Abstract

Environmental Valuation and Life Cycle Assessment

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Today many companies try to investigate the environmental impacts of their products in a “cradle-to-grave” perspective. In these life cycle assessment (LCA) studies are needed ways to decide which impacts are the most severe and to express overall environmental impact in a simple format. A number of methods to this end have been developed by other researchers.

This thesis investigates how such methods are used and perceived in practice. A need for many different methods to match the world-view of the concerned decision-maker was observed. Another observation was that aggregated measures of environmental impact were difficult to understand and to use in product development and decision-making. It was also concluded that it is important that the analyst in life cycle studies makes clear to the problem-owners that they need to be involved in the study. It was noticed that the view of LCA as being a highly standardised calculation tool can be a hinder for such involvement.

The thesis also discusses some underlying difficulties of measuring values and attitudes for the development of these methods. It was found that LCA methodology is built on a number of assumptions that make such investigations problematic. An example is the idea that environmental damages caused by an activity may be meaningfully assessed without involving the utility provided by the activity. It was argued that people are likely to assess a certain environmental change differently depending on what was the cause of that change.

A further development of LCA methodology and practice requires deepened insights in both these fields: how results from LCA studies are interpreted and used, and how peoples values and concerns for the environment may be investigated and included in such studies.

Key words: life cycle assessment, LCA, environmental valuation, environmental values, systems analysis, weighting methods, modelling, decision-making.

I believe it might interest a philosopher, one who can think himself, to read my notes. For even if I have hit the mark only rarely, he would recognize what targets I had been ceaselessly aiming at.

Ludwig Wittgenstein, On Certainty.

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Research is not a one-man job. My work has been no exception. Without the participation of a number of people this thesis would never have been written.

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Göteborg in April 2000

Magnus Bengtsson

Papers included in the thesis

Paper **I**, *An approach for handling geographical information in life cycle assessment using a relational database,* deals with the modelling of environmental aspects of technical systems in general. It originates from a contribution to a conference on risk and GIS held in 1997. The paper includes a brief presentation of the modelling approach where the social, technical and environmental spheres are handled as separate subsystems. This approach is discussed in more detail in the introductory part of the thesis. The main idea put forward in the paper is that the development of methodology for life cycle assessment (LCA) should be open to the inclusion of site-specific factors. It is argued that this is desirable and feasible for technical, environmental and social information, and that it contributes to the relevance of life cycle studies. In our article we propose a database structure to support LCA modelling with geographically referenced data.

Published in *Journal of Hazardous Materials* 61, 1998.

Paper **II**, *Life Cycle Assessment of Wastewater Systems: Influence of System Boundaries and Scale on Calculated Environmental Loads,* reports the findings of two LCA case studies of wastewater systems. In the paper we also discuss methodological issues related to choice of system boundaries, something that is often not dealt with in a satisfactory way in this kind of studies. It is argued that in evaluations of separation wastewater systems it is highly relevant to include potential effects on the need for mineral fertilisers. We conclude that with too narrow system boundaries new solutions may be treated unfairly, since their potential advantages are not taken into full consideration.

Published in *Environmental Science & Technology* Vol. 34, No. 1, 2000

Paper **III**, *Weighting in LCA: Approaches and Applications,* is a contribution to a special issue presenting various parts of LCA methodology and practice. The paper is an introduction to how weighting of different kinds of environmental loads can be handled in LCA. In a general discussion of the nature of the weighting element, we characterise weighting as a test of how effect profiles match with different value profiles. In relation to this, we also discuss why the weighting element in LCA has been a controversial issue. The paper includes an example where four different weighting methods are used to make LCA inventory data more intelligible and to inform decision situations about the environmental priorities as seen from different perspectives.

Accepted for publication in *Environmental Progress*

Paper **IV**, *Weighting in Practice: Managing Environmental Trade-offs in Life Cycle Assessment*, is the outcome of an interview-based study of how weighting methods are used and perceived in decision-making processes in industry. In this study, weighting was studied as a social activity including communication and interaction between people. Questions concerning the understanding, interpretation, and justification of environmental trade-offs are discussed. One main conclusion is that LCA studies in most cases should not be run as pure expert activities. Active involvement of responsible decision-makers is needed for relevant and effective outcomes of LCA studies. All respondents expressed a need for weighting methods to help in the interpretation of LCA results. They also expressed differing preferences for approaches to weighting.

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1. Introduction

This introductory part of the thesis briefly presents and discusses the life cycle approach to environmental issues and environmental systems analysis in general. It pays special attention to what we can call the social side of environmental systems analysis. This has a double meaning, reflecting both the view that environmental problems are social constructions, and that analyses and assessments of environmental change are always embedded in social processes of learning and decision-making.

THE LIFE CYCLE PERSPECTIVE

The idea of Life Cycle Thinking – studying the overall environmental impacts related to the production, use, and waste treatment of a product – seems appealing at an intuitive level. However, the realisation of this idea in the form of Life Cycle Assessment (LCA) is somewhat problematic, posing many difficult issues. Since the early 1990s, considerable effort has been put into the development of guidelines, codes of practice, and standards in order to facilitate LCA studies (e.g. SETAC 1993, Lindfors et al. 1995, ISO 1997). These guidelines, and the general attractiveness of the life cycle perspective, have led to an increase in LCA studies by both private companies and in public authorities. The development of software tools and databases to facilitate life cycle studies has also contributed to this increase.

The appeal of the life cycle approach is due to a number of factors. One is the desire to avoid arriving at sub-optimal solutions, in which an improvement at one stage in the life cycle causes increased environmental loads at other stages. The idea is that by looking at all stages of the life cycle at once, such mistakes may be avoided.

Another reason underlying the popularity of the life cycle approach is that it fits well with the technology-focused paradigm of contemporary environmental discourse. In most LCAs, environmental impacts are studied in terms of units of consumption or utility, and not on an overall aggregated level, which would be more in line with the often-heard call for increased eco-efficiency. The goal is to improve technology in order to reduce environmental impact per unit consumed, which is much less controversial than trying to reduce consumption levels; in today's economy-oriented view of society, increased consumption seems to be more or less equal to development.

THE MULTI-DISCIPLINARY CHARACTER OF THE FIELD AND THE NEED FOR MULTIPLE PERSPECTIVES

Paper **I** includes a brief presentation of model that describes the world as consisting of three different aspects or subsystems: technical, environmental, and social. These subsystems are not physically separate entities in the real world, but rather different aspects of the same thing. The technical system is largely controlled by humans, while the environmental system is affected by human action, but is not directly controllable. In some cases it is easy to distinguish between the two, as when industries emit gases into the atmosphere or when coal is taken out of a mine. In other cases it is not obvious what is under human control and what is not. For example, in agriculture the soil is only partly controllable. A special case is the human body, which should be regarded as part of the environment; like the environment, the body can be physically affected by technical systems and their emissions. But to ask for a purely descriptive account of environmental problems is to place the problems into the wrong category. Environmental problems are "problems" because they represent a deviation from some ideal state; any description of the "problem" must use this ideal state as a reference. Hence, there will always be a normative element present in descriptions of environmental problems. This raises an interesting question: Who is to define the ideal state and who is to say what deviations from this state are problematic? These must be decided within human society. "Nature" cannot tell us what to do. The third subsystem represents society – how it reacts to immediate and predicted environmental change, and what it identifies as problematic.

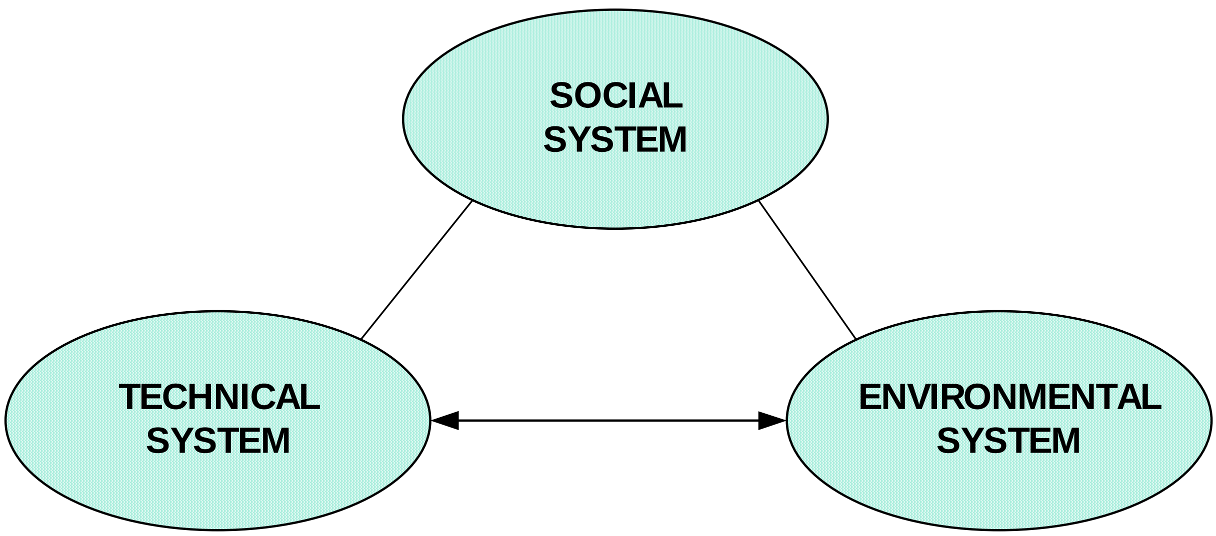

Figure 1 *A model of three sub-systems representing the interplay between society and environment.*

This three-systems model gives a highly abstract and very general picture of how society (through technology) causes changes in the natural surroundings and biological systems, how such changes are identified as problems, and how (in some cases) efforts are made to counter those problems. The model offers a picture of environmental systems analysis on a societal level and it shows that the study of society's handling of environmental issues must be of a multidisciplinary character. The natural sciences have their role to play in explaining and predicting changes in the environment. However, environmental problems are also social problems, since they are caused by humans. This is true on two levels: in a physical sense, because environmental problems are by definition results of human activity; and in a symbolic (constructivist) sense, because only humans have the intellectual, moral, and linguistic capacity to identify environmental changes as problems. Hence, the study of environmental problems is as much a concern for the social sciences and the humanities as it is for the natural sciences. Many different kinds of investigations are needed, and co-operation across disciplines is a prerequisite for a good understanding of the interaction between society and environment.

For environmental management to take place at all levels of society, there is a strong need for simplified descriptions of complex relationships. This complexity is present in both the physical and social worlds. What level of simplification is defensible? What short-cuts would be acceptable to the general public and to different stakeholders? These questions represent great challenges both for scientists and for decision-makers.

The terms "decision-making" and "decision-maker" appear frequently in this thesis. These terms do not refer to an individual who, at a certain time, is presented with a number of alternatives and a lot of information and who there and then chooses a path of action. On the contrary, the kind of decision-making that is of interest in this thesis involves many people. It is also more relevant to talk about "decision-making processes" to make clear that these are activities that take place over time, in which information is collected, interpreted, and negotiated repeatedly until some option is deemed acceptable.

The development of LCA has largely concentrated on how to make models of products' life cycles, which are part of the technical subsystem, and on how results from such models can be used as input for models of environmental change. Models of the social system have been regarded with great scepticism. This scepticism is discussed to some extent in paper **III**. This sceptical attitude towards elements that are not based on natural science is observable, for example, in the ISO 14 042 standard for LCAs. When discussing the weighting of different environmental impacts, the authors have found it necessary to explicitly point out that "Weighting steps are based on value-choices and not on natural science" (ISO 2000). As if they could be.

AIM OF THE THESIS

As the title indicates, this thesis deals with environmental valuation and LCA. More specifically, it deals with how questions concerning environmental values arise in the study of life cycles, and how those questions correspond with the way people in a society develop and express values and opinions. Methods for responding to these information needs in LCA studies are analysed. How can such methods be made useful in decision-making processes, and how can they be justified to stakeholders?

STRUCTURE OF THE THESIS

The following three sections discuss the modelling of the subsystems in more detail, paying special attention to how these systems are modelled in LCA. The discussion of the technical and environmental systems will be rather brief, while the section on the social system will be somewhat more extensive and will apply a broader perspective than just LCA. Following these sections, there is a separate section on the models of social systems currently used in LCA, and a discussion of how these can give relevant inputs into decision-making processes. A discussion of the nature of LCA and its role in decision-making follows. Some lines of thought presented in earlier sections are brought together, and the final section presents an outline of some possible research directions for the future.

2. Models of production systems and their interaction with the eco-sphere

Flow models of production systems have been used for a long time, for example, for optimisation in the chemical industry. Rudd and Watson (1968) is just one example of a textbook on this issue from a time when LCA had not yet been developed.

In the development of LCA, the flow model approach, which had been used to optimise operations within single companies, was applied to the study of product chains from “cradle to grave”. The scope of the modelling was also expanded to include not only one single parameter, such as energy, but a whole array of environmentally relevant aspects. Such product chains, however, consist of companies and activities that are not connected to each other in same way as two chemical reactors within one plant would be. Most of the activities in a life cycle model will have only physical connections; they will have no economic, geographical, juridical, or technical relationships, and there will be no co-operation between them. What is the rationale behind calling them one system? They are all physically connected to the same product. However, companies interact more on an economic than a physical level in the market environment, and they go through markets where goods are bought and sold. That one more unit is bought from a market does not necessarily mean that one more unit is produced. It depends on the price elasticity of the product in question, and the degree to which an increased demand will result in a higher production volume. This means that the level of activity in the different parts of a product chain is governed not through physical one-to-one relationships as in a standard flow model, but rather by economic relationships. Hence, the physical flow model is not an adequate representation of *consequences of changes* in industrial production systems. That kind of model does not answer questions concerning changes – it answers a different question, namely, "What environmental burdens are caused by the activities that are, in a physical sense, involved in the life cycle of the product in question?" This can be interesting in some situations, even though it is not consequence-oriented. Recent discussions of different approaches to the modelling of technical systems and product chains can be found in Ekvall (1999) and Weidema et al. (1999) who both argue for a more widespread use of consequence-oriented modelling.

The physical flow model is popular mainly because of its simplicity. It is easy to understand and to communicate, and in most cases it will be easier to agree upon what should be included in such a model than for a more consequence-oriented model. The use of consequence-oriented modelling approaches is also hampered by the difficulties of finding data on price elasticities for different product markets.

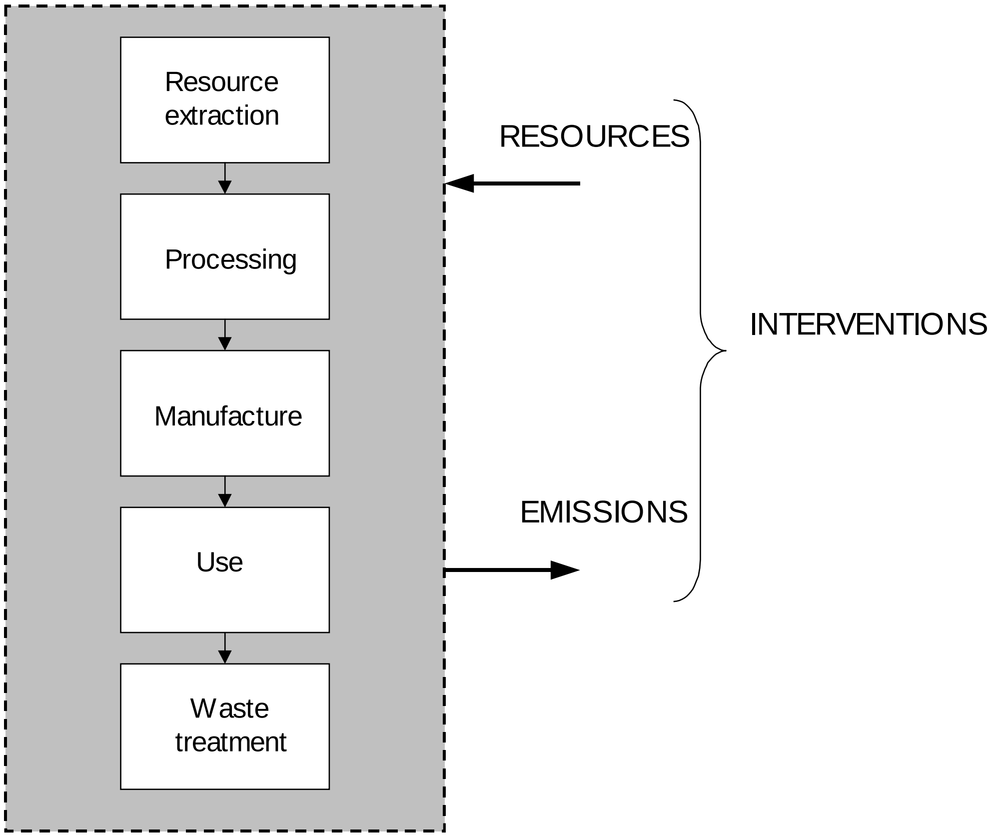

Figure 2 *Schematic representation of a life cycle model.*

In the study reported in paper **II,** we investigated environmental consequences of different wastewater treatment options, and here we chose to include the production of fertilisers. Even though fertiliser production is not directly part of the product chain of a wastewater treatment system, the activities associated with it might be affected by changes in these systems. Since the aim of the study was to compare and evaluate different options, it seemed relevant to include such consequences in the modelling. We did not, however, attempt to model fertiliser markets with price elasticities, but simply assumed that one kilogram less consumption would result in an equally large decrease of the production. This kind of extended physical flow model has been described by Tillman et al. (1994) and used in numerous case studies on different kinds of products.

As has been shown, the choice of modelling approach is a value-laden part of LCA. This does not mean that it is an arbitrary choice – different approaches are likely to be found relevant in different situations. However, the character of the situation at hand and the related information need do not prescribe how the technical system should be modelled.

The result from a life cycle model (known as life cycle inventory, LCI) is a summary of all inputs and outputs of the system model. Of course, this does not mean that all inputs and outputs of the activities in the real world are included. For the modelling, data are collected on certain parameters where they are available and regarded as relevant. Most of these parameters represent physical flows of resources and emissions, but other aspects, such as land use, are sometimes included as well. In this thesis, the term “intervention” will be used to signify all these in- and outflows. The LCI parameters may be analysed for the whole life cycle model or for different parts or activities.

In LCA modelling, geographical and temporal differences are usually disregarded. This means that emissions and resource extractions of the same kind are lumped together, regardless of where or when they take place. This is a gross oversimplification, and in this paper **I** we argue that further development of LCA methodology should be open to some kind of geographical differentiation, so that when it is feasible, geographical differences can be taken into consideration. For some parts of a life cycle, for instance when materials and components are bought from a spot market, geographically specific information will be unobtainable. In other cases it is well known where an environmental intervention will occur. The geographical dimension is important not only because physical and biological conditions differ from place to place, but also because environmental priorities and preferences can be expected to differ between places and regions.

The lack of temporal differentiation means that in LCA there is no discounting – the severity of an impact is regarded as equal no matter when it takes place. This is not completely true, since it is common practice to exclude interventions that will take place far into the future. The length of time considered differs from study to study.

3. Models of environmental change

The role of the natural sciences in environmental systems analysis is to provide us with models that make it possible to connect specific environmental changes with specific technical activities, and to make tenable predictions about cause–effect chains and about future states. This scientific modelling, however, results in mere descriptions of states and changes in the biosphere – it cannot distinguish between what is serious and what is not, not even whether a certain kind of change is desirable or not. Making such distinctions are inevitably acts of practical reason and judgement.

A common practice in LCA has been to use models that describe different substances’ relative contribution to impact categories such as global warming and eutrophication. This procedure is known as characterisation. These models make an aggregation of inventory results possible, and thereby the number of parameters can be reduced to about 10 to 15. The results are typically expressed in units such as kg CFC 11-equivalent or kg benzene-equivalent. For some categories, such as global warming, the characterisation models can be relatively precise, while for others, like ecotoxicity, they are highly uncertain and very dependent on the exact location of the intervention. The characterisation models developed by Heijungs et al. (1992) have been widely used.

Other methods developers have taken a different approach to the modelling of environmental effects (Steen & Ryding 1992, Goedkoop 1995, Hofstetter 1998, Goedkoop & Spriensmaa 1999). According to these, a model on the level of effect categories gives results that are difficult to understand and to form an opinion on. Effect models should, according to these researchers, follow the cause-and-effect chains all the way to the level of damages, where the things we value and care about are harmed. This would facilitate the evaluation of results. However, the level of uncertainty in these models of higher-order effects on the damages level will be even greater than in the characterisation models. We will come back to this dilemma in section 5, on weighting approaches in LCA.

In the ISO standardisation process, where standards for LCA have recently been developed and agreed upon, both modelling approaches were recognised (ISO 2000).

Quantitative models are central in LCA. Things that are difficult to express in quantitative terms will in most cases be left out of the analysis. For this reason, LCA has difficulties addressing emerging environmental problems in a way that corresponds with a precautionary approach. Dutch researchers Bras-Klapwijk (1999) and Tukker (1998) have studied the debate on PVC and chlorine, and they show that the life cycle studies that were performed could not properly take into account people’s anxiety about the effects of these substances. There were indications that chlorinated substances might under certain conditions cause problems, but there were no stable quantitative models of the effects that could be used for the assessments. Similar problems are likely to apply to all emerging environmental issues. At the moment, there are indications that potential endocrine disruptors, brominated flame retardants, and antibacterial substances might cause problems, but there are no ways to quantify their consequences. This limitation of the LCA methodology has been the cause of some criticism, not least from the environmental movement.

4. Models of social systems' response to environmental change

The purpose of making models of how individuals and groups react to, or would react to, different environmental changes is simply to help in setting priorities in decision-making processes. The most problematic environmental changes should be given the greatest consideration and they should take priority when actions are taken to avoid or mitigate impacts. This is a good plan, but as we will see, it is not easy to realise.

THE TERM "VALUE"

The term "value" is used in many different situations and by different scientific disciplines. For this reason, there is a risk of confusion. Among philosophers, a broad range of positions concerning the ontological and epistemological aspects of values can be found. Some claim that values have a real existence (value realism) and that it is possible to gain knowledge about values (value cognitivism); others deny these possibilities (value scepticism) and give values the same status as emotions (value nihilism). Various combinations of these and other positions can also be found. For the purposes of this thesis, it is not necessary to examine these philosophical views in detail; it will be more fruitful to focus on how the term is used in the behavioural sciences. With human beings as the object of study, behavioural scientists regard values as internal attributes of persons rather than as external objects. Feather (1994) has suggested that such values have the following properties:

- They are general beliefs about desirable behaviour or goals.
- Unlike wants and needs, they involve goodness and badness and have an 'oughtness' quality about them.
- They both transcend attitudes and influence the form these attitudes may take.
- They provide standards for evaluating actions, justifying opinions and conduct, planning behaviour, for deciding between different alternatives, engaging in social influence and presenting self to others.
- They are organised into hierarchies for any given person, and their relative importance may alter over the lifespan.
- Value systems vary across individuals, groups and cultures.

This broad definition of values can be useful in discussing environmental valuation. First, the relationship between values, attitudes, intentions, and behaviour should be investigated further. Values are supposed to be relatively stable over time and are of an unspecific character. Health can be a value of this kind. Attitudes are not so general; they are directed towards something more specific. A positive attitude to bicycling can be a consequence of health being a highly valued goal. Intentions are directly related to behaviour. I might, to continue our example, intend to go to work by bike tomorrow morning. (But it may rain and in that case I may decide otherwise.) The relationships between these different levels are not simple and straightforward, and studies have typically shown weak correlations between general attitudes and values on the one hand and behaviour on the other (e.g. Atkinson et al. 1990).

Unlike behaviour, which is fairly easy to observe directly, intentions, attitudes, and values require a different study approach. They can either be studied directly by means of interviews or questionnaires, or they can be indirectly deduced from observed behaviour. The latter is problematic, since different kinds of values can lead to the same behaviour. Consider customers who buy organically produced food products as an example. The underlying motives for this can be highly diverse: to protect their own health (egoistic value); to protect plantation workers from pesticide exposure (altruistic or moral value); to reduce the use of finite resources (altruistic or moral value); or to protect ecosystems from pesticides (value connected to ecosystems). Hence, from a study of behaviour alone, it is difficult to draw conclusions concerning value orientation and to make predictions about what preferences the person in question will have in other contexts. Direct methods have their own shortcomings, as will be shown below.

ENVIRONMENTAL VALUATION

The literature on the subject of environmental valuation is vast and diverse. However, two main paradigms can be distinguished. Using the terminology of O'Connor et al. (1998) we can call these the value revealing approach (VRA) and the social process approach (SPA). The two paradigms are, as we shall see, based on different epistemological views on values and value expressions.

The value revealing approach

The value revealing approach is consistent with what Macnaghten & Urry (1998) call a "polling culture". The idea is that public opinion on different environmental issues should be frequently surveyed and that survey results should be used as an input to policy formation and decision-making. Embedded in this approach are the following assumptions:

- That people have attitudes/preferences/value orientations etc. concerning the environment that are distinct from other concerns.
- That such values are real and that they are relatively stable over time.
- That it is possible to somehow measure these values, i.e., to identify what is valued and how much it is valued on a relative scale.

- That these values are commensurable, i.e., they can be expressed on a single scale, and there can be trade-offs between different values.
- That researchers have negligible influence on the result of measurements of values.
- That individuals' prima facie expressions of values give a relevant picture of what is collectively desirable.

According to this view, people have coherent and stable ideas and opinions that can be measured, brought out of the context in which they were expressed, and used instrumentally to support decisions in other contexts. In studies of values, the researcher discovers or reveals something that already exists. Contingent valuation studies used in environmental economics for investigating the value of non-market goods is an example of this style of inquiry.

The social process approach

The paradigm here called the SPA has developed partly as a critique of the VRA. It holds that our ideas and opinions regarding the environment are highly intertwined with other concerns; they are ambiguous, contradictory and context-dependent. Macnaghten & Urry express such a view when they say that "… no *a priori* boundaries can be drawn as to how environmental issues are to be defined or 'constituted'; these should be derived from listening to and arguing with people's own categories of experience, value and agency. This points to the need for qualitative methods to examine the complex and often ambivalent ways in which people discuss and argue about environmental matters, and how they connect these to wider concerns…" (1998, 102). Values do not have an abstract free-floating existence; they exist only in concrete situations. Values are expressed, shaped, reacted to, negotiated, reshaped and so on in the various discourses where we interact with others. This is how our ideas about the acceptability or unacceptability of different phenomena in our surroundings evolve. When the researcher investigates values, he or she acts as co-producer of these values. According to the SPA, values should pass a test of social justification in order to be valid, i.e., they should have been found legitimate by a significant number of people. There is no reason why prima facie accounts of individual preferences should count as valid in the environmental field. Due to the collective character of the environment, one individual's preferences are of concern to other as well. According to the proponents of this approach to environmental valuation, people who have a stake in a certain decision-making process should not simply be surveyed as individuals, but they should be actively involved in that process. These ideas are related to the call for a democratisation of decision-making processes related to risk and environmental problems put forward by scholars such as Funtowitz & Ravetz (1991), Shrader-Frechette (1991) and Stern & Fineberg (1996).

My own opinion is that the SPA is based on a sounder epistemological basis than the VRA. Its use, however, seems to be limited to situations where interested and affected groups are easy to identify and to involve in deliberative processes. It also seems to be feasible only for 'big' decisions on a strategic level. The SPA should, however, serve as an ideal to strive for when designing investigations aimed at eliciting values and opinions related to the environment. SPA is also a reminder about how simplified VRA-type investigations are and that results from such studies must be interpreted with great caution, taking into consideration that they have a weak epistemological foundation.

5. Weighting approaches in LCA

In most cases of environmental systems analysis it will be found that new technical solutions are better than existing ones in some respects, but worse in others. It cannot be expected that allegedly improved products and systems will have lower inputs of all kinds of resources, as well as decreased emissions to air, soil and water of all substances that have potential environmental impacts. So in most situations we are faced with trade-offs, which means that we must somehow compare different kinds of impacts. In most cases, these kinds of comparisons are inevitable if we want to be able to talk about improved environmental performance.

WEIGHTING METHODS

In life cycle studies these comparisons or weightings can be done on a case-by-case basis. However, life cycle analysts have perceived a need for ready-made methods to help with interpretations of LCI results – methods that incorporate both models of environmental change and of societal response. This section presents some of these weighting methods and discusses the valuation part of them in the light of what was said in section 4. But first a few things need to be said about the models of the environment and how these connect to the models of society.

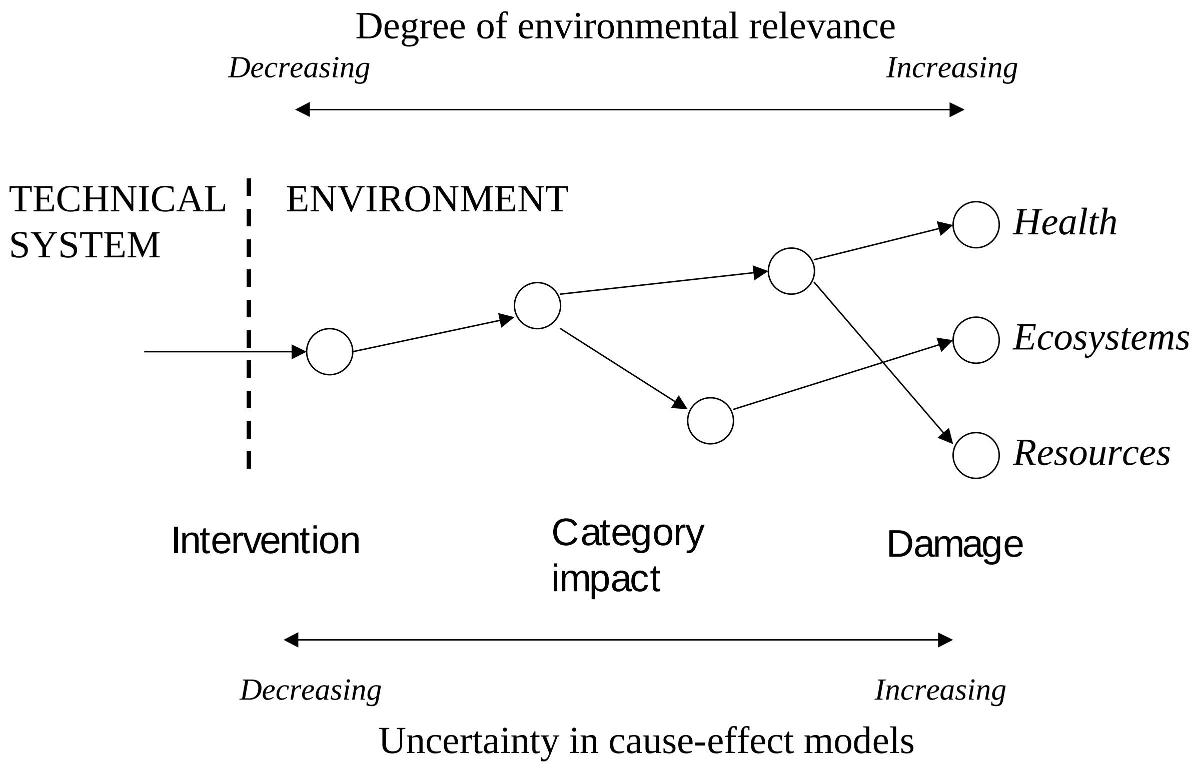

Figure 3 *The modelling of cause–effect chains from interventions via impact categories to the level of damages. The figure illustrates the dilemma involved: the higher the environmental relevance of models, the higher the uncertainty.*

Figure 3 illustrates the problems associated with combining environmental effect models with social models. The closer we get to the higher-order effects and the things we care about, the higher becomes the uncertainty in the effect models. On the other hand, the closer we get to these effects the easier it will be to understand what damages different kinds of interventions can cause, and how and to what degree they may harm things we value and want to protect. This poses a problem: How far is it reasonable to try to follow the cause–effect chains? It was noted in section 3 that this has been a point of contention within the community of LCA researchers. One position has been that modelling on the level of impact categories is the most relevant approach, and the only one that is possible to defend scientifically. Other methods developers have found these models inadequate, so they have tried to follow the cause–effect chains further and to model damages. Which is the best approach is still an open question. Some decision-makers will probably prefer to have results presented on the impact categories format, others are likely to prefer a damage modelling. Both approaches will probably continue to exist in parallel. However, which one is chosen has implications for how a subsequent weighting can be done.

Existing methods for weighting can be described and presented in different ways. In his exhaustive overview, Lindeijer (1996) described the "equivalency principle" of different methods. That principle was his interpretation of when, according to each method, impacts or systems are considered as environmentally equivalent. Lindeijer also grouped the methods according to five characteristics: proxy, technology, monetarisation, authorised targets or standards, and panel.

In this thesis, a somewhat different framework will be used for discussing weighting methods. In Table 1, nine different methods are described in a framework focussing on the valuation process, i.e., how and from whom the value statements were elicited. Only humans can act as evaluating actors, a rather obvious observation which, however, often appears to be overlooked. Who, in the different methods, were regarded as legitimate valuators? Someone has investigated these values or value statements. This has been done either actively, through direct questions to the valuators, or passively, by looking at decisions or written documents ex post. How was this done? The value statements were made in different formats. What formats were used? The valuators were answering a specific question. What was that question? By investigating how the different methods have handled these parts, we can more easily form an opinion on whether the methods are able to provide the decision-making process with relevant information.

Table 1 *A number of frequently encountered weighting methods in LCA presented in a framework focussing on the value eliciting process used.*

Method	**Valuators: Who were "asked"?**	**Process: How was the question asked and the answers given?**	**Question type: What was the question about?**	**Level of indicator**
Ecoscarcity (Ahbe et al. 1990, Baumann et al. 1993, BUWAL 1998)	National politicians	Passively. Goals in environmental policy.	Reduction targets/ critical flows on national level.	Interven-tions
Eco-indicator 95 (Goedkoop 1995)	Methods developers themselves	Actively. Group discussion.	Define levels of damage to ecosystems and to humans that are equally severe.	Damages
EDIP (Hauschild & Wenzel 1998)	National politicians	Passively. Goals in environmental policy.	Reduction targets/ critical flows on national level.	Impact categories
Environmental themes, short term (Baumann et al. 1993)	National politicians	Passively. Goals in environmental policy.	Reduction targets/ critical flows on national level.	Impact categories
Eco-indicator 99 (Goedkoop & Spriensmaa 1999)	LCA researchers and practitioners	Actively. Postal survey.	Express relative weights of human health, ecosystem health and resources.	Damages
Landbank (Wilson & Jones 1996)	Environment researchers and professionals	Actively. Postal iterative survey, Delphi procedure.	Rank and rate the desirability of a 1% reduction of a number of substance flows.	Interven-tions
Environmental themes, long term (Baumann et al. 1993)	Environment researchers	Passively. Interpretation of published results.	Critical flows on national level.	Impact categories
Tellus (Tellus institute 1992)	Authorities	Passively. Interpretation of earlier decisions.	What levels of emissions to air are acceptable? (From that was deduced a highest acceptable cost for cleaning.)	Interven-tions
EPS (Steen & Ryding 1992, Steen 1996, 1999)	Mix, differs between impact types. E.g., the general public for health impacts.	Passively. Mix, differs between impact types. E.g., results from contingent valuation studies for health.	Economic value of different impact types.	Damages

How much consideration has been given to the underlying valuation processes in the development of the methods presented in Table 1? For the methods based on political goals, there has been a democratic process informed by scientific findings. However, these goals also reflect many considerations that are not connected to the environment, such as regional balance, employment, and international competitiveness. It is not evident that such consideration should be embedded in weighting methods for private companies. Another problematic feature of this group of methods is that we cannot automatically assume that all goals of the environmental policy will have the same significance. Hence, in these methods there would be a need for additional weighting to reflect such differences correctly (Finnveden & Lindfors 1997).

For the *Eco-indicator 95* method, the method developers chose to act as valuators themselves. They admit that their approach was subjective and that they could have defined their damage levels in other ways. They also point out that a clearly formulated principle, as in their case, makes the subjectivity explicit and also makes it possible to criticise the method (Goedkoop 1995).

Environmental scientists were used as valuators in very different ways in the *Landbank* and the *Environmental themes, long term* methods. In the view of the public, environmental scientists have rather high credibility. At least, this is true in Sweden. However, most scientists are specialised to a high degree and will therefore only have deeper knowledge in a small part of the broad spectrum of environmental problems. They will also have a personal stake involved, since they want "their" problem to be recognised as one of the most important so that they can get funding for continued research. These factors may introduce some bias to their judgement of environmental values. Furthermore, their factual knowledge does not imply that their value statements should be more valid than anyone else's. In the *Landbank* method, these biases could be handled to some degree by an iterative procedure where the results from the first survey was presented to the panellists so that they had the chance to revise their initial response. In the *Environmental themes, long term* method, critical levels, as defined by the community of environmental scientists, were used as target levels. One problem with this, similar to the critique raised against methods based on political goals and also noted by Finnveden & Lindfors (1997), is that scientists might have meant different things when they defined the levels as critical. There is not one clear definition of what critical should mean, and which has been consistently applied for different environmental problems.

For the *Eco-indicator 99* method, the developers used a survey sent out to persons associated with the "Swiss discussion platform on LCA". The response rate was low (22%) and there is no information on what categories of people responded. In a procedure inspired by Hofstetter (1998), the responses were divided into three groups that were thought to have different cultural orientations and views of nature. Results were presented both for the three groups separately, and for the whole group of respondents combined.

The *EPS* method used a combination of methods to elicit economic value statements. The underlying idea is that these valuation methods should all reflect society's willingness-to-pay to avoid negative environmental impacts. However, the values for some problems are elicited directly from individuals in the form of stated preferences; in other cases they drawn from decisions made in democratic institutions, and in some cases from market prices. This is inconsistent and a source of confusion. It is hard to tell whose values are really represented. Furthermore, the values derived in these different ways, even though they are all expressed in the same monetary unit, represent different kinds of values and are not directly comparable. This weakness was also pointed out by Finnveden (1998).

Some of the methods mentioned above, most notably the *Eco-indicators*, *EPS* and *EDIP*, have developed sophisticated models on the environmental side. For all methods, however, the elicitation of values has not been given much attention at all.

All of these methods can be schematically described as in Figure 4 (Bengtsson 1998). They consist of a principle, which states who the valuators are and how their values should be investigated. The principles of different methods were discussed briefly above. In case these values are not given as explicit weights, but rather in some other format such as target levels for the emission of different substances, some kind of algorithm is also needed for transforming the value statements into weights. The same principle and the same algorithm may be applied in different places and at different times, resulting in separate sets of weighting indices. Apart from this, assumptions made in the environmental models may also be varied, resulting in other versions of these weighting sets. The idea behind a schematic representation like this is that it can serve as a structure for discussing strengths and weaknesses of different methods, and their applicability in different contexts.

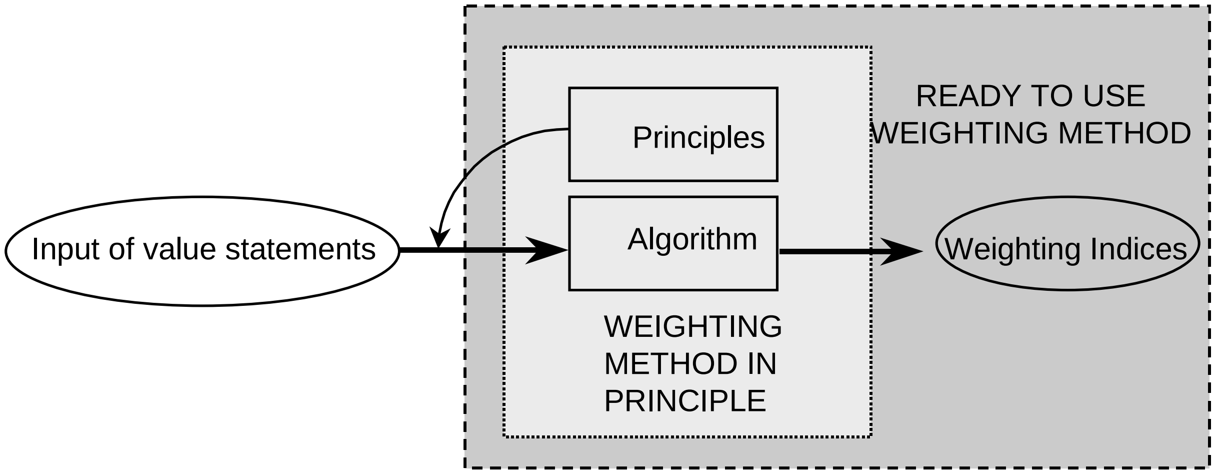

Figure 4 *The structure of weighting methods.*

In a recent overview of operational weighting methods, Finnveden (1999) makes a critical analysis and concludes that none of these can be recommended for use. He suggests that more research is needed. It may be true that existing methods have shortcomings, but where does that leave the LCA practitioner of today? Even if I agree in general with Finnveden's conclusion that more research should be carried out on these issues, I do not think that we should recommend that practitioners refrain from using the existing operational methods. As we argued in paper **III**, these methods do contribute additional information to decision-making processes, even though they may not be suitable for determining final verdict in choices between alternatives. An interpretation of what the methods say about the system under study and how relevant it is for the present situation will always be necessary. This is true for existing methods and for methods that may be developed in the future. In the present situation, it is better that practitioners learn about existing methods, including their shortcomings and limitations, and that they learn how to handle these with caution. The question concerning good weighting methods should, in my opinion, be broadened to deal more with good weighting practices than with just methods per se.

The use of weighting methods, or rather weighting as a social activity, was the focus of paper **IV**. It was argued that it is not weighting methods and their properties per se that are of interest, but how these can function in the social process of LCA. Can methods of this kind help practitioners to interpret LCI results? By applying this perspective to weighting, some difficulties were found. It was shown that quantitative measures of environmental performance have a strong rhetorical impact and that the uncertainty of such measures can be very difficult to communicate.

From that study it was also clear that weighted results were difficult to use in product development. One reason is that weighted results are expressed in units that are not familiar to product developers and other decision-makers. Another reason is that the technical performance is very seldom constant, but varies between product versions. The combination of these two factors raises problems when attempting to make an overall judgement of the environmental impact and the product performance. Was the improvement of technical performance significant enough to compensate for the increased environmental impact? There are no useful tools available to address these kinds of questions.

In paper **III** it was noted that data gaps, i.e., the inability to cover all parameters normally investigated in an LCA, have been regarded as a shortcoming of weighting methods (e.g., Lindeijer 1996). But since LCA does not include all kinds of environmental problems anyhow, weighting methods should not be expected to cover each and every problem that is included in LCAs. In any case, life cycle studies will not answer the questions about “total environmental impact” that decision-makers may be interested in, so it is hard to see why full coverage of all impact categories currently included in most LCAs should be a “minimum requirement” as Finnveden (1999) suggests.

WHAT IS WRONG WITH THE “PLAGUE OR CHOLERA” QUESTION?

The way in which values are investigated for the purpose of developing LCA weighting methods is problematic. The questions about values are asked in a way that would lead to protests from many respondents (valuators) if they had the chance to do so and if they were asked explicitly. The ideas present in LCA about how values can be meaningfully investigated seem to be related to the value revealing approach presented above. The problems encountered here are related to how environmental problems are framed in LCA in general. We can describe that framework with reference to five assumptions, and discuss each one these critically.

Damages can be assessed separately from their causes. The emission of a certain amount of nitrogen into water, for example, is to be regarded as equally problematic no matter why it was released, i.e., no matter what purpose the technical system under study served. The rationale behind this is that the environmental consequences will be the same no matter why the emission occurred. This is, however, not in accordance with the way we usually think about these things. Consider painful animal testing as an example. More people would agree to such testing if it was done in research aimed at finding a cure for child leukaemia than if the purpose were a less noble one. Descriptions of damages become less meaningful and much more difficult to form an opinion about when they are separated from descriptions of the purposes with which they are associated.

Increased environmental impact somewhere in a product chain can be compensated for by reductions of environmental burdens in other parts of that chain. The increase and the reduction in environmental impacts may take place at different locations, at different points in time, and they may affect different environmental objects and groups of people. Under such conditions, is it obvious that the one can compensate for the other? In order to accept LCA methodology and results of LCA studies, one must be prepared to answer the following question in the affirmative: "My increased suffering can be sufficiently compensated for by a reduced suffering for someone else". Not all people would agree to that statement, yet one of the basic assumptions in LCA is that such compensation is possible.

Values are commensurable and can be traded off, even if they are of fundamentally different character. This means that it is possible to express values on a common scale. This assumption is, like the compensability discussed above, connected to the utilitarian character of LCA, and it is merits equal criticism.

Damages can be assessed separately from each other. Underlying the effort to weight damages is an assumption that we can compensate for one thing with another. A problem related to this can best be illustrated with an example. In the development of the *Eco-indicator 99* weighting method, respondents were asked to indicate on a relative scale how important they think it is to protect human health, ecosystem health, and finite resources. But can these three be regarded as independent from each other? It can be argued that a healthy environment is of greater value to me if I am in full vigour, while a person who is ill cannot appreciate the value of a sound environment. If this is true, the values of human health and ecosystem health are interrelated, and they should be regarded as complements rather than substitutes.

The relative severity of different kinds of damage is independent of the scale of change, i.e., linearity is assumed. This is another assumption that would make the valuation task difficult for a respondent.

Taken all together, these five assumptions make the valuation for LCA very difficult. They belong in a framework that we cannot assume to be universally valid and accepted. There are many common and quite reasonable ways to think about values and the environment that simply do not fit into this framework. Since these positions are excluded almost by default, we should not be surprised if LCA in general, and the weighting element especially, is met with scepticism and suspicion.

PATHS FOR FURTHER DEVELOPMENT

Weighting methods can be tested and further developed in two fundamentally different ways:

1. Analytically, through the clarification of principles and ethical positions underlying different methods. This means making sure that the foundations for the methods are legitimate and that the methods have been consistently developed according to their basic principles.
2. Taking an evolutionary approach, through the repeated application of different methods to real-life cases where the results are compared to well-discussed opinions on what is more environmentally adapted and what is less so. A method that leads to results which appear to be unreasonable cannot be regarded as a good method no matter how sound its underlying principles are.

Both approaches are iterative and should be seen as complementary rather than competitive. They have both been pursued in the academic research on weighting methods, but the evolutionary approach could be further developed and it could be used more systematically. An open discussion around these methods and the results from their application, both within and outside of the scientific community, is necessary since no method is better than its level of acceptance.

Five problematic features of how the valuation issues are framed in LCA were presented above. Are these inherent in the methodology or is there a way to deal with them? Some problems are related to a lack of context dependence that is a result of the strive for general applicability. The separation from causes is one example of this. In that case it may be possible to arrange assessments where the utility of the product can be included to some extent.

In the study reported in paper **IV** it was found that the decision-makers investigated had differing preferences concerning valuators. In those cases politicians, biologists, and environmental scientists generally were explicitly mentioned as legitimate valuators. In the development of weighting methods, such individual differences must be taken into account. Otherwise the methods will not be able to meet the information needs of decision-makers. This is not static, however. As LCA analysts and decision-makers use methods for interpretation and try to communicate LCA results to different audiences, they will learn about the merits of different approaches and develop their views of both what is desirable and of what is possible.

6. LCA as systems analysis

This section investigates the nature of life cycle studies and some of the issues that arise from these.

DEALING WITH MULTIDIMENSIONALITY

Decision-making with multiple objectives is not unique to environmental issues. On the contrary it is commonplace and occurs in many different kinds of situations. In everyday life we often make decisions under such circumstances and in most cases we seem to make them quite easily. According to Payne et al. (1993) people are to a high degree adaptive decision-makers. This means that a number of different decision strategies are available to us and that we choose strategies according to how cognitively demanding they are and according to what degree of precision is required. Sometimes we do things out of sheer habit, not bothering about analysing the situation at hand. If this is not the case, we have to find ways to deal with the often ambiguous information about the alternatives at hand. The easiest way out is of course to just pick one alternative arbitrarily. This is what we would do if we did not care much about the outcome or if we had so little time at our disposal that a random choice would be the only feasible option. In circumstances where we care more and where we have the time needed to analyse the situation to some extent, we might choose one attribute which we regard as the most salient (for good or bad) and then compare the alternatives, selecting the one that scores highest in that attribute. If we are even more sophisticated, we might define levels of acceptability for a number of attributes and then make a comparison aiming at reducing the number of alternatives. This decision-making strategy might be used in combination with one of the less elaborate ones, such as random choice. As soon as we have made sure that certain tolerance limits are not exceeded we do not care much which alternative is chosen. The time-consuming and cognitively demanding decision-making strategy is one involving a weighting of attributes is done. This is the kind of decision-making behaviour favoured in normative decision theory and the one that is in line with the general idea of rationality. In reality, however, we often tend to employ the simpler decision-making rules.

Simplified strategies seem to be unproblematic when the outcomes evaluated are primarily of interest to the decision-maker personally. However, for environmental decision-making this is not the case. Others are affected by the decisions made, and they have a legitimate stake in the process. This means that the decision-making strategy used must be justifiable. Stakeholders will often demand that all relevant attributes (as seen from their perspectives) are investigated and that no potentially important environmental disturbances are left out. There will be a pressure to include all potentially relevant aspects, a demand that makes the assessment task difficult. It can thus be expected that there will be a constant tension between our wish to choose simple decision-making strategies, in order to make the task cognitively manageable, and the demands on including all aspects.

The LCA weighting methods presented in the previous section are intended to help in those cases where many attributes are regarded as relevant. However, alternative evaluation methods that focus on one environmental aspect only have been developed. Measures of total energy requirement and total displacement of material (the MIPS method, Schmidt-Bleek 1994) have both been used in this way as proxies of environmental impact. They can be seen as examples of the simpler decision-making strategies described above. To what extent the results from these proxy methods are possible to justify to other actors is not clear.

In connection to this discussion of expectations from external actors, it is needed to take a closer look at the term stakeholder and what meaning it might have in relation to a company and to LCA. It can be useful to make a distinction between:

- *Interested parties*, the groups that the company itself regards as important. These are groups that have the potential power to directly or indirectly influence the position of the company. Among these we may find customers and customers' organisations, share-holders, banks, insurance companies, business partners, labour unions, authorities on local and national levels et cetera.
- *Affected parties*, the groups that may be regarded as having legitimate stakes in the activities of the company. In this broader category we also find groups which are affected by the operations of the company but who essentially lack the power to influence these operations. Examples of affected parties may be socially marginalised groups and victims of transboundary pollution.

When discussing the environmental impacts of companies, it will often be found that there are far more people belonging to the second group of stakeholders than to the first one. It is not unreasonable to say that even people who are not yet born can be included in the second group. They will be affected by the global climate change, resource depletion et cetera that the present generation is causing. Some may even argue that other species can be seen as stakeholders in this respect. Birds that are damaged by oil spillage is an example of a case where such an opinion can easily be defended.

But what about LCA and stakeholders? Who are they? The activities in a product life cycle will in most cases be geographically spread out. Is it possible to identify those who have a legitimate stake in a decision? The relevant starting point is a single activity in the chain and the decision-making processes in that activity. Those who are directly concerned as interested parties can be identified but for affected parties in other parts of the product chain this will be more difficult. LCA is based on an ambition to investigate environmental interventions also in distant parts of the product chain, but is it reasonable to demand that we also should try to look at the situation through the eyes of those who may be affected? To what degree should they have a say in the evaluation of a life cycle study? This question is related to the compensability assumption criticised above in relation to weighting methods. Do people have to accept arguments of the following kind, “You will have to live with this increased environmental degradation, because the alternatives would have entailed other kinds of problems elsewhere, and our assessment shows that those problems would have been even worse”? Were there really no other alternatives available? Was a zero-alternative investigated? These are legitimate reactions.

A far-reaching inclusion of stakeholders into decision-making based on a life cycle perspective would, as we have seen, not be feasible in most cases. Nonetheless, there are lots of people whose views are relevant in relation to these decision-making processes. Is there any way in which these can be represented? It could be argued that these issues are, at least to some extent, considered in democratic fora on the national and international levels. However, the problems involved in using decisions made in that kind of fora for weighting were discussed in section 5.

INFORMED DECISION-MAKING AND LCA AS DECISION SUPPORT

The aim of LCA is to make better decisions in the sense that they are more informed about the environmental aspects of different alternatives when regarded from a ”cradle-to-grave” perspective. In order to develop the methodology for acquiring and structuring this information so that it makes sense to those involved we need to understand who they are and what their organisational and social contexts look like. Better still, we need to understand the decision-making contexts from the point of view of those involved directly. The study reported in paper **IV** was an attempt to contribute to this understanding. Knowledge and experience of decision-maker(s) and other actors or parties, time at their disposal, the amount of relevant information already at hand, the way in which the decision-making is organised in terms of authority and responsibility, and the individual characteristics of main actors are just a few examples of factors that will differ between cases. Different situations mean different needs for processing information and different capacities for doing so. For environmental trade-offs this means that in some cases the only kind of result that will have a chance of being considered is a one-dimensional indicator that gives an unambiguous signal about whether alternative A is regarded as more or less environmentally disturbing than alternative B or whether intervention X should be regarded as more severe than intervention Y. In other situations the preconditions might be totally different with more time and resources available for the evaluation and where the decision-makers who are experienced in processes like these.

Under such circumstances the ability to handle a complex description of the environmental impact will be much higher. It is not only time and material resources that are of importance for determining the kind of procedure to be used for handling trade-offs that will be feasible; things like corporate culture can also be assumed to have a great influence on how these questions can be addressed. This was found in the study presented in paper **IV**.

In reality, most decision situations will be not be of one kind or the other, but a combination of the two. The point is that the wish to assess the environmental performance from a ”cradle-to-grave” perspective will appear in different kinds of decision-making contexts and an adequate methodology for LCA must have the flexibility to fit with the preconditions and demands in these contexts. The plurality of decision-making situations has so far not been fully reflected in the development of LCA methodology. Even less understood is the relationship between the characteristics of these situations and different methodological choices. That the methods used shall be consistent with the aim of the study has almost become a mantra amongst methodology researchers, but few attempts have been made to identify what this would mean in concrete terms, i.e., about how the life cycle perspective can (or cannot) be made meaningful in different contexts. Contributions to this end have, however, been made by Baumann (1998), Wenzel (1998) and Tillman (2000). Understanding of these issues is as yet limited partly because LCA is a young field of research and partly because the questions dealt with are highly complex. Nonetheless, amongst LCA methods developers, the decision-making processes that LCA is intended to be able to support are often discussed in a simplistic and overly rationalistic fashion.

WHAT KIND OF SYSTEMS ANALYSIS IS LCA?

Jackson (1991) offers a typology of systems analysis approaches. Based on the level of agreement between participants or stakeholders, Jackson distinguishes between problem contexts that are of a unitary, pluralist or coercive character. In a unitary context, participants can be expected to have common interests and to share values and beliefs. In a pluralist context, participants will have values and interests that differ to some extent, but acceptable compromises are possible. In coercive situations, there will be fundamental conflict which can only be overcome through domination and the exercise of power. This classification can be used to study different kinds of systems analysis approaches and to understand their strengths and weaknesses. More specifically, it can be useful for analysing assumptions made by different approaches concerning the relationship between participants.

LCA might at first seem to belong to the “unitary” category, since it is about limiting or reducing environmental impacts. This is illusory and stems from a misunderstanding of the epistemology of environmental problems. As it has been argued elsewhere in this thesis, such problems are aspects of social reality as much as of ecosystems and landscapes, and there is no good reason to believe that there will be wide-spread agreement on environmental values. Why is this observation – that LCA might easily be placed in the wrong category of systems approaches – of interest? Because in the unitary category we find mathematical algorithms for optimisation and other hard systems tools – techniques that are appropriate to the kind of reality dealt with if the situation really is unitary. LCA, on the other hand, deals with issues that are of a different kind, and life cycle studies are therefore more closely related to soft systems methodologies, which are explicitly developed to deal with multiple perceptions of reality. Associating LCA with the hard techniques simply sends the wrong signals, since the process of LCA must be open to subjectivity and differing values. Following the same line of thinking, it can be pointed out that optimality never can be the goal for LCA, since, as Schwarz et al. (1985, 220) observe, "Optimization is a technical concept, inapplicable in situations where differing values, uncertainty, ambiguity, multidimensionality, and qualitative judgement are present and possibly dominant." Only in unitary problem contexts can such a technical concept be meaningful. It is of course possible to find mathematically optimal solutions once a number of assumptions have been made and the criteria for evaluation have been chosen. It is, however, not possible to claim that these solutions are environmentally optimal in the real world. Optimisation is a strong word with large rhetorical power and if such a word is used it is difficult to safeguard against over-interpretations of results. And again; it sends the wrong signals concerning the nature of LCA.

There is an interesting parallel between the development of LCA and that of Operational Research and Systems Analysis (OR/SA). Keys (1995) presents a number of articles which reflect the development of OR/SA from the 1940's and onwards. These texts show how the field has evolved from a number of mathematical algorithms to a ”style of inquiry”, how the role of the analyst has changed from problem solver to ”midwife” of problems management, and how the scientific aura has been gradually replaced by the notion of craft or technology. Instead of limiting themselves to the parts of OR/SA that might be standardised the theoreticians and practitioners in the field have tried to expand their scope so that also the ”softer” issues of problem formulation and implementation are dealt with. I do not think it is unfair to say that there is a mismatch between the approach currently used in LCA and the kind of problems that are handled. The discussion of LCA procedures, or the process of LCA, has so far been focused to a high degree on technicalities – the process of defining and seeking solutions to problems has in most cases been understood in an abstract, manner not taking into account the plurality of social contexts where real-life LCA studies are initiated, performed and received. The aim of methods development seems to have been to develop the science of LCA, and not the craft of LCA even though the latter would have been a more appropriate and realistic goal. As it was argued above, LCA as it is usually described and known today is basically a ”hard systems” approach to ”soft systems” problem situations. The hard approach promises one-dimensional and clear-cut answers, but in order to be applicable it requires a consensus on goals and values – something that we cannot assume when we are dealing with the environment. The unwillingness to go beyond the natural sciences is not helpful to LCA practitioners since it means that the important question of how to improve the overall process of LCA is not dealt with. If we look at LCA as an intellectual descendant of the process modelling and optimisation, these difficulties are understandable. If we also notice that most people who have been involved, and who are involved for that sake, in the development of LCA methodology have their backgrounds in engineering or toxicology, then it is not hard to understand why the interest in the softer aspects of LCA has been weak. The challenges ahead lie in developing improved understanding of the social processes of justification, the way that arguments for environmental weights and trade-offs are constructed, received and validated in concrete discourses. To this end both theoretical and empirical investigations are needed.

To act on the basis of good reasons means to be aware of many possible aspects of the matter in question, so that the opinion guiding the action is formed out of a reflection over many different perspectives. Since there is not *one* best opinion, the opinion to strive for is the one which is able to incorporate many different views. Such an opinion is truly worthy of being called objective, a term which should not be understood as value-free but rather as value-full (Ackoff 1979, Flood & Romm, 1996). Value-full opinions are the basis for good judgement and legitimate decisions and it is objectivity in this respect that should be sought in order to increase the usefulness of methods for environmental analysis and assessment.

QUESTIONS AND ANSWERS

The value of LCA is dependent upon its ability to answer to the concrete questions that arise concerning product life cycles and environmental problems. Different actors may, even if they are in objectively the same situation, ask different kinds of questions and perceive different information needs. Take as an example an environmentally concerned consumer who is considering buying a product. What information will be of interest to that person? Some will be interested in knowing how their decision about buying this product will affect the world, i.e. what the consequences will be compared to if the product is not bought. Others will be more interested in knowing about the environmental impacts of the various activities that have been involved in producing the product, and maybe also of the activities that will be involved in taking care of the waste when the product is worn out. These two ways of thinking correspond to two radically different ways of modelling production systems and their environmental interventions. We cannot prescribe that the customer in our example should think in one of these ways and not in the other. Furthermore, we cannot assume beforehand that he or she will have a preference for one of these approaches. If the flexibility to meet such differences in need for information cannot be achieved, then it is of great importance to make clear what questions that match to the answers that LCA studies can deliver. But it is not only the methodology that needs to be flexible, life cycle analysts and the decision-makers they assist also need to learn how to ask proper questions. As it was argued in paper **IV**, the analysts have a great responsibility for helping the decision-makers to formulate questions that are both relevant in relation to the present situation and that are possible to answer.

WHY LCA?

Why do companies engage in LCA work? What problems do they try to solve by this? The pioneering work of Baumann (1998) has given us some insight on these issues, but more practice-oriented research is clearly needed. One aspect that is not often mentioned is that companies just by engaging in LCA send out signals to other actors. In paper **IV** it was noticed that the ability to provide customers with life cycle information could have a value in itself. One comment in the interviews of that study pointed out the value of using “modern tools”, thereby communicating that the company is on the front edge of environmental management. But to what degree does the collected life cycle information affect companies’ decisions? Are the decision-makers able to use the information or is so that they ask for this information just because it is expected from them? Is the act of collecting life cycle information performed just in order to build reassurance and credibility? These questions are inspired by March (1994) who makes the following observation regarding decision-making and the gathering of information:

”Decision-makers ask for more information than they could conceivably use. Though they subsequently ignore the content, the act of gathering information provides reassurance that they have acted properly.” (March 1994, 216).

Following the same line of thought, Baumann (1998) asked the question about to what extent and how LCA studies lead to environmental improvements. This remains a challenging question for both practitioners and methods researchers.

7. Conclusions

Where have the winding paths in the preceding sections of this text taken us? What conclusions can be drawn at this stage? The thesis starts with the observation that environmental problems are “problems” only to the extent that someone recognises them as such. Today, many companies try to investigate the environmental problems that are associated with their products. This leads them to questions of the following kind: What impacts on the environment are important? What emissions et cetera cause these problems, and what parameters should we measure and try to improve? Answers to these questions must be sought both in nature and in the human society. Methods to help companies with these judgements have been developed. However, a number of difficulties are related to these attempts to evaluate the environmental performance:

- People have differing ideas about what environmental changes are problematic, what levels of risk are acceptable and how much consideration we should give to coming generations.
- The relevant stakeholders in relation to a product's life cycle are hard to define. Whose values should a company take into account when life cycle studies are carried out?
- Values and attitudes are not possible to measure in the same sense as physical parameters may be.
- As was shown in section 5, LCA methodology includes a number of assumptions, e.g. that different environmental values are commensurable and may be traded off, that might not be accepted by stakeholders and other valuators.
- To be useful for the evaluation of environmental performance, the severity of different interventions needs to be expressed as relative weights. If value statements are not in this format, they need to be converted into relative weights. This conversion can be done in different ways leading to different results.

To give valid results, the methodology used for investigating environmental impacts must be compatible with the world-view of those concerned. This requires that the methodology is flexible, so that a number of reasonable standpoints and perspectives are not excluded by default.

8. Further research

So, how do we proceed from here? What kind of research can contribute to our understanding of the issues discussed in the preceding sections? LCA is an attempt to make a very complex reality somewhat more intelligible. To what extent does it succeed? Do decision-makers get information that they find meaningful, that they can understand and communicate to other actors? Do they have confidence in this information? How can trust and confidence in environmental assessments be built within an organisation? How can it be built in relation to external parties? Core issues in all these questions is how environmental values are expressed and managed, how valuation is carried out and integrated into decision-making processes at different levels in product chains. Here I will point out three possible research tasks related to these issues.

How can values management on a strategic level in companies be organised in a way that is more in line with the epistemology of the social process approach as it was described in section four above? How can processes be initiated in which a company defines its own environmental priorities on grounds that are justifiable and objective (in the value-full way)? How can such priorities and value statements be communicated and integrated into the operations of an organisation? These are research tasks of great importance. The aim of this research would be to investigate how learning about social response to environmental change, in decision-making processes in companies, can be facilitated. The organisation of this learning would be one of the focus points. What competencies are needed for carrying out life cycle studies that produce meaningful outcomes, results that are seen as trustworthy and justifiable? Who needs to know and understand what in order to achieve this?

In section 2 it was concluded that in the life cycle model are included activities that are connected only in a physical sense. Decisions made in these activities may affect other parts of the life cycle, but they may also affect other activities that are not physically involved in the product chain. A complicating factor when studying life cycles is that these activities will be spread out geographically. They will have different stakeholder groups, they will be subject to different environmental legislations and they will probably have differing ambitions in the field of the environment. How can such a group of activities be fruitfully studied, assessed and managed? The different actors in a chain can be expected to look upon their respective roles with different eyes. They will think that different kinds of questions in relation to the system are relevant. They will also most certainly have differing opinions on the relative importance of different environmental impacts. To what degree do the actors in a product chain see themselves as being part of one system? Do they think that there are environmental problems for which they have some kind of joint responsibility? How environmental valuation and priority-setting is handled in this kind of multi-actor assessments seems to be important to investigate.

In section 5 it was suggested that an evolutionary approach to the development of weighting methods could be used more systematically. A possible research task would be to apply some selected methods to a few simple cases and let representatives of different societal groups discuss the results and to what degree they agree to these results. The reasons behind the results of the different methods, why they give these results, could also be analysed and discussed in order to build a better understanding of how these function.

The original focus point for my research was weighting methods and their characteristics. After some time it became apparent that the study of such methods in isolation would be of limited value. It seemed more fruitful to try to explore how such methods are used and understood in those social contexts for which they have been made. This led to an increasing interest in what I, in the introduction to this thesis, called the social side of environmental systems analysis and the double meaning of this expression.

Some may say that the way of reasoning and discussing represented by this thesis obscures the issues more than it sheds light on them. My answer to that would be that rationalistic approaches to a reality that is perhaps not all that rational, or rather: where many different rationalities exist in parallel, are not likely to be very successful. Furthermore, it is my firm conviction that every field of science needs not only its brave modellers and methods developers – it also needs its critics.

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