Sustainability Constraints as System Boundaries

An Approach to Making Life-Cycle Management Strategic

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Keywords

backcasting
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Summary

Sustainable management of materials and products requires continuous evaluation of numerous complex social, ecological, and economic factors. A number of tools and methods are emerging to support this. One of the most rigorous is life-cycle assessment (LCA). But LCAs often lack a sustainability perspective and bring about difficult trade-offs between specificity and depth, on the one hand, and comprehension and applicability, on the other. This article applies a framework for strategic sustainable development (often referred to as The Natural Step (TNS) framework) based on backcasting from basic principles for sustainability. The aim is to foster a new general approach to the management of materials and products, here termed "strategic life-cycle management." This includes informing the overall analysis with aspects that are relevant to a basic perspective on (1) sustainability, and (2) strategy to arrive at sustainability. The resulting overview is expected to help avoid costly assessments of flows and practices that are not critical from a sustainability and/or strategic perspective and to help identify strategic gaps in knowledge or potential problems that need further assessment. Early experience indicates that the approach can complement some existing tools and concepts by informing them from a sustainability perspective—for example, current product development and LCA tools.

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Introduction

A Troubled History

Historically, many "safe" materials have been commercialized, followed by later realization of negative effects on humans and the environment. This has led to subsequent large costs to redress the damage. Freons (CFCs), for example, were initially introduced as safe substances (Geiser 2001) but are now known to be powerful ozone-depleting substances. Unfortunately, society continues to repeat similar mistakes. A lesson that should have been learned for future planning is that impacts from societal activities typically occur through very complex interactions in the biosphere and often can be clearly related to certain activities only long after they have occurred, and then with great scientific difficulty. Consequently, an approach based on detailed knowledge of causes and impacts usually results in significantly delayed corrective actions.

A Complex Mix of Tools and Methods

The increasing complexity of social, ecological, and economic impacts from society's current unsustainable course has led to the development of a growing number of tools and methods to address the situation—each with its own unique assumptions and perspectives. Some of the most influential are related to or fall within the emerging field of industrial ecology and include the ecological footprint (Rees and Wackernagel 1994); material intensity per service unit and Factor 10 (Schmidt-Bleek 1997); cleaner production (Aloisi de Larderel 1998); natural capitalism (Hawken and Lovins 1999); zero emissions (Pauli 1998; Suzuki 2000); and life-cycle assessment (LCA) (Lindfors et al. 1995; ISO 1997). Such tools and methods have become so numerous and poorly linked to each other that decision makers are now increasingly confused about how they fit together and should be used. Several attempts have been made to bring clarity and direction to future research (e.g., van Berkel et al. 1997 and Wrisberg et al. 2002). Another influential effort was made by several pioneers—representing their own tools and methods—attempting to build a consensus on the best use of each and potential synergies between them (Robèrt et al. 1997; Holmberg et al. 1999; Robèrt et al. 2000; Robèrt 2000; Robèrt et al. 2002; Korhonen 2004).

LCA is one of the most rigorous and frequently used tools, with the objective of evaluating impacts of materials and products from the "cradle" (resource extraction), through transport, production, and use, to the "grave" (fate after end use). Obviously this leads to a more comprehensive view of the full impact than if only the material or product itself is evaluated. As will later be discussed, though, LCAs often lack a sustainability perspective and bring about difficult trade-offs between specificity and depth on the one hand, and comprehension and applicability on the other. In response, a new field of research and practice, called life-cycle management (LCM), is emerging, in which the focus is shifted toward the relationship between sustainability issues and life-cycle thinking in practice (e.g., Wrisberg et al. 2002 and Heinrich and Klopffer 2002).

Moving Forward with Strategic Life-Cycle Management

Instead of applying a problem-oriented approach to planning, where impacts are dealt with one by one as they appear in the system, it is possible and desirable to plan ahead with the ultimate objective of sustainability in mind. Doing so requires a *backcasting* approach where a successful outcome is imagined, followed by the question, "What shall we do today to get there?" (Dreborg 1996; Robinson 1982). We argue that this approach could inform life-cycle management, allowing coverage of the full scope of sustainability for material and product life cycles.

This article aims to (1) emphasize the need for management of materials and products through a lens of basic principles for sustainability, and (2) apply this new perspective to life-cycle management techniques, bringing forward a new approach we term strategic life-cycle management (SLCM). Its objective is to identify viable investment paths toward social and ecological sustainability.

The underlying framework for strategic sustainable development based on backcasting from basic principles for sustainability is first described briefly, in preparation for the discussion of SLCM.

Backcasting from Basic Sustainability Principles

Backcasting was first elaborated as *scenario planning*—a planning methodology based on envisioning a simplified future outcome (Robinson 1990). A games metaphor for this method of planning would be *jigsaw puzzles*, where the picture on the game's box provides guidance and helps the player deal with its complexity. Although backcasting from scenarios is a more strategic, that is, goal-oriented, methodology than fixing problems as they appear, and often encourages people to merge forces around shared visions, it also suffers from three potential shortcomings. First, given differing values, it can be difficult for large groups to agree on relatively detailed descriptions of a desirable distant future. Second, given technological evolution, it is best to avoid overly specific assumptions of the future. And third, if basic principles for sustainability are not explicit, it is difficult to know whether a scenario is sustainable or not.

It has been argued that it should be possible to backcast directly from a principled definition of sustainability, and/or from scenarios that are scrutinized by such principles (Holmberg and Robèrt 2000). This method of *backcasting from basic principles* builds on a framework for strategic planning (Robèrt 2000) and general experiences from the strategic management field (e.g., Mintzberg et al. 1998). More specifically, this framework for planning lets five interdependent but distinct levels communicate with each other as their respective contents and relationships are explored (Robèrt 2000):

1. *The System*. The overall principles of functioning of the system, in this case the biosphere and the human society, are studied enough to arrive at a . . .
2. *Basic definition of success* within the system, in this case sustainability, which, in turn, is required for the development of . . .
3. *Strategic guidelines*, in this case a systematic step-by-step approach to comply with the definition of success (backcasting) while ensuring that financial and other resources continue to feed the process of choosing the appropriate . . .
4. *Actions*, that is, every concrete step in the transition toward sustainability, which should follow strategic guidelines, which, in turn, require . . .
5. *Tools* for systematically monitoring the (4) actions to ensure they are (3) strategic to arrive at (2) success in the (1) system.

Developing basic principles for success from an understanding of the system, and then systematically planning ahead with those principles in mind, resembles chess more than jigsaw puzzles, in that principles of success (i.e., principles for checkmate, or basic principles for sustainability) guide the game, instead of a single fixed outcome. Chess represents a dynamic planning method with each move taking the current situation of the game into account, minimizing the risk of losing pieces, while at the same time optimizing the possibility of arriving at compliance with the principles for checkmate. A large number of winning combinations (i.e., checkmates) exist. Similarly, rather than agreeing on detailed descriptions of a desirable distant future, it might be easier to agree on basic principles for sustainability and some initial concrete steps that can serve as flexible stepping-stones toward compliance with those principles. Thereafter, each new step of the transition should be continuously reevaluated as the game unfolds.

To be useful, we argue that the sustainability principles should be

1. Based on a scientifically agreed upon view of the world
2. Necessary to achieve sustainability
3. Sufficient to cover all aspects of sustainability
4. Concrete enough to guide actions and problem solving, and preferably
5. Mutually exclusive to facilitate comprehension and monitoring

It has been argued elsewhere that the principles behind ecological footprints (Holmberg et al. 1999), Factor 10 (Robèrt et al. 2000), natural capitalism, zero emission and cleaner production (Robèrt et al. 2002), and Daly's five principles (Robèrt et al. 1997) do not meet these criteria. This meant that something new was needed.

A process of scientific consensus building was therefore convened by Karl-Henrik Robèrt and led to the initial formulation of four basic principles for sustainability (Holmberg et al. 1996). First, basic principles of socioecological *non*-sustainability were identified by clustering the myriad of downstream socioecological impacts into a few well-defined upstream mechanisms. Thereafter a "not" was inserted in each to direct focus to the underlying system errors of societal design. They form the basic sustainability principles (SPs), also known as "The Natural Step (TNS) System Conditions," after the nongovernmental organization (NGO) promoting them:

In the sustainable society, nature is *not* subject to systematically increasing

I. Concentrations of substances extracted from the Earth's crust
II. Concentrations of substances produced by society
III. Degradation by physical means and, in that society . . .
IV. People are *not* subject to conditions that systematically undermine their capacity to meet their needs.

Experience has been gathered from a variety of companies (Robèrt 2002; Nattrass 1999; Anderson 1998) and municipalities (James and Lahti 2004; Gordon 2004) on applying these principles and creating a bird's-eye perspective on an array of sustainability-related problems. A metaphor has been identified, in which society is seen as moving into a funnel of declining opportunities. This metaphor mirrors long-term "enlightened self-interest" in backcasting from basic sustainability principles. As long as societal structures do not prevent unsustainable system behavior, increasing pollution and decreasing economic accessibility of natural resources will represent the walls of a funnel and function as dynamic constraints on human activities. Actors that contribute significantly to global unsustainability are therefore exposed to a systematically higher relative risk of economically hitting these funnel walls. This translates into higher costs for waste management, insurance, and taxes, bad publicity, and so on (Holmberg and Robèrt 2000).

The parts of the planning process are (see figure 1) (A) sharing and discussing the suggested framework with all participants of the planning exercise, (B) assessing current material and energy flows and practices in relation to the basic sustainability principles (SPs; rather than relying solely on today's perception of impacts), (C) creating options and visions that support society's compliance with the basic SPs, and (D) prioritizing early actions from the list C that not only take care of the short-term challenges but also prepare for coming actions to eventually make society comply with the SPs.

Rationale for Strategic Life-Cycle Management

The Dynamics of Dematerialization and Substitution under each Sustainability Principle

The backcasting planning process results in a set of measures that can be categorized into dematerialization and substitution/change under each SP (Robèrt et al. 2002).

Dematerialization measures should here be taken in their widest possible meaning and include not only leaner production (Romm 1994) but also recycling, new business models such as leasing (Fishbein et al. 2000), and completely new innovations outside the box that meet human needs with higher material performance per unit of utility. Such measures are helpful in avoiding accumulation of elements and compounds (SP I and SP II) and reducing physical pressure on productive ecosystems (SP III). Increasing resource productivity and reducing waste are also ways of ensuring sufficient resources for people on the global scale (SP IV).

Substitution/change is sometimes required or preferred over and above dematerialization. Examples include replacing the use of metals that are scarce in ecosystems (ones that consequently pose a greater risk of increasing in concentration in ecosystems if not kept in essentially closed societal loops)—for example, cadmium—with the use of more abundant metals (Electrolux 1994; Johansson 1997) (SP I); replacing chemicals that are relatively persistent and foreign to nature, such as certain plasticizers (Leadbitter 2002) and CFCs, with more biodegradable chemicals (SP II); replacing materials from poorly managed

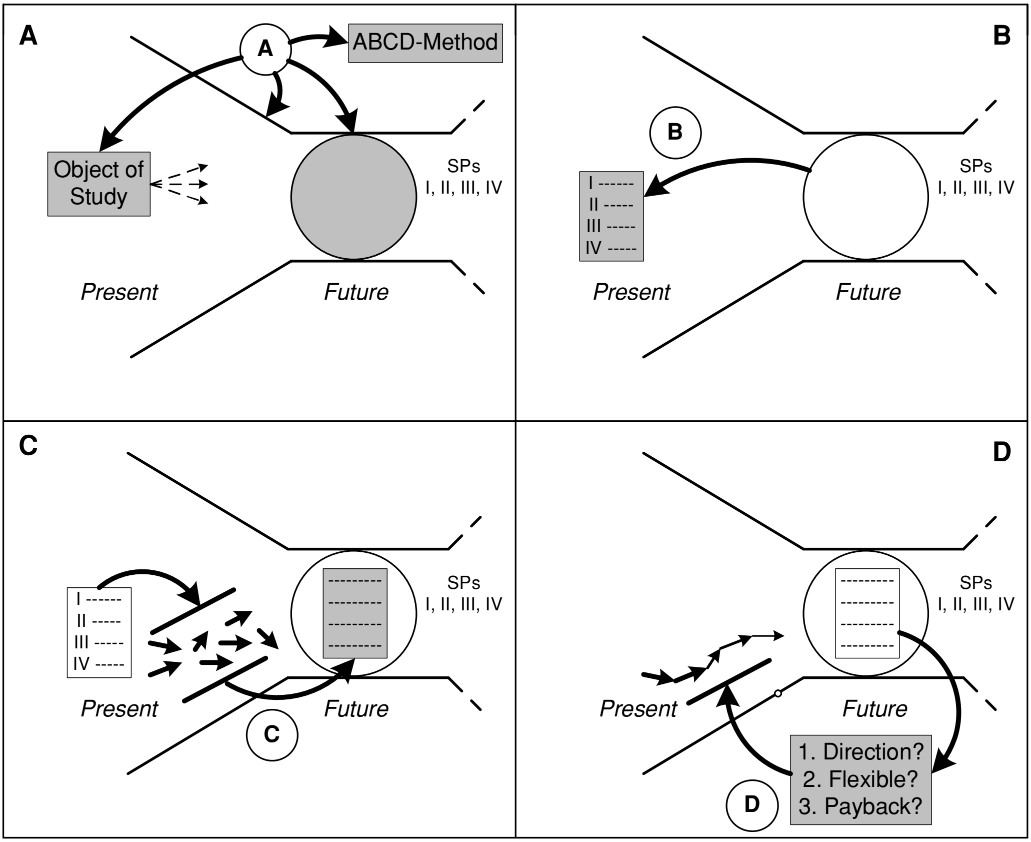

Figure 1 Backcasting from principles as illustrated by A-B-C-D planning. A. Agree on (1) the object of study, (2) the sustainability challenge (a funnel of declining opportunity), (3) the future sustainable landing place for the planning (defined by compliance with Sustainability Principles [SPs, denoted by roman numerals]), and (4) the method of study—ABCD. B. For each SP (I–IV), list critical practices from the perspective of SPs. C. Develop a list of possible solutions and investments ("brainstorming"). D. Use guiding questions to prioritize early solutions and investments from C. The procedure is repeated as the development unfolds.

ecosystems and mining areas where natural systems are not restored after mine decommissioning (Holmberg et al. 1999) with materials from well-managed ecosystems and mines (SP III); and narrowing rationales for meeting market needs with a wider humanized perspective given human needs at the global scale (Max-Neeff et al. 1989; Cook 2004) (SP IV). New materials and practices should, of course, be selected by considering all SPs collectively.

It is also possible that some materials may at times be required to increase in use to replace other materials. For example, the use of biofuels will probably increase as fossil fuels are gradually phased out. Moreover, photovoltaics may play a key role in the transition to sustainability, probably leading to expanded need for certain scarce metals (Andersson et al. 1998). Such materials then must, of course, be safeguarded by essentially closed-loop societal processes to ensure compliance with the SPs (Karlsson 1999). Thus, it must be ensured that such closed loops are economically viable or at least realistic over time. For photovoltaics, the material turnover is rather small, the use is inherently fairly nondissipative, and the long-term economic potential is probably large enough to carry the costs of the closed loops. But again, if more abundant metals or other materials could provide the same functions, those may be preferred.

Economic relationships also exist between dematerialization and substitution/change. Sometimes economically viable dematerialization is insufficient, because involved materials are relatively nondegradable (e.g., CFCs or PCBs [polychlorinated biphenyls]), and/or have already surpassed thresholds in natural systems due to the size of their flows (e.g., nitrogen oxides [NO_x]). In this case, substitution/change, rather than extensive and expensive closed-loop recycling, may be the best option, even though it may be relatively expensive if economies of scale are lacking. Furthermore, substitution/change often requires investment in new infrastructure. An example is the development of substitutes for CFC refrigerants, as well as new refrigerators that accept new refrigerants. But profitable implementation of new technologies can often be supported or made possible through *dematerialization*, that is, higher resource productivity and less waste within the new production lines and products (Robèrt et al. 2002; Byggeth 2001).

In summary, the SPs inform a dynamic (economic) relationship in this regard: Dematerialization may support certain substitutions/changes, substitution/change may prompt certain dematerializations, and substitution/change may eliminate some need for dematerialization. These linkages are essential when strategic investment paths are considered, and will surface if the applied method(s) allow(s) the transparency that follows from basic principles (in contrast to methods that either build on aggregation into one-dimensional information and/or certain selected impacts).

An example of how this dynamic has been handled in practice is the phasing out of CFCs by the Swedish-based multinational appliance producer Electrolux (Robèrt 1997). Introducing HCFCs would have meant an improvement in relation to CFCs as regards ozone layer destruction potential. HCFCs, though, just like CFCs, are relatively nondegradable in nature and therefore also potentially problematic as regards SP II. This meant that HCFCs, even though less damaging than CFCs, were not seen as a permanent solution (considering also the amounts necessary and type of use). Instead, a different strategy using the refrigerant R134a as a flexible platform was undertaken (Electrolux 1994). Given the relatively low degradability of R134a and the fact that it is foreign to nature, it was therefore not thought of as a long-term solution in itself. It could for technical reasons, though, be used as a step—linked to far lower subsequent investments than an HCFC-step would have required—in preparation for the next generation of hydrocarbon cooling agents. Electrolux expected to have the technology to ensure safe use of those agents (they are explosive) within a few years. With the chosen strategy, detailed LCAs comparing CFCs and HCFCs were unnecessary because these substances, using the overview assessment described above, could be ruled out as less viable paths to sustainability than R134a. The phase-out plan for R134a also made a detailed LCA unnecessary for that substance. Electrolux was the first company to launch an entire family of Freon-free refrigerators and freezers, resulting in increased market shares. The company also presented a new overall business strategy based on the SPs (Johansson 1997). It came to encompass a subtle balance of strategically chosen dematerializations and substitutions/changes for a number of product families.

The market introduction of compact fluorescent lamps (CFLs) by IKEA, the Swedish-based multinational home furnishings retailer, is another example of this type of systematic planning. CFLs are energy-efficient, but contain mercury, meaning that they are not sustainable in their present form unless the mercury is kept in a closed loop (which is very difficult). The head of environmental affairs at that time, Russel Johnson, presents an abridged version of the story (Johnson 2004):

> The trade-off problem here was between higher use of mercury (SP I), lower expenditure of energy (mainly SPs I and II), and higher costs for the lamps, thereby lowering their availability to the public (SP IV). A more creative methodology than trying to estimate whether the impacts outweighed the benefits was to start the planning procedure from a point where the trade-offs no longer existed—that is, backcasting from the system conditions [the SPs] to find a strategy to comply with them. In short, the following actions resulted:
>
> 1. A producer who could provide an adequate combination of the listed criteria to serve as a platform was identified.

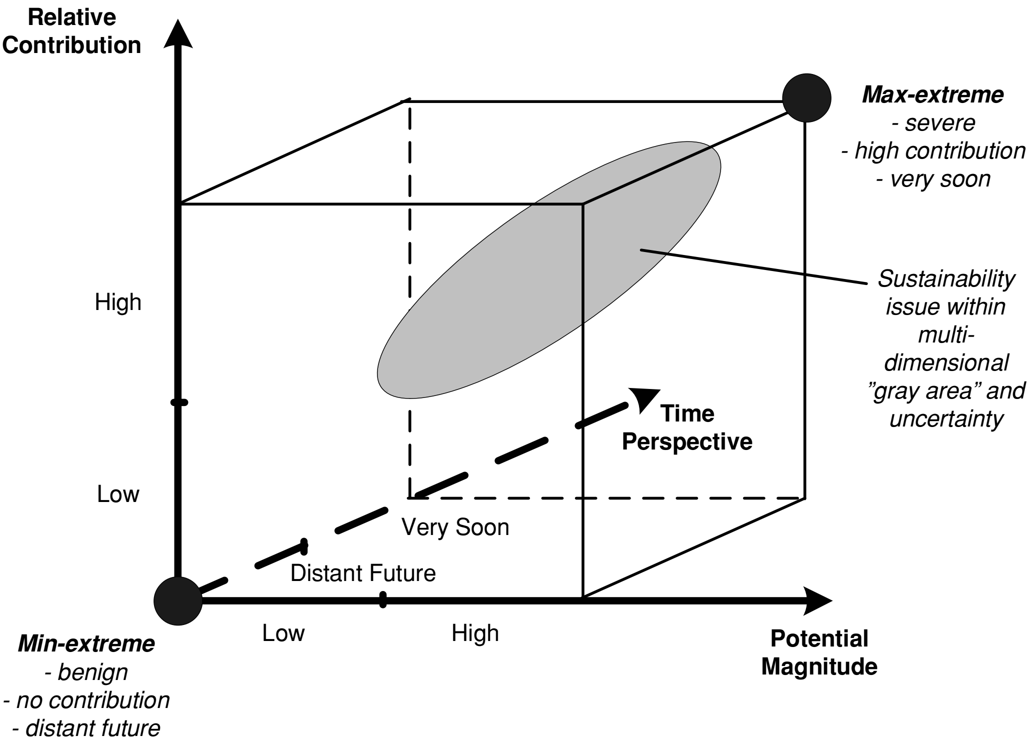

Figure 2 Gray areas of ambiguity for prioritization criteria for sustainability issues. Competent decision making often relies on strategic trade-offs where sustainability issues are evaluated against criteria such as potential magnitude, relative contribution to issue, and time perspective. Two extreme points exist for each, with gray areas between them. Three dimensions may already create considerable complexity, but more dimensions are often in play. Furthermore, uncertainty due to knowledge gaps may speak in favor of adding safety zones along the dimensions (the precautionary principle). Issues between the extreme points should be given an increasing degree of priority the closer they are to the max-extreme.

A reliable CFL with max. 3 mg Hg (mercury)/lamp—comparable to the EU environmental labeling system of max 10 mg on the global market (i.e., a reduction to one-third of previous levels or a factor 3) for such lamps—was then selected as the standard. A Chinese manufacturer, outstanding both from product design and production technology perspectives, met the requirements while also being price-competitive.

2. This producer and its competitors were notified that as long as they were ahead of the competitors on price, energy expenditure, and mercury content, they would continue to do business with IKEA. Backcasting from the system conditions [the SPs] had allowed the trade-off problem to support a *process* to arrive at principally sustainable low-energy lamps.

The Complexity of Making Detailed Priorities

How can trade-offs and uncertainties during the transition be managed? Some trade-off dimensions include potential seriousness of the social/ecological impacts of the issue, the individual actor's relative contribution to the issue, and the temporal perspective of impacts. Together, such issues present themselves within areas of varying ambiguity (“gray areas”) along these and other dimensions (see figure 2). Sustainability issues should be dealt with more urgently and

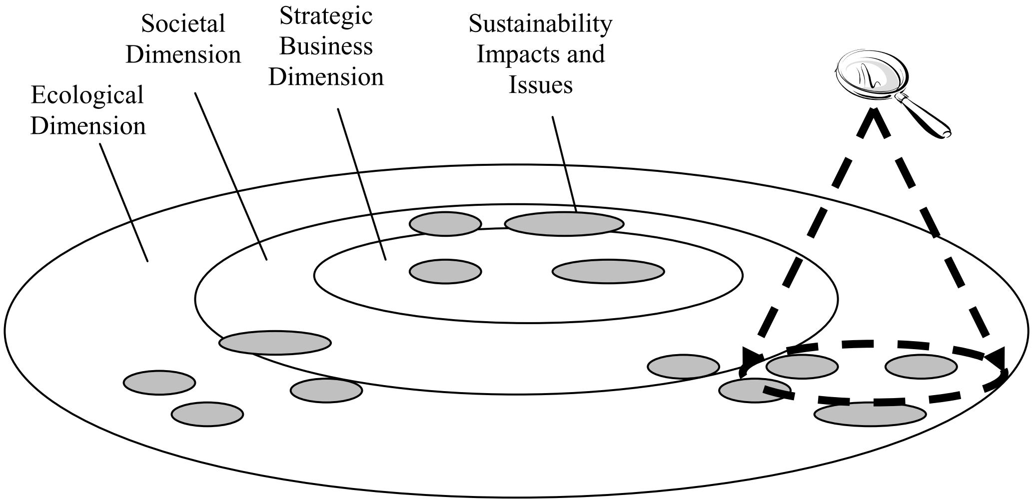

Figure 3 System boundaries in traditional life-cycle assessment (LCA)—based on selected known issues. The sustainability arena of a company starts with the strategic business dimension under company control, and continues with the surrounding societal and ecological dimensions that the company ultimately depends upon. The gray areas represent hot-spots, that is, impacts and issues that are essential from a sustainability perspective within those dimensions. Traditional LCA focuses mainly on a selection of known environmental impacts.

vigorously the closer they are estimated to be to the max extreme. Furthermore, uncertainty about where to put the issue along the different dimensions adds yet another trade-off dimension. This implies that greater uncertainty surrounding these and other dimensions (larger grey areas) is generally a rationale for undertaking proactive measures, as dealt with by the so-called precautionary principle.

Simultaneously, the economic dimension must be considered. It may be wise to schedule early measures that pay off quickly ("low-hanging fruit") to obtain the economic power necessary to deal with the more severe challenges. This article presents an approach to accomplish this comprehensively through a framework based on a large enough systems perspective. Without such a framework, the uncertainties regarding the respective relationships between the issues, each presented in a multidimensional grey area, will make trade-offs and prioritizations unmanageable from a strategic systems perspective.

So far, most LCAs have been performed without a generally accepted framework for discussing impacts beyond the environmental perspective (Brattebø 1996; Hoagland 2001; Pennington et al. 2004). It is important that sustainability-related life-cycle methods (including social life-cycle assessment) use the same, and sufficiently wide, system boundaries (Klopffer 2003). But to limit the complexity and size of studies, most of today's commonly applied forms of LCA use geographic and time-related system boundaries, focusing on a few ecological impact categories such as emissions of greenhouse gases, acidification and eutrophication (see figure 3).

Many authors have discussed the complexity of, and difficulties related to, the assessment of impacts from societal activities. Efforts have been made to streamline LCA to make the results easier to interpret (Graedel 1998; SETAC 1997; Todd 1996; Udo de Haes et al. 2004). A recent survey of available environmental evaluation tools in the EU concluded, though, that there are many approaches for simplified LCAs but they are not always clearly and consistently defined (Widheden 2002). This therefore likely translates into inconsistencies when they are used.

A Swedish study of the implementation of environmental management systems in Swedish companies concluded that only 10% of corporations have allowed results from LCAs to influence the measures taken (Zackrisson et al. 1999). The study did not explain why, but others have discussed the issue (Frankl and Rubik 2000; Heiskanen 2000), and after talking to business leaders (e.g., Johnson 2004), we suggest some presumptive reasons for the (as yet) relatively low use of LCA by decision makers in business:

- The results from LCA, performed by scientists to evaluate a scientific question, may be too complex to interpret from a business perspective.
- Efforts to aggregate information from different categories of impacts into simplistic figures for decision makers may be perceived as questionable.
- The impact perspective may be too narrow, that is, missing important aspects of sustainability such as social aspects, unsustainable management routines for ecosystems, and unsustainable emissions of compounds with as yet undiscovered impacts.
- The commonly applied LCA methods generally lack a strategic business perspective.

In conclusion, it is possible that the relatively low impact of LCAs on business decisions is related not only to relatively low *use* of the method by decision makers in business, but also to relatively low *relevance* of traditional LCA for such purposes. LCA as currently practiced is neither complete from the sustainability perspective, nor business-oriented, nor practical from a user-friendly perspective. But as discussed in the next section, this does not mean that LCA cannot evolve to embody these characteristics.

Preliminary Guidelines for Strategic Life-Cycle Management

Experience from Management of Complex Systems

It seems difficult to create comprehensible and user-friendly detailed checklists or manuals to detect optimal investment paths toward sustainability. Experience from management of any complex system (e.g., chess, traffic, or medical practice), though, points toward some guidelines for the selection of strategic paths:

- Once basic principles for the ultimate goal are clear, the individual's potential for dealing with trade-offs and for optimizing chances in multidimensional and complex situations (e.g., medical treatment) grows with experience.
- The complete investment path need not necessarily be determined up front, only smart flexible steps followed by continuous reassessment as the "game" unfolds.
- Beyond a certain level of specificity, checklists may confuse more than help decision makers.

The overall recommendation from this would be to (1) establish clear basic principles for sustainability up front; (2) develop smart overall strategies and guidelines for how to approach societal compliance with these principles (i.e., to apply a framework for decisions as a shared mental model among team members); and then (3) proceed with the learning, that is, play the game and gain experience in seeing the big-picture goals and selecting stepping stones in that direction. Once the need for more sophisticated tools, such as multidimensional decision support (see figure 2) and other support systems, evolves, (4) *those too ought to be selected and designed in line with the structured overview that the basic principles provide*.

The capacity of basic principles to directly inform relatively advanced strategic decisions has been seen in many cases, such as the previously presented Electrolux and IKEA examples. Could this inform LCA and provide a method for assessing materials and products, and developing new products, from a full sustainability and life-cycle perspective?

Desired Features of Strategic Life-cycle Management

Preliminary ideas for strategic life-cycle management connecting current LCA methodology to a strategic sustainability perspective are indicated in table 1, figure 4, and table 2.

Instead of further narrowing the LCA scope, as is done in streamlined LCA, a sustainability-related LCA approach, such as SLCM, would require a systems view that tackled the problems

Table 1 Strategic life-cycle management (SLCM) compared to other life-cycle related sustainability assessment approaches

Approach	*Abridged description*	*Analysis specificity*	*Sustainability issues covered*	*Objective*
Streamlined LCA	Overview of life-cycle environmental aspects or impacts.	Mainly overview analysis.	Focus on known environmental problems.	To give decision makers a simplified picture of system environmental load.
Traditional LCA	Detailed compilation and evaluation of materials and energy flows between a chosen system and its environment.	Detailed analysis.	Resource consumption and emissions of known pollutants within chosen scope.	To facilitate a choice of material or product with lowest environmental load values within chosen scope.
Strategic LCM	Sustainability assessment of a product life cycle using backcasting from sustainability principles.	First overview and then detailed analysis, as required.	Potential socioecological and economic problems from a full systems perspective.	To identify strategic pathways toward sustainability.

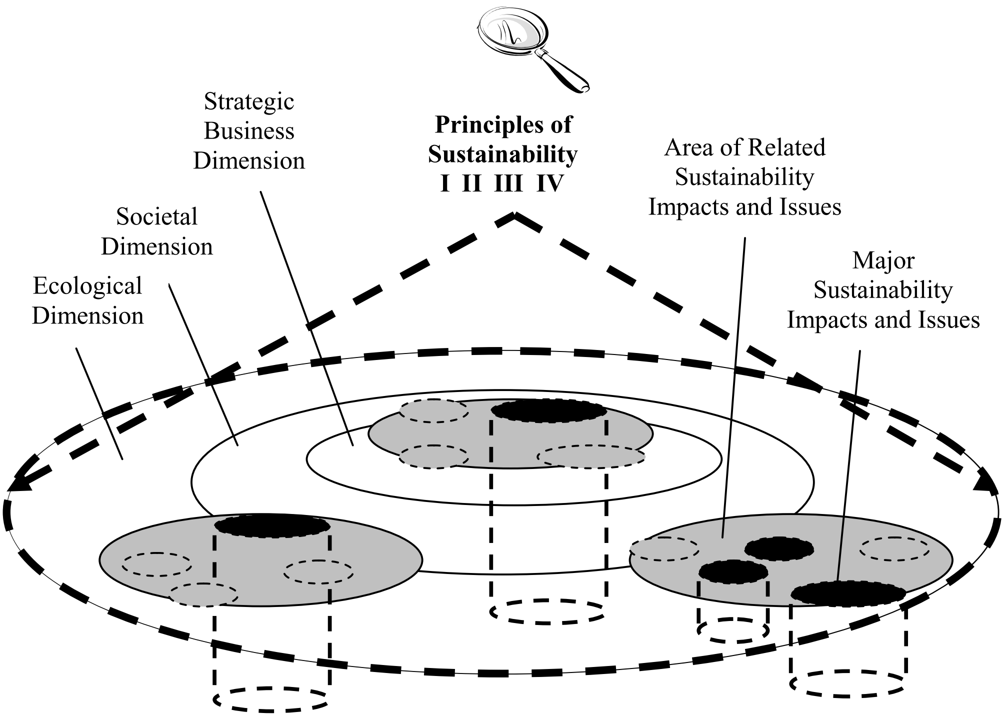

Figure 4 Strategic life-cycle management (SLCM)—sustainability principles as system boundaries. This approach starts with an overview of the whole system through the lens of the four sustainability principles (SPs). The large gray areas denote related hot spots, that is, impacts and issues found to be in conflict with the SPs and therefore essential for winning in the system. The smaller areas (black, or gray enclosed by a dashed line) may partly be impacts and issues newly discovered using the SPs, and partly the same impacts that were identified in figure 2, but now put into context. Some of these impacts and issues may be sufficiently described from the overview, whereas others (the solid black areas) may require deeper analysis using tools such as comprehensive life-cycle assessment. Other hot spot areas may not require any further analysis if, for example, the initial overview analysis reveals a strategic need to completely phase out a flow regardless of its exact size.

from the broadest possible perspective (Bucciarelli 1998). The four steps in a traditional LCA would then need to reflect the following:

Goal/Scope

The goal/scope of the study should be clearly linked to the ultimate purpose of *society reaching sustainability*. It should be recognized, for example, that for some purposes certain materials will probably ultimately not be used at all, given the large investments such use would require to ensure society's compliance with the SPs. The goal/scope should also include consideration of indirect impacts that come from, for example, how ecosystems such as forests, agriculture, and fisheries are managed. Attempts should be made to include issues not yet known to harm the environment. (Had CFCs been scrutinized through a SP lens, it could have been determined up front that large-scale use, outside of tight technical loops, was not compatible with SP II.).

Inventory Analysis

The inventory analysis should start from the top, with essentially no system boundaries but the ones that apply for the whole biosphere. This means asking how a certain organization or product, throughout its life cycle, *contributes* to society's violation of the SPs. This overview will identify important issues ("hot spots") that may later require more detailed mapping, to give more

Table 2 How a framework for sustainability can add to traditional life-cycle assessment (LCA)

LCA Stage	*A-B-C-D analysis step*	*Benefits of integration*
1. Overall process	A-B-C-D	Provides a structured A-B-C-D manual and a set of questions with which one can "backcast from basic principles."
2. Scope/goal definition	A	Relates the exercise to the sustainability principles (SPs) so that scope is not limited to impacts that are certain and/or known.
3. Inventory analysis	B	Focuses on flows and practices relevant to the broadened sustainability-related scope.
4. Impact assessment	B	Impacts seen as contributions to violations of basic principles make it possible not only to fix problems, but also to avoid yet unknown problems.
5. Interpretation and Improvement assessment		
(i) Option generation	C	Provides overall strategic organizational objectives and improvements based on the four SPs, and categorizes them into two distinct and useful mechanisms for option generation—dematerialization and substitution/change.
(ii) Option analysis and option choice	D	Provides a set of questions (which are particularly useful at this stage) to ensure that the full context of sustainability, including the strategic business/economic dimension, is taken into account.

information on priorities. Moreover, other issues may be identified as less important and therefore omitted from further studies by *conscious* decisions (not a priori from gaps in methodological design).

Impact Assessment

A full LCA normally uses the inventory analysis as input, divides consumption and emissions into categories, and assigns quantitative indices according to their perceived threat to the environment. This results in one or several environmental impact indices that are presented to the decision-maker. This could be valuable provided that the scope was wide enough, and included areas where society's violations of basic SPs were also registered as impacts, regardless of whether documented damage had surfaced or not.

Results Interpretation and Improvement Assessment

The results interpretation and improvement assessment should include the full scope of options available given the full context of impacts identified above, and should also incorporate the business perspective. In a systematic way, it should deal with the complex trade-offs and prioritization exercises that are inevitable parts of choosing options. The strategic focus should be "smart stepping-stones toward sustainability" rather than relying solely on "the least harmful option right now." Although ISO 14040 and 14043 refer to this component as an "interpretation" stage (ISO 1997, 2000), a wider meaning is proposed here, implying that an improvement assessment (or a gap analysis) in relation to the SPs should also take place at this stage.

Introductory Steps toward Strategic Life-Cycle Management

LCA has previously been discussed in relation to a sustainability perspective. Cooper (2003) suggests using the traditional LCA approach but focusing more on impacts that are directly or indirectly linked to certain sustainable development indicators of national interest. Andersson and colleagues (1998) use an approach similar to the one put forward in this article. They also state that this perspective would open up a more strategic approach to LCA, but they do not elaborate on this idea, nor deal with the issue of complexity.

The framework for strategic sustainable development that is presented here has also been integrated with a traditional model for product development (Byggeth 2001). Product development teams from 10 small- and medium-sized enterprises (SMEs) were exposed to guiding questions under each SP and in each stage of the product development process. With this experience, a Web-based method for sustainable product development (MSPD) is under development, aimed at creating a generic approach that can be applied to any product category. The method encompasses problem-related questions referring to the step II, current flows and practices (see figure 1), and solution-related questions referring to step III (option and vision creation). Both question types refer to the full life cycle. These questions are run in a brainstorming session format where the answers under II and III are listed, and smart early moves from III are selected to form a strategic plan (IV). Each question may trigger further extensive/quantitative analysis and the creation of

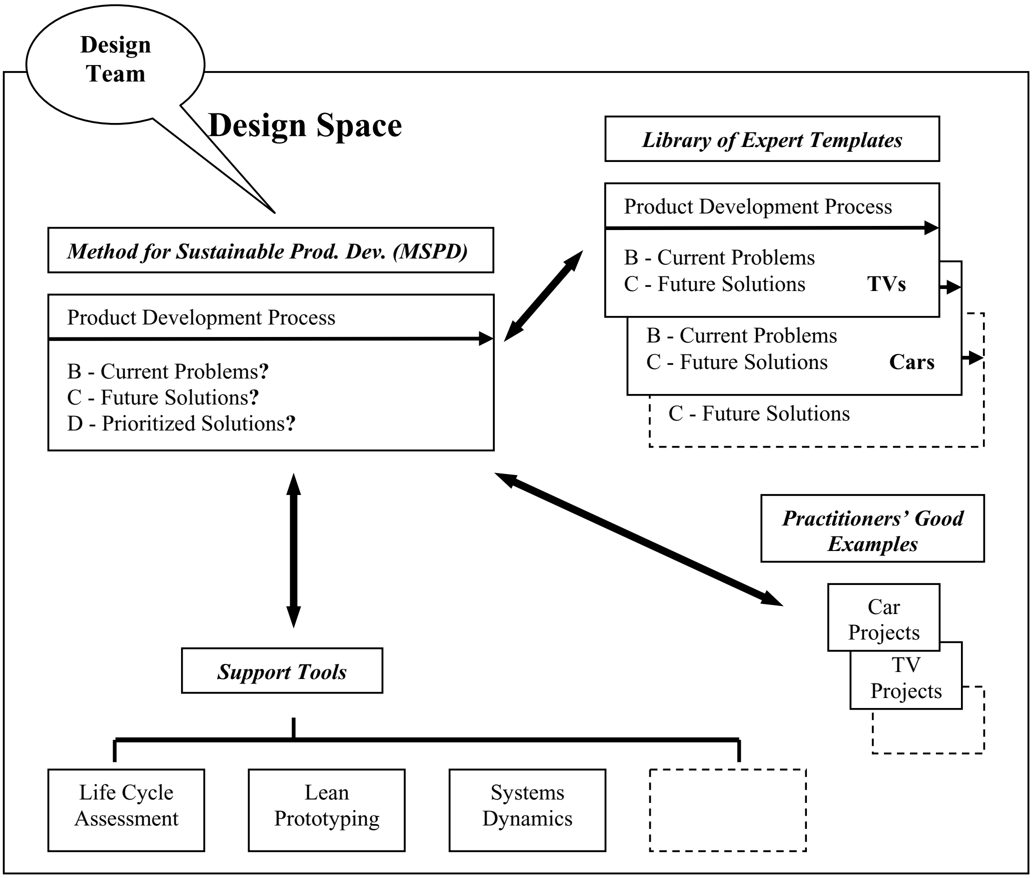

Figure 5 A future design space. Tools and concepts that are all informed by the strategic life-cycle management (SLCM) perspective constitute the design space. Tools that are already under development are the method for sustainable product development (MSPD), a library of expert templates for sustainable product development (TSPDs), a practitioners' experience library, practitioners' good examples, and support tools.

indicators that would be suitable to monitor the phase out of critical flows and practices. Examples of 2 questions under SP I, for instance, are "Does our project/process/product systematically decrease its economic dependence on fossil fuels? Is it economically dependent on dissipative use of materials from the lithosphere and/or mined materials that are relatively scarce in ecosystems? Are elements from those materials currently increasing in concentration anywhere in the biosphere?"

The MSPD has also been used to produce templates for sustainable product development (TSPDs), where groups of sustainability and product experts develop tailored descriptions of various product categories. Thus, the TSPDs are product-category-specific, but still general within the categories. Industrial designers can use the templates for filling the general sustainability gaps with innovative solutions for televisions, refrigerators, and so forth. This is intended to provide businesses with a time- and resource-efficient opportunity to see the sustainability contexts of their respective products and services. Templates have been tested in a beta study of Matsushita's televisions and refrigerators and of their recycling plant (Matsushita Eco-Technology Center [METEC]) in an effort to produce sustainability reports for those items (Matsushita Electric Group 2002). A more detailed description of the television case study is being prepared by MacDonald and colleagues (in preparation). Both new ideas and potential hot spots requiring incorporation into strategic planning and future detailed assessments (e.g., by LCA) were identified.

Future Steps toward Strategic Life-Cycle Management

Recent MSPD and TSPD experience is suggested as a basis for developing more concrete guidelines for SLCM. We aim at a computer-based working environment ("design space") containing tools that are all informed by a framework for strategic sustainable development, thereby providing more synergistic decision support for sustainable products and services (see figure 5).

Conclusions

This article argues that a framework for sustainable development based on backcasting from basic principles for sustainability (often referred to as The Natural Step framework) could and should be used to foster a new general approach to the management of materials and products that allows the overall analysis to be informed by (1) all issues that are essential from a basic sustainability perspective and (2) all suggestions that can serve as flexible actions to eventually arrive at sustainability. It is suggested that this combination of framework and life-cycle assessment and management techniques, such as LCA and other support tools, be termed "strategic life-cycle management." Introductory applications of this approach suggest that it makes it possible to avoid costly assessments of flows and practices that are not critical from a sustainable development perspective, and to identify strategic gaps in knowledge or potential problems that need further assessment. Benefits are discussed particularly in relation to product development and LCA tools, but this approach could probably also improve the performance of other existing tools for the management of materials and products as well as facilitate the identification of need for, and the development of, new tools.

It is also argued that analysis dealing with system boundaries should start with an overview of the whole system, allowing *all* issues that are found to be in conflict with basic sustainability principles (SPs), as described earlier, to be taken into account. This requires a perspective that (1) is large enough in time and space (humanity and ecosystems on Earth, both now and in the future); (2) supports assessment of products and services through the full life cycle, where the lens is the SPs—and only thereafter are detailed studies on specific impacts undertaken by means and tools that are selected and designed for the purpose; (3) includes the strategic dimension of senior management and decision makers, that is, views innovations and design changes as economically feasible platforms and strategic tradeoffs toward sustainability; (4) supports handling of complexity in a feasible and simple enough way to be practical, yet not simplistic in such a way that essential aspects of sustainability are inherently lost in the process; and (5) catalyzes innovation so that problems as well as solutions can be dealt with in a way that frees creativity from traditional constraints.

A more traditional assessment of targets might, for example, suggest that a corporation recycle 30% more than before or set recycling targets based on global best practices, instead of the more rigorous standard of recycle as much as is required to prevent the organization's contribution to the societal problem of systematic accumulations of minerals anywhere in the biosphere. Though the latter does not always give immediate answers as to how much recycling of a certain mineral is therefore required, given that there are so many possible solutions to this objective, the difference is still fundamental. Not maintaining continuous sight of the ultimate objective deprives the creative process of its ultimate driver. The potential for leapfrogging and for preventing investments that may lead to dead ends in which present problems are replaced with other ones in the future is also probably greater with the bird's-eye perspective.

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