation and business development.

Result control is a commonly used control methodology when professional employees are to be controlled. Targets can then be budgeted and the employees can decide themselves what actions to take to achieve the desired result. LCA can be seen as a potential result control tool since performance measurement is one goal for the LCA tool. A critical management role would then be to set these goals and targets, as already discussed above.

Cultural or personal control builds on employees' natural tendencies to control themselves and is to some extent part of all control systems. The social mechanisms involved in this type of control can both stimulate and prohibit desired actions. There are good reasons to believe that firm cultures with a positive "atmosphere" related to environmental issues could stimulate employees to take environmentally sound actions more often than employees in companies without such culture. Professional traditions and pressure from colleagues ("we have always done it in this way") could effect in the opposite direction and prohibit environmentally sound actions. See also Karlsson (1998) who discussed barriers, like professional traditions, in development of eco-efficient technologies.

### **3.2 Management accounting**

Management accounting may be looked upon as a more narrow perspective compared to management control. Management accounting is focused on development and

improvement of information systems, often with the goal to find one best solution to the control problem. Agency theory is one approach used in management accounting research (Eisenhardt, 1989 or Indjejikian, 1999). The main idea behind this theory is the principal-agent relationship that could be seen as a solution to the risk-sharing problem. A critical issue in the agency theory is performance evaluation and compensation since they affect employee's incentives to increase shareholder value. During the latest decades management accounting has been criticised by several authors (Johnsson, 1992 and Johnson, Kaplan, 1987). One part of the criticism is related to the level of aggregation for information retrieved from management accounting systems, resulting in loss of important details. Another part of the criticism is related to the fact that accounting information is based on historical information and gives a bad guidance for decisions related to the future. Management accounting also reflects a non-complete picture from a model of the reality, and not the reality itself. Management accounting as it developed during several decades' requests large amounts of input data and is thus a resource demanding method. Much work has been spent during the last decades in developing information systems and databases aimed to provide management with economic accounting information. The criticism of management accounting has obvious similarities to the criticisms seen in the LCA community. Since management accounting has been used much longer than LCA it should be relevant to make more use of experiences from management accounting practice in the LCA community. This could presumably increase the efficiency of the LCA tool, and then especially in relation to data and information management.

ABC, activity based cost, has been seen as one possible solution to address the problem with aggregated information. ABC is however connected to other problems, it is e.g. not always possible to trace all costs to a specific product or object based on causality (Lind, 1996). Lind does not conclude that management accounting has lost its relevance, but its use as well as design has certainly changed a lot. His conclusion is that during the period 1985 to 1994 there has been a change of focus from cost to performance for the measurement dimension, and from operation to product for the object dimension. This fits well into the subject for this thesis since the LCA tool is product focused and its aim is to measure the environmental impact (that could be translated to environmental performance) of a product. Lind describes three major

purposes for the use of management accounting: direct personal responsibilities, basis for decisions and direct attention to specific issues. The first purpose is probably the most common application and is often implemented by the continuous budget-calculation- follow up loop. The second is a more discontinuous application used when economic decisions are taken, e.g. investments. The third could be to increase awareness for a specific problem or to identify aspects for marketing purposes. The first and third of these perspectives are most relevant in relation to LCA. If the LCA tool is used as a result control tool, as also been discussed in 3.1, the environmental impacts could be “budgeted” based on LCA results and it should then be easy for management to follow up the result on product level. It should however be emphasised that management as a starting point then must- as well as setting economic objectives and targets- set clear ecological objectives and targets on product level.

## **4 Results and conclusions**

Industrial users perceive LCA as a relevant but not enough cost efficient tool. The LCA tool do not seem to be enough integrated in operational activities or linked to other established management tools, see e.g. paper III. Two major tasks have to be dealt with if LCA should become a sustainable tool in industry. The first is to improve the efficiency of the LCA tool itself and the second is to define the role of LCA in relation to management control, e.g. by identifying the demands for ecological information in different management control situations. One main road to improve the efficiency of the LCA tool is to “build away” the drawbacks, e.g. through developing databases facilitating access to inventory data. It is however important to not underestimate the costs to develop and update the databases as well as to define responsibilities and other requirements related to them. Another opposite main road is to narrow the scope and develop LCA into an easy to use and resource efficient tool aimed for coarse judgements with the option to conduct more complete assessments when necessary. These two alternatives are not necessarily in opposition to each other. The best solution would probably be to explore both in parallel.

The role of LCA in management control is the most critical aspect to elucidate and the large base of experiences from other management control ambitions, as e.g. management accounting could be used in this work.

### **4.1 Efficiency of the LCA tool**

The efficiency of the LCA tool is by LCA tool users described to be modest, i.e. the beneficial outcome related to the cost from using the tool. The efficiency of the tool depends upon many factors, e.g. the large amount of inventory data requested by the tool and the complexity of the tool, see paper I and III. Various measures could be taken to enhance the efficiency of the LCA tool. Easier access to inventory data is one potential way to decrease the cost for conducting LCA studies and thus to increase the efficiency of the LCA tool. Development of scientifically based methodologies to control and improve the quality of data is one way to solve (some) problems related to inventory data compilation. (Weidema 1993, Lindfors et al 1995, Bahr 2001). Another route to make the inventory analysis phase more efficient and to handle the balance

between transparency, aggregation and quality is to develop quality assured and publicly available inventory databases (Suter et al, 1996, Carlson R et al, 2001). Inventory databases related to commercial organisations have also been developed, the credibility of them could however be questioned. Publishing them, thus making the data open for critics from anyone, is one way to control the quality and increase the credibility of such databases (Boustead 1994). Development of “public” databases containing inventory data however raises many questions that should be considered:

- Economic aspects. The costs for developing and maintaining inventory databases are easy to underestimate and experiences from implementation of management accounting systems could be very useful when inventory databases are developed. Irrespective of whether the databases are organised by governments or on private base they have to be financed. It may be assumed that those who use these databases may be forced to pay most of the bill. It is far from obvious that taxpayers should pay for the control tools used in industry.

- Judicial aspects, e.g. ownership of data and confidentiality issues. If a company develops a unique product with low environmental impact it could be difficult to motivate them to give away detailed inventory data that could (direct or indirect) expose unique process and/or product solutions to competitors. This could be solved by aggregation of the data but then there is a risk to loose transparency and credibility. Signing confidentiality agreements between the partners could of course solve this problem, but this is not a trivial procedure. Using data from a public database creates also problems on who should be responsible for trustworthiness of the data and, in the end, the LCA.

- Organisational aspects, e.g. centralised and/or decentralised, national and/or international databases? What organisation/s could and should be responsible for the databases?

- Political aspects, if and then what type of involvement (control) from governmental organisations is relevant and/or desirable? Should these databases be driven by market mechanisms or controlled by policies and/or regulations? International/ regional/ national trading policies and agreements is another political aspect.

- Long-term survival of the databases. What driving forces and incentives can be identified and are they strong enough to keep the systems alive for more than an initial (probably subsidized) period?

Another obstacle related to efficiency is the perceived complexity of the LCA tool, since there is an obvious risk that complex tools demand a lot of resources to learn and use. This is especially true for those users who conduct a LCA for the first time in an organisation, see e.g. paper I. One reason for this perceived complexity is probably the system analytical character of the LCA technique. LCA consists of many different elements and dimensions and it is understandable that a beginner in the LCA field perceives the LCA technique as complex. Researchers, e.g. Finnveden (1998) and Bras-Klapwijk (1999), also bring up this complexity issue. Finnveden concludes that decision makers must realise that LCA is a complex technique and that decisions have to be taken without complete information. Bras-Klapwijk concludes that LCAs are not conclusive due to complexity and uncertainty of the LCA technique. The perceived complexity is probably possible to overcome only by properly designed education programs, aimed to clarify the system analytical character of the LCA tool, and giving the user a realistic perspective of the possibilities and limitation of the LCA tool.

Another (more indirect) aspect related to efficiency is to utilise the result from conducted LCA studies in as many applications as possible, since each LCA study represents a relatively high cost. This should however be done with some care for already made LCAs since each LCA study is based on a specific goal and scope definition including a description of the intended application/s. One LCA application that could be used on a more regular basis is to use the results as input to other actors in the value chain, since most products in industry are manufactured through complicated production chains and networks which involves not only different plants but also different firms. This application is of special importance to explore for manufacturer of complex products that consist of many different components and subsystems, like cars, electronic and electrotechnical equipment. This inter firm perspective on LCA is discussed in paper IV and property right and transaction cost theories discussed in this paper should be considered also in this type of value chain application. The property right issue is related to ownership of the problem, capability to solve the problem as well as to access to information. If these aspects are not present in the same organisation (asymmetric information) it is a built in conflict that has to be handled either by changing or extending the property rights and obligations

for some actor/s or by transaction of information from one actor possessing the best information to another actor. Then, however, the transaction cost, i.e. the cost for compiling and transferring the information has to be considered and minimised. The potential for cost efficient improvements should be higher and the risk for sub-optimisation lower when actions are taken on inter firm level. The actor who possesses the best capability could then take desirable actions by giving them business incentives to take these actions. Business incentives are critical for all types of environmental management activities and thus also important to consider for achieving an efficient LCA tool use. The methodology suggested in paper IV could then also serve as a theoretical base to bridge the gulf between ecological and economical goals that Karlsson (1998) identified as a major problem.

#### **4.2 Relevance of the LCA tool**

The empirical material shows a positive picture of the perceived relevance of the LCA results. Furthermore LCA is judged to be a sustainable tool in the management toolbox and LCA gives an enough good basis for taking decisions in a sustainable direction, see e.g. paper I and III. Rydberg (1994) describes the LCA tool as relevant in product development. Both Finnveden (1998) and Bras-Klapwijk (1999) sees LCA as a relevant tool presumed that its assumptions and limitations are well known. Karlsson (1998), identified a clear need for analytical techniques, like LCA, as one driver to implement environmental issues into the business process. Paper I indicates that LCA use in the product development process may result in a more eco-efficient product. To conclude: LCA seems to be a relevant and useful tool, e.g. in product development, despite its low efficiency. However a prerequisite is that the user properly understands the limitations and assumptions behind the LCA result as well as the result itself.

The LCA results can be presented in more or less aggregated form, e.g. in diagrams, tables or written text or in different combinations of them. Aggregated indexes are often criticised to oversimplify the reality and to aggregate entities that are not comparable. As discussed in section 3.1 it is not necessarily desirable to “simplify as much as possible”, e.g. by weighting the impacts together into one single score.

Management's responsibility and skill is to handle large amounts of information and to compile this into a decision. Ecological information is from a principal point of view neither easier nor more difficult to handle than other types of information. Aggregation of LCA results should be done with this in mind and not done for its own sake. An alternative or complementary way to aggregating data, to enhance the relevance of the LCA results, could be to develop new presentation models for LCA results. Such models have been developed for e.g. economic information (Walldius, 1997). He suggests a multidimensional presentation model considering several aspects in the same diagram.

### ***4.3 LCA versus management control and accounting***

LCA is, as already mentioned, (mostly) not implemented in normal operational procedures and the tool must therefore be more properly integrated and/or linked to other established management tools. The low level of integration of the LCA tool in normal procedures corresponds well with Baumanns (1998) conclusions that LCA has been used more as a tool for learning than a tool for supporting decisions. Learning can be seen as a beneficial outcome from the LCA tool, but some researchers do not agree in this statement. Ekvall (1999) as one example argues that “ a LCA practice is good, if, and only if, it can be expected to result in environmentally sound decisions and actions. Decisions are here perceived as environmentally sound if they result in lower environmental burdens per functional unit than would have been the case without the LCA”. In this thesis we agree in the opinion that organisational learning should be seen as a positive outcome of LCA tool use.

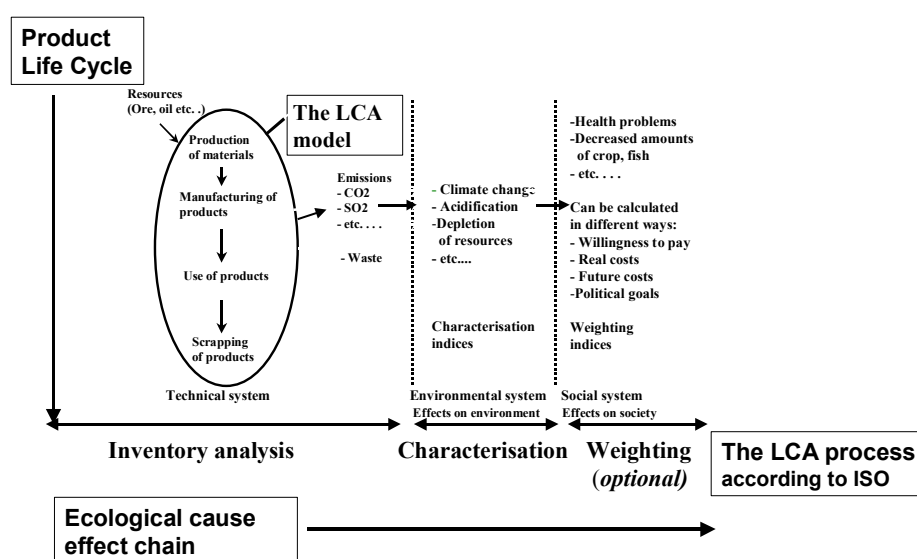
The general control perspective, i.e. to control the environmental performance from a company's activities, is important to consider when the LCA tool is implemented in industrial organisations. This should be looked upon from a cost perspective to find a proper balance between costs and benefits. Viewed from a management control perspective it is neither possible, nor cost-efficient to control all types of aspects on an organisation or process. LCA could in this controllability perspective serve as a management control and priority setting tool, provided that the LCA is conducted in a cost efficient way.

The questioning of management accounting is very similar to the questioning of the LCA tool, as already been discussed in 3.2. Management accounting experiences, e.g. related to input data and information systems could be of special importance for the LCA community to explore further. The situation for the LCA tool is however even more complex. Results are expressed in monetary values in management accounting, but as a vector of information in LCA. The data could of course be aggregated to one value in LCA as well, but the quality and relevance of the results could then be difficult to judge.

#### 4.4 Elements in the LCA technique- a presentation model

With the aim to facilitate the understanding of the complexity and systems analytical character of the LCA technique we suggest a model for visualisation of the most critical elements in one figure (fig. 2). This could offer a better understanding of the LCA technique as well as the relations between its different components in line with the need identified by Baumann.

Fig 2. Elements in the LCA technique.

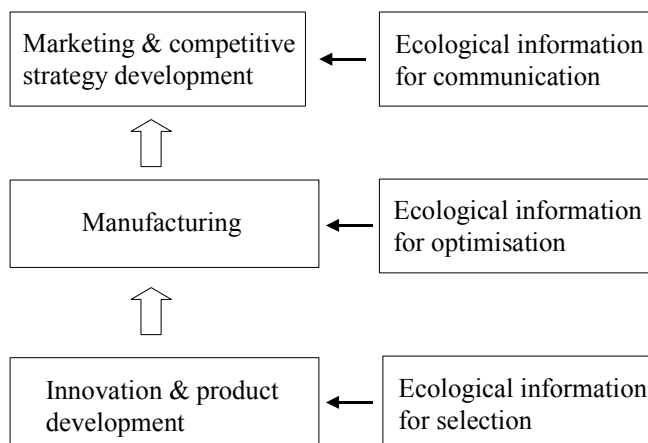


Comments to fig 2: The definition of a *LCA model* of the technical system (product, system or service) forms the foundation for conducting a LCA study. The LCA model defines the relations between all included unit processes. Examples of included unit processes could be manufacturing of steel and lorry transports, unit processes could also be much less aggregated, like annealing of a piece of steel or heating of a liquid. The LCA model defines the system boundary between the technical system and the environmental system. Resources from the environmental system, like iron ore and wood, are inputs to the technical system. Emissions and wastes are outputs from the technical system to the environmental system. The *product life cycle*, often called “cradle to grave” represents all relevant life cycle phases in the products life cycle, starting with extraction of raw materials from the earth to scrapping of the product. The *LCA process* defined by ISO is a process to compile and evaluate inputs, outputs and the potential environmental impacts from a technical system or product system throughout its life cycle. The three interrelated systems in the *ecological cause effect chain* are: the technical system, the environmental system and the social system. This chain could start with e.g. carbon dioxide emissions from the technical system resulting in a potential climate change effect that as a next step could be translated to a total cost for the society through weighting.

## 5 Future outlook

Two major tasks have to be dealt with if LCA should become a sustainable tool in industry. The first is to improve the efficiency of the LCA tool, as already been discussed in section 4. The second, more unexplored task is to define the role of LCA from a management control perspective. This is probably also relevant for most other types of environmental management tools, but we limit our scope to the LCA tool in this thesis. Future developments of the LCA tool should be based on the information necessary (and not necessary) for management decisions and control of environmental burdens from industrial activities. Experiences from other management tools, e.g. management accounting could be utilised more, since these areas have a much longer tradition and are more commonly used than LCA tools. It is also important to define environmental objectives and targets for products; else it is very difficult to implement any type of environmental management control system and consequently also LCA into industrial organisations. As a final part of this thesis we suggest a model that illustrates the demand for environmental information in different management control situations, see fig 3. It should be emphasised that this model is only aimed as a principal model and starting point for future work. The situation is much more complex in reality when production is conducted in complicated production chains and networks.

**Fig 3. Demands for environmental information in different management control situations.**



Comments to fig 3: the three boxes at the left represent the main process in industrial organisations. The other three boxes are examples of supporting processes, here processes for supplying ecological information, but there are also numerous other supporting processes in a company. The main process should define the demands for ecological information. Innovation and product development processes could, as one example demand ecological information to support selection, since a major task in innovation processes is to select the best alternative among several different alternatives. In manufacturing of products it is a common goal to strive for cost reduction, i.e. to optimise the production process and the product. It is furthermore necessary to outline a marketing and competitive strategy and to communicate the ecological performance of the product to the customer in an understandable way. One example of a LCA based communication tool developed the last years is EPDs, Environmental Product Declarations (Swedish Environmental Management Council).

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## 7 Enclosed papers

- I. *Life Cycle Assessment (LCA) in product development of medium voltage switchgears.*

Karlson, L., Fröberg, H., Arnborg, C., Sintorn, J.

Presented at conference “LCA based priority setting in product development” at Chalmers University of Technology, June 16, 1997.

- II. “Environmental aspects of electricity generation from a nanocrystalline dye sensitised solar cell system”.

Greijer, H., Karlson, L., Lindquist, S-E., Hagfledt, A.

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- III. “Ecoefficient products and services through LCA in R&D/design”.

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*Environmental Management and Health*, Volume 12, nr 2 and 3, p.181-190, 2001.

(Selected by the editor and editorial team as the most “outstanding paper” in the 2001 volume).

- IV. “Business incentives for sustainability: a property rights approach”.

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*Ecological Economics*, Volume 40, Issue 1, p.13-22, 2002.