# STRATEGIC LIFE-CYCLE MODELING FOR SUSTAINABLE PRODUCT DEVELOPMENT

Henrik Ny

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Henrik Ny

# Abstract

Decision makers are challenged by complex sustainability problems within the socio-ecological system. In response, a vast range of sustainability-related methods/tools have been developed, each focusing on certain aspects of this challenge. Without a unifying theory it is, however, unclear how these methods/tools can support strategic progress towards sustainability and how they relate to each other. This need for clarity and structure urged some sustainability pioneers to start develop an overarching framework for strategic sustainable development (SSD), often called "The Natural Step (TNS) framework", from the NGO that has facilitated its development and application, or the "backcasting from sustainability principles (BSP) framework" from its main operational philosophy.

The aim of this thesis is to study if, and in that case how, this framework can aid coordination and further development of various sustainability-related methods/tools, specifically to increase their capacity to support sustainable product development (SPD). Life-cycle assessment (LCA), "templates" for SPD and systems modeling and simulation (SMS) are the methods/tools in focus.

A new strategic life-cycle management approach is presented, in which the main sustainability aspects, LCA "impacts", are identified through socio-ecological sustainability principles. This creates new opportunities to avoid the reductionism that often follows from traditional system boundaries or from a focus on specific impacts. Ideas of how this approach can inform the studied tools are given. This may eventually lead to a whole integrated toolbox for SPD (a "Design Space"). As part of such a Design Space, a new "template" approach for SPD is developed. A case study of a sustainability assessment of TVs at the Matsushita Electric Group indicates that this approach can create a quick overview of critical sustainability aspects in the early part of the product development process and facilitate communication of this overview between top management, product developers, and other stakeholders. A potential integration between BSP and SMS is also discussed. It is suggested that this should start with BSP to create lists of critical present-day flows and practices, ideas of long term solutions and visions, and a first rough idea about prioritized early investments. After that, SMS should be applied to study the interrelationships between the listed items, in order to create more robust and refined analyses of the problems at hand, possible solutions and investment paths, while constantly coupling back to the sustainability principles and guidelines of the BSP framework.

Decision makers seem to need more of an overview and of simplicity around sustainability issues. A general conclusion is, however, that it is important that this is achieved without a loss of relevant aspects and their interrelations. Over-simplifications might lead to sub-optimized designs and investments paths. Combining the BSP framework with more detailed methods/tools seems to be a promising approach to finding the right balance and to get synergies between various methods/tools.

***Keywords:*** *backcasting, life-cycle assessment (LCA), modeling, planning, strategic life-cycle management, strategy, sustainable product development, systems, The Natural Step (TNS).*

# Thesis

## Disposition

This thesis includes an introductory part and the following papers, which have been slightly reformatted from their original publication. Their content, though, is unchanged.

### Paper A

Ny, H., MacDonald, J.P., Broman, G., Yamamoto, R. and Robèrt K.-H. 2006. Sustainability Constraints as System Boundaries. An Approach to Making Life-Cycle Management Strategic. *Journal of Industrial Ecology*, vol. 10, issue 1-2, 61-77.

### Paper B

Ny, H., Byggeth, S.H., Robèrt K.-H., Broman, G. and MacDonald J.P. Introducing Templates for Sustainable Product Development through a case Study of Televisions at the Matsushita Electric Group. Submitted to the *Journal of Industrial Ecology*.

### Paper C

Ny, H., Haraldsson, H.V., Robèrt K.-H. Broman, G. and Sverdrup, H. Systems Modeling and Simulation within Sustainability Constraints. Manuscript.

# The Author’s Contribution to the Papers

The appended papers are the result of joint efforts. The present author’s contributions are as follows:

## Paper A

Took part in the planning of the paper, provided most of the new theoretical concepts concerning the scope of the paper – Life-Cycle Assessment, and led the writing process.

## Paper B

Took part in the planning of the paper and the development of the new theoretical concepts. Completed the illustrations and led the writing process.

## Paper C

Led the planning and writing of the paper and came up with most of the new theoretical concepts. Completed the illustrations.

# Abbreviations

| | |
|---|---|
| **BSP** | Backcasting from Sustainability Principles |
| **CE** | Concurrent Engineering |
| **CLD** | Causal Loop Diagram |
| **DfE** | Design for Environment |
| **IE** | Industrial Ecology |
| **ISO** | International Organization for Standardization |
| **LCA** | Life-Cycle Assessment |
| **LCI** | Life-Cycle Inventory |
| **LCM** | Life-Cycle Management |
| **LCT** | Life-Cycle Thinking |
| **MSPD** | Method for Sustainable Product Development |
| **NGO** | Non-Governmental Organisation |
| **OBP** | Observed Behavior Pattern |
| **RBP** | Reference Behavior Pattern |
| **SA** | Systems Analysis |
| **SCs** | System Conditions |
| **SD** | Systems Dynamics |
| **SFD** | Stock and Flow Diagram |
| **SLCM** | Strategic Life-Cycle Management |
| **SME** | Small and Medium-Sized Enterprize |
| **SMS** | Systems Modeling and Simulation |
| **SPA** | Sustainbility Product Analysis |
| **SPD** | Sustainable Product Development |
| **SPs** | Sustainability Principles |
| **TNS** | The Natural Step |
| **TSPDs** | Templates for Sustainable Product Development |

# Contents



# Appended Papers

# 1 Introduction

## 1.1 The Sustainability Challenge

There is an increasing consensus among scientists of various fields that society is currently on a long-term unsustainable course (Meadows et al. 1972; Steffen et al. 2004; MA 2005). Already In 1987, a first overarching definition of sustainable development (often called the Brundtland definition) was put forward by the World Commission on Environment and Development:

> *“Humanity has the ability to make development sustainable - to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.”(Brundtland 1987)*

This definition was later adopted at the Earth Summit conference in Rio de Janeiro in 1992, and its “Agenda 21” (an action plan for the 21st century) was initiated as a challenge to the world to move in a more sustainable direction. However, the Brundtland definition of sustainability is at a very high philosophical level, and need to be broken down into operational principles for practical use. In response to the complex nature of interrelated socio-ecological problems, a vast range of sustainability-related ideas, methods, tools, concepts, and approaches have been developed. Most of these have dealt with particular aspects of the societal sustainability problems from the perspectives of established research fields. While proven successful for the study of isolated expert fields, for instance the study of carbon dioxide emissions throughout product life-cycles, such approaches cannot be solely relied upon. That would be reductionistic and not sufficient when dealing with complex systems such as human society in the biosphere. Trans-disciplinary, trans-sector, and other interactive approaches for sustainability will be needed in such cases (Huesemann 2001).

## 1.2 Industrial Ecology and Life-Cycle Assessment

Industrial ecology (IE) is an emerging research field that aims to explain how the industrial system works, how it is regulated, and how it interacts with the biosphere. Then, on the basis of present knowledge about ecosystems, IE aims to determine how the industrial system could be restructured to make it compatible with the way natural ecosystems function (ISIE 2004). The field encompasses and relates to areas of research and practice such as “material intensity per unit service” (MIPS) and factor 10 (Schmidt-Bleek 1997), ecological footprint (Rees and Wackernagel 1994), life-cycle assessment (LCA) (Lindfors et al. 1995; ISO 1997), zero emissions (Pauli 1998; Suzuki 2000), and extended producer responsibility (Lindhqvist 1992, 2000). Out of these areas, LCA is one of the most rigorously developed and frequently used. It has the objective of evaluating environmental impacts of materials and products from the “cradle” (resource extraction) through transport, production and use, to the “grave” (fate after end use). This leads to a more comprehensive view of societal environmental impacts than if only the material or product itself would be evaluated.

Nevertheless, 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 this was the case, but others have discussed the issue (Frankl and Rubik 2000; Heiskanen 2000), and according to business leaders (Broman et al. 2000; Johnson 2004), some presumptive reasons can be suggested for the (as yet) relatively low use of LCA by decision makers in business (Robèrt 2000; Robèrt 2002a):

- 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 line with the above, it is possible that the relatively low impact of LCAs on business decisions is related not only to a relatively low *use* of the method by decision makers in business, but also to a relatively low *relevance* of traditional LCA for such purposes. LCA as currently practiced is neither complete from a sustainability perspective, nor business-oriented, nor user-friendly. But, as discussed in Paper A (Ny et al. 2006), this does not mean that LCA cannot evolve to embody these characteristics. How could this evolution take place in practice?

A new exciting IE-related field, tentatively called "strategic sustainable development" (SSD), may deal with such questions. A framework has been developed since the early 1990s that applies a five-level model to structure complex planning endeavors like societal transition towards sustainability (Robèrt 2000). This framework is also called "The Natural Step (TNS) Framework" from the NGO that has facilitated its development and application, or the "backcasting from sustainability principles (BSP) framework" from its main operational philosophy. Several pioneers on tools, concepts and approaches for sustainable development have already used this framework to assess how their respective tools relate to sustainability and to each other (Robèrt et al. 1997; Holmberg et al. 1999; Rowland and Sheldon 1999; Holmberg and Robèrt 2000; Robèrt 2000; Robert et al. 2000; Robèrt et al. 2002; Korhonen 2004; MacDonald 2005; Byggeth et al. 2006; Byggeth and Horschorner 2006, Ny et al. 2006). Before describing the BSP framework in more detail it makes sense to say a few words about the field of systems science that it also relates to.

## 1.3 Methods to Study Complex Systems – Systems Science

A system consists of interrelated components. Some systems contain so many components and relationships that it is impossible to get a robust overview of their behavior without scientific approaches and sophisticated tools. Systems science is a field that has emerged to face such challenges and as a result, for example, quite a lot can now be said about both short-term local weather and long-term average weather (climate) of different regions. Systems science uses a trans-disciplinary approach to build understanding of complex causal relationships and feedbacks between system components. Systems science embeds other terms like game theory, network science, "systems analysis" (SA), "systems dynamics" (SD), etc. The two latter terms partly overlap. In the literature, there are many competing descriptions of the actual or desired workflow of SA/SD (Randers 1980; Richardson and Pugh III 1981; Roberts et al. 1983; Wolsteholme 1990; Sterman 2000). One could also roughly say that SA takes problems apart, building and studying conceptual models, whereas SD moves on to making simulations of model behavior over time (Haraldsson 2005). In this licentiate thesis, when referring to SA and SD taken together, the term “systems modeling and simulation” (SMS) will be used.

## 1.4 Backcasting from Sustainability Principles

The backcasting from sustainability principles (BSP) framework lets five interdependent but distinct levels communicate with each other as their respective contents and relationships are explored (Robèrt 2000; Robèrt et al. 2002):

1. *The System.* The overall principal 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 systematic monitoring of the actions (4) to ensure they are strategic (3) to arrive at success (2) in the system (1).

A starting point when developing the BSP framework was that strategic progress towards sustainability could probably not be achieved by a sole focus on gaining ever more knowledge about the system as such (level 1) – in this case “society within the biosphere”. To be able to plan strategically, it is essential to not only understand the system per se, but to also have a robust definition of “purpose” or overall goal. To that end, it is essential to study the system level *enough* to approach a rigorous principled definition of sustainability (level 2).

The BSP approach recognizes that there are principled flaws of societal design upstream in cause-effect chains that systematically undermine the ecosystem and the social fabric – the two ”commons” on which the whole human society relies. The ecosystem provides services like fresh water and natural resources while the social fabric provides services like personal safety and help from fellow human beings (Capra 1996; Hayashi et al. 1999; Ostrom 1999; Folke et al. 2002). Metaphorically speaking, as the two commons are eroded more and more, society is moving deeper and deeper into a declining window of opportunity for long-term prosperity (figure 1) (Robèrt 2000). The environmental and social problems that have surfaced to date are serious, but the most serious problem is that such problems are bound to systematically increase due to the basic design and operation of today’s society. This is the meaning of unsustainability.

The sustainability principles (SPs) of the five-level framework (level 2) were developed with the following criteria in mind. The set of SPs should be:

- *science-based*, that is compliant with relevant scientific knowledge available to date
- *necessary* for sustainability, that is, failure to comply with any one of the SPs would make sustainability impossible
- *sufficient* for sustainability, that is, the SPs taken together should cover all relevant aspects
- *general*, that is, people from various societal sectors and scientific disciplines should be able to understand and use them
- *concrete*, that is, capable of guiding actions and problem solving, and preferably
- *distinct*, that is, mutually exclusive to facilitate comprehension and monitoring

After several revisions the current wordings of the principles are (Ny et al. 2006):

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 business leaders (Electrolux 1994; Robèrt 1997; Anderson 1998; Nattrass 1999; Broman et al. 2000; Leadbitter 2002; Matsushita 2002; Nattrass and Altomare 2002; Robèrt 2002a; Robèrt 2002b) and policy makers (Cook 2004; Robèrt et al. 2004; James and Lahti 2004; Gordon 2004) on applying these principles and creating a bird's-eye perspective on an array of sustainability-related problems.

Practical application of the BSP framework is facilitated by an A-B-C-D-procedure (figure 1), including (A) sharing and discussing the suggested BSP 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 takes care of the short-term challenges but also prepares for coming actions to eventually make society comply with the SPs. This means that each investment, at least if it is large and tie resources for relatively long time periods, should (i) strengthen the organisation's platform (Flexible) for coming investments that are likely to take it towards success as defined by the SPs (and other goals set up by the organisation). As a basic mindset, the organisation should in each investment (ii) seek to move towards reducing its contribution to society's violation of the SPs (Direction) and (iii) strive to be "economic" with resources so that the process is continuously reinforced (Payback). However, in the decision regarding an individual investment, (ii) and (iii) need to be assessed in a dynamic interplay between each other and with the longer term plans (i). Just as it in chess may sometimes be smart to lose a piece or "take a detour" if it creates interesting options for the longer term, it could sometimes be smart to temporarily increase an organisation's expenses or its contribution to society's violation of some SP if that is a necessary early step to get a long term proactive plan started. An example could be a government sending delegates, by fossil fuel driven airplanes, to an international conference aiming at an agreement on long term reductions of $CO_2$ emissions on the global scale.

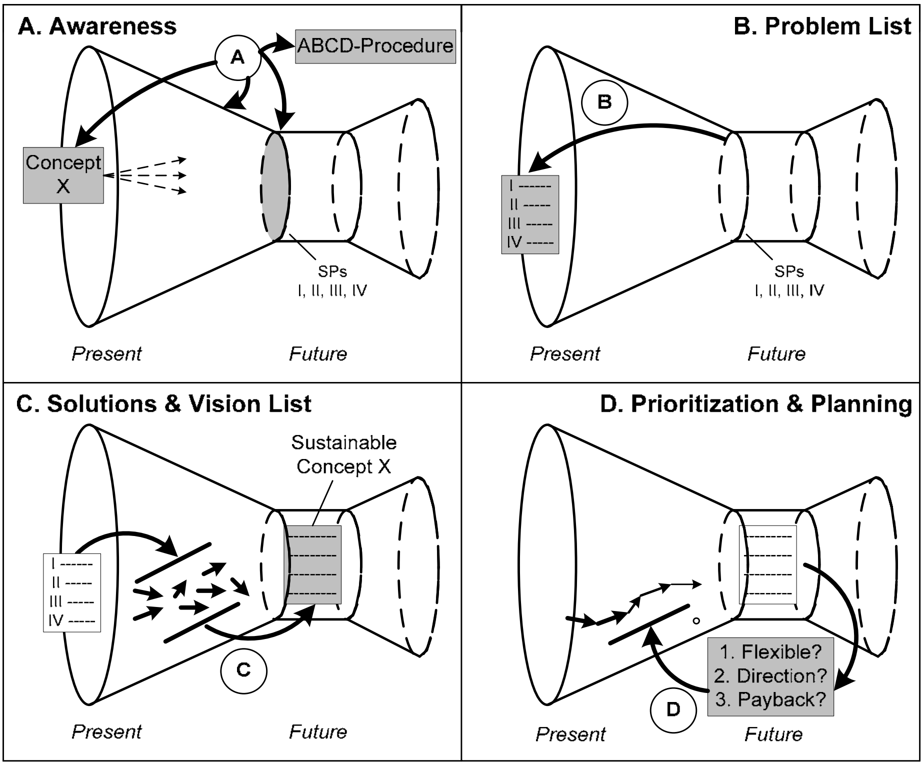


***Figure 1. The ABCD Procedure of Backcasting from Sustainability Principles.*** *Start by agreeing on a mental model of the concept of study (Concept X), the sustainability challenge (a decreasing window of opportunity, the funnel), the SPs and the ABCD procedure as such (A). Then identify present practices that are either problematic with respect to the SPs or assets for solving the problems (B). Continue with brainstorm to list potential solutions to the problems and envision new sustainable concepts (C). Based on the C-list and strategic guidelines, prioritize actions into a strategic plan (D).*

## 1.5 Sustainability through Product Development?

Some general trends in product development methodology can be identified, even though many companies use company-specific product development processes. Traditionally, so called “serial engineering” has been used, in which each design stage starts when the previous one is completed. This might unfortunately lead to poor communication and interaction between the various phases, resulting in little attention to key issues from later stages (e.g., manufacturing and delivery aspects) during the earlier concept and design stages (Syan 1994; Ottosson 1999). In order to minimize the time for product development, serial engineering evolved into “integrated product development” (Barkan 1988; Evans 1988; Winner et al. 1988). Integrated product development, or “concurrent engineering” (CE), means that people with different competencies and often from different departments in a company, such as marketing, design, and production, are working at the same time with the same project. Several authors have presented integrated product development models (Olsson 1976b; Andreasen and Hein 1987; Pugh 1991; Ulrich and Eppinger 1995; Ullman 1997).

The early part of the product innovation process is a critical intervention point for the transformation of society towards sustainability. Once a product design has been set its sustainability attributes are largely fixed. It is therefore imperative to develop rigorous and operational methods and tools for sustainable product development (SPD) (Charter and Chick 1997; Ritzén 2000). In the last decades, growing awareness of global environmental problems has added a whole new design challenge for product development. This led to a new industrial ecology-related product development field called “eco-design” or “design-for-environment” (DfE). There are several reviews of previous methods and tools with relevance to this field (de Caluwe 1997; van Weenen 1997; Tischner et al. 2000; Robèrt et al. 2002; Byggeth and Hochschorner 2006). A general method for SPD (MSPD) has been proposed (Byggeth et al. 2006), using the BSP framework to integrate social and ecological aspects of sustainability with a strategic business perspective in an integrated product development model. When testing the MSPD, some Swedish businesses expressed a desire for some kind of guidance for specific product categories and for improved interaction with other methods and tools (Byggeth and Broman 2000; Byggeth 2001; Byggeth et al. 2006). This need for more sophisticated decision support for SPD was an important factor behind the initiation of this thesis.

# 2 Aim and Scope

The aim of this thesis is to study if, and in that case how, this framework can aid coordination and further development of various sustainability-related methods/tools, in particular to increase their capacity to support sustainable product development (SPD). Life-cycle assessment (LCA), templates for SPD, and systems modeling and simulation (SMS) are the methods/tools in focus.

The theory and support tools developed should have the following characteristics:

(i) a full sustainability perspective throughout the respective life-cycles of products and services so that all practices will be assessed that are inherently unsustainable, not only those that are linked to presently known impacts,
(ii) a strategic perspective that includes the strategic business dimension,
(iii) a time perspective based on backcasting rather than forecasting,
(iv) a level of detail that makes the complexity manageable, without leading to the loss of vital information due to simplifications and aggregations.

The intent is not to replace existing support methods/tools for SPD but rather to put them within an overarching structure that facilitates the use of each one where most applicable. The intention is also to use this overarching perspective to identify the need for new methods/tools.

# 3 Overarching Research Questions

## 3.1 Paper A

1. Is it possible to create a strategic life-cycle overview of a system of study – without too convoluted manuals, and if so, what would such an approach look like?

2. Is it possible to build an approach on how to gradually integrate support tools for SPD within a strategic life-cycle overview, and if so, how?

## 3.2 Paper B

3. Could backcasting from sustainability principles be applied to develop a user-friendly non-reductionistic methodology for concrete sustainability assessments of products and services?

4. If so, could such methodology be applied to facilitate the organization's ability to link product improvements to an overriding strategic sustainability course for the company?

## 3.3 Paper C

5. Is it feasible to integrate systems modeling and simulation with an overarching framework for SSD, and if so what could such integration look like?

# 4 Research Methods

## 4.1 Scientific Methods and Techniques

Scientific method is a field of study in itself and depending on the perspective, many different definitions and distinctions can be made. One author (Maxwell 2005) makes it simple by saying that the scientific method of a study is everything that a researcher actually does to search for results that might answer the research questions. Even though the exact choice of method or combination of methods should be adapted to the specific requirements of each study there are some generic methods, including theory building, hypothesis testing, comparing, classifying, conducting case studies, and so on. Sometimes a distinction is made between such overarching scientific methods and the more detailed techniques or methodologies used to gather data (Ejvegård 1996). For example, when using the case study method some data gathering techniques/methodologies could include literature studies, questionnaires, interviews, etc.

## 4.2 Empirical versus Theoretical Science

Another fundamental distinction could be made between empirical and theoretical scientific methods. Empirical science is often quite practical, using experiments to gather data about particular cases and then drawing particular conclusions from those data. Theoretical science, on the other hand, aims to create models of reality that helps identifying the underlying mechanisms and relationships that explain the empirically collected data. This distinction could be exemplified by the difference between experimental and theoretical physics. Experimental physics aims to discover and explain measurable data about how different parts of nature behave while theoretical physics searches for unifying overarching explanations and models, demonstrating context, relationships, and causalities behind the collective data.

Similarly, the aim behind the BSP approach that this thesis builds on is the development of the “theoretical physics” of sustainable development. The present version of the BSP framework is the result to date of a 17 year TNS-facilitated learning dialogue between academia and industrial and municipal sustainability practitioners. Instead of tackling each socio-ecological subsystem and sustainability problem at a time, the BSP focus is (i) to study the socio-ecological systems enough to be able to arrive at common basic mechanisms that cause all those detailed problems, and (ii) to develop a framework able to strategically deal with the root causes behind the problems and to design them out of the system.

## 4.3 Research Methods of this Thesis

This thesis applies the above-mentioned unifying theory for SSD (the BSP framework) for assessing LCA (Paper A), developing a new SPD tool (Paper B) and, complementing SMS (Paper C). The overarching research method follows some generic steps:

1. The terminology of each method/tool is studied, so that each term is understood in relation to the BSP framework.
2. Each method/tool is assessed from a BSP perspective, which means to assess its ability to contribute to "strategic backcasting-planning towards full sustainability". In practice, present strengths and gaps of the method/tool are mapped out in relation to the five levels (i.e., systems, success, strategic, actions, and tools levels).
3. Some potential improvements of the respective method/tools are suggested for each level.
4. New theoretical approaches combining the respective methods/tools with BSP are elaborated.

Paper B adds another methodological step since it not only introduces and analyzes a new template approach for SPD, but also presents and critically assesses a practical case study of this approach on TVs at Matsushita Electric Group in Japan. Apart from literature studies, the main data gathering technique of this case study was a series of interviews with the external experts that conducted the sustainability assessments at Matsushita.

# 5 Summary of Papers

## 5.1 Paper A

Life-cycle assessment (LCA) is applied to visualising impacts from products and services throughout their full life-cycles from resource extraction through transport, production, use and disposal. 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 (Wrisberg and Udo de Haes 2002; Heinrich and Klopffer 2002).

This paper investigates whether it would be possible to develop LCA, the prime tool of industrial ecology, in a way that would expand from the traditional focus on a few selected and verified damaging “impact” categories to a full sustainability perspective. Would then such an approach (i) give improved guidance for businesses to conduct planning with a bird’s eye view of sustainability to bridge gaps to full sustainability (rather than rear-view mirror improvements of the chosen impact categories), and, when needed, (ii) inform more detailed and quantitative methods like quantitative LCA when such are needed, and, (iii) provide a platform for the development of other tools and methods for sustainable development, all informed in the same way?

A result is an overall recommendation for businesses to expand the traditional LCA and LCM approaches into something tentatively called strategic life-cycle management (SLCM). This new approach would, among other things: (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 within the respective company’s own specific life-cycle value chains (i.e., to apply a framework for decisions as a shared mental model); (3) proceed with doing and learning, that is, play the game and gain experience in launching action programs in relation to the big-picture goals, and; (4) as the game unfolds and a need for more detailed methods such as traditional LCA and other support systems may evolve, *select and design those too in line with the same principled overview that informs the overall business planning*.

Paper A also looks into whether product development, a potential leverage area for societal transition towards sustainability, could be modified into a platform for further product-related sustainable development research. A vision of an integrated tool-box, with tools aligned through the BSP framework for SSD is given. The format for presenting it could be a computer-based web portal (the "Design Space") centered on the idea that product development teams could use a previously published "method for sustainable product development" (MSPD) (Byggeth et al. 2006) for prioritization support throughout the design process while having access to a growing number of adapted interfaces towards other sophisticated support tools from systems science (e.g., SMS) and industrial ecology (e.g., LCA) (figure 2). A library of expert statements or templates (TSPDs) for sustainability within larger product categories could also provide a shortcut for some companies when approaching the MSPD for the first time. Experiences should be gathered continuously from all types of SPD activities in a database here called "practitioner's good examples".

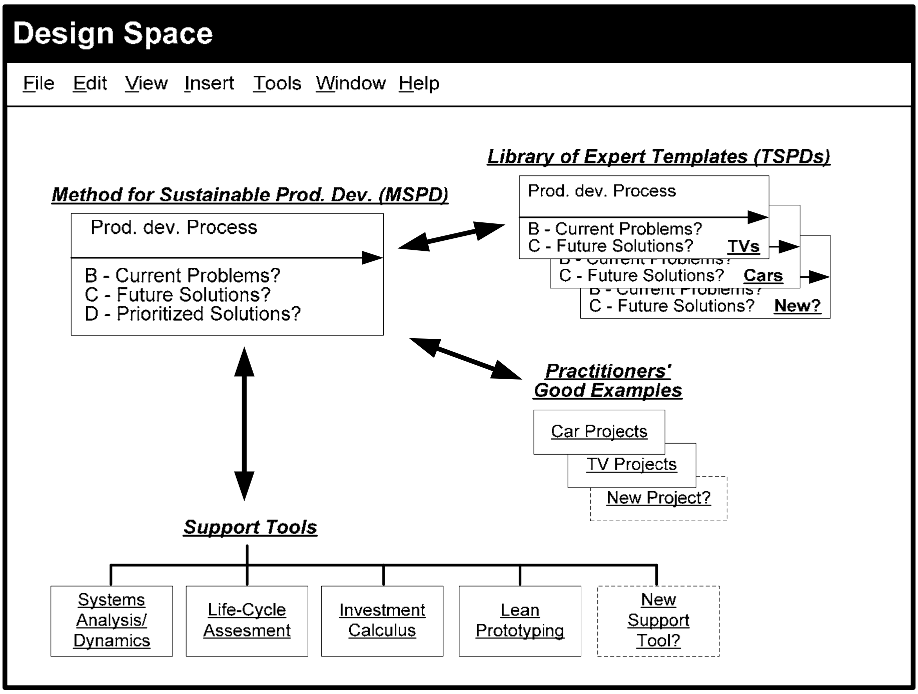


***Figure 2. An envisioned "Design Space" with integrated tools and concepts for sustainable product development (SPD).*** *All these tools and concepts are informed by the BSP framework for strategic sustainable development (SSD). The method for sustainable product development (MSPD), a library of expert templates for sustainable product development (TSPDs), a practitioners' experience library, practitioners' good examples, and some related support tools are already under development.*

## 5.2 Paper B

The previously mentioned method for sustainable product development (MSPD) (Byggeth 2001), applies BSP to inform traditional product development processes. This emerging method has been tested by teams from several small- and medium-sized enterprizes (SMEs). They were exposed to guiding MSPD questions throughout their product development processes. Even though the SMEs found the MSPD helpful, there were considerable lead times both when teaching the teams how to use the method and when they later used it in practice (Byggeth et al. 2006).

When the Matsushita Electric Group, a major Japanese corporation, wanted a sustainability assessment of their TVs and refrigerators, they were suggested to apply the MSPD as assessment tool. Instead, though, they insisted on starting with an external expert opinion. In response, the expert template approach was developed. This is a new pedagogical approach to conduct sustainability assessments for products. Rather than teaching the MSPD methodology and expect it to be used as intended, the idea with the template methodology is to first allow experts to develop generic sustainability challenges and opportunities in relation to the product or service in question. Experts then apply the MSPD approach on the whole product or service *category*. What are, in general, the sustainability challenges and opportunities for TVs, cars, houses, etc? The resulting "templates" can then serve as generic "benchmarks" to which specific products and services can be compared. In the Matsushita case, two experts from The Natural Step (an international NGO) produced templates for TVs and refrigerators. Based on Matsushita's responses to the generic sustainability claims of the respective templates, the sustainability challenges, opportunities and actual performance at Matsushita, were assessed and evaluated.

Paper B takes a closer look at expert templates and their relationship with the platform for product development research (the "Design Space") that was introduced in Paper A (figure 3). Paper B also assesses how the early version of the template approach was used in the case study for TVs at Matsushita (Robèrt 2002b) in an effort to produce sustainability reports for those items (Matsushita 2002).

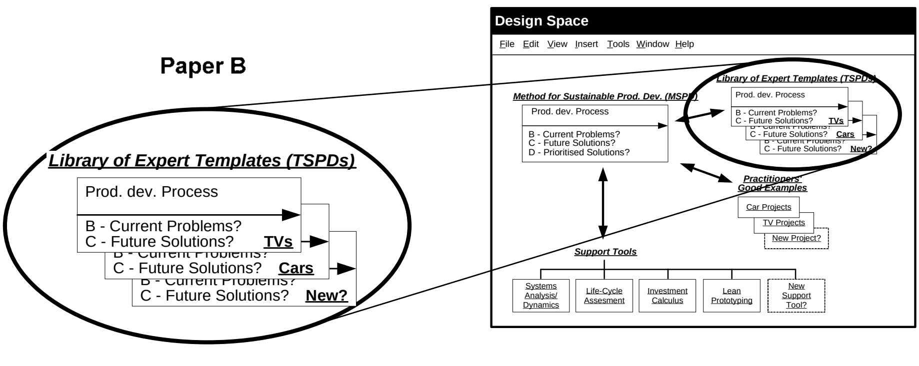


***Figure 3. Paper B focuses on Templates for Sustainable Product Development (TSPDs).***

The Matsushita case study was analyzed to find out whether the template approach (i) helped bridge the competence gap between the sustainability expert and the client, and (ii) facilitated sustainability-related decisions both for top management and product developers, and (iii) facilitated communication between the top management and the product development levels, and (iv) influenced the organization's ability to find product improvements that are relevant for strategic sustainable development.

The findings indicate that the template approach is a relatively simple and manageable, yet not simplistic, method that – depending on the quality of the respective templates produced – may capture essential sustainability aspects of the life-cycle of a certain product category. Furthermore, the template approach seemed to influence top management to foster sustainability efforts at the product development level. This indicates that the template approach could also support the bridging of communication gaps between organizational levels.

## 5.3 Paper C

Paper C investigates whether the BSP framework could be used to show how some systems science support tools, here referred to as systems modeling and simulation (SMS), could be used to strengthen decision-making within the "Design Space" (figure 4). This includes a description of a potential integration between BSP and SMS.

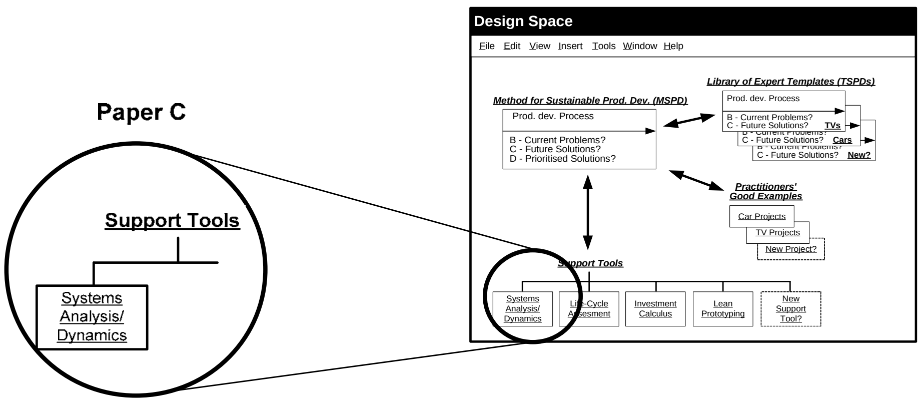


***Figure 4. Paper C investigates Systems Analysis/Dynamics or Systems Modeling and Simulation (SMS) as Support Tools for MSPD.***

SMS is an approach focused on the study of complex systems and not necessarily for strategic planning in such systems. As such, SMS does not in itself contain a rigorous definition of the overall goal – in this case sustainability – or strict guidelines for strategic planning to get there. Instead, the goal is reinvented in each planning exercise and thus to a large extent relies on intuition among the people in the planning group.

BSP, on the other hand is an approach focused on framing strategic planning in complex systems, while using suitable support tools along the way. As such, BSP does not in itself contain rigorous tools for aiding understanding of the dynamics of the systems of study. This implies a risk of missing aspects such as potentially important feedback-loops, delays in cause-effect chains, counter-intuitive system aspects, and intervention points. This, in turn, opens doors for an integration between the approaches. SMS could be equipped with a strict framework to provide generic principles and guidelines that are more firmly linked to the purpose (sustainability) and the process (strategic sustainable development) and thereby provide more effective direction of the analyses, and the BSP framework could be equipped with a strict methodology to assess relationships between aspects, thereby providing a safer basis for decisions in complex situations.

A new integrated approach is suggested that starts with analyzing the problem at hand, utilizing BSP. This frame creates lists of critical present-day flows and practices, solutions and visions, and smart prioritized early investments, all relevant from a full sustainability perspective. After that, SMS tools could be applied to study the interrelationships between the listed items. This is likely to create more robust analyses of the problems at hand, possible solutions, and early prioritized investments. Furthermore, the new integrated approach could probably also simulate potential solution scenario outcomes and thereby support choices as regards the best road (out of several) forward towards sustainability, within the overall frame.

# 6 Conclusions and Future Research

Previous research and an ongoing consensus process between pioneering scientists of many sustainability-related methods/tools and concepts (Robèrt et al. 1997; Holmberg et al. 1999; Broman et al. 2000; Holmberg and Robèrt 2000; Robèrt 2000; Robert et al. 2000; Robèrt et al. 2002; Korhonen 2004; MacDonald 2005; Byggeth et al. 2006; Byggeth and Horschorner 2006; Ny et al. 2006; Ny et al.), policy makers (Rowland and Sheldon 1999; Cook 2004; Robèrt et al. 2004; James and Lahti 2004; Gordon 2004), and business leaders (Electrolux 1994; Robèrt 1997; Anderson 1998; Nattrass 1999; Broman et al. 2000; Leadbitter 2002; Matsushita 2002; Nattrass and Altomare 2002; Robèrt 2002a; Robèrt 2002b) has shown that the BSP framework could be used to analyze existing methods/tools from a full systems perspective on sustainable development and sustainability.

The aim of this thesis was to study if, and in that case how, this framework could aid coordination and further development of various sustainability-related methods/tools, in particular to increase their capacity to support sustainable product development (SPD). Life-cycle assessment (LCA), "templates" for SPD (TSPDs), and systems modeling and simulation (SMS) were the methods/tools in focus.

Paper A showed that it was possible to create a strategic sustainability-related life-cycle overview of a system of study – without too convoluted manuals. It also presented a model (the "Design Space") for how the BSP framework could be used to systematically integrate methods and tools for sustainable product development. The work on LCA could thereby also be seen as a study of a support tool in relation to the Design Space model.

Paper B developed a crucial aspect of the Design Space model into a concrete sustainability assessment approach (TSPDs). This new approach was also successfully tested in a case study for TVs at the Matsushita Electric Group.

Paper C elaborated on a new approach to integrate SMS and BSP, one that seems able to create more robust and refined analyses of the problems at hand, possible solutions, and investment paths.

Decision makers seem to need more of an overview and of simplicity around sustainability issues. A general conclusion is, however, that it is important to achieve this without a loss of relevant aspects and their interrelations. Over-simplifications might lead to sub-optimized designs and investments paths that will later run into serious sustainability problems. Combining the bird's eye perspective provided by the BSP framework with more detailed methods/tools, selected when needed and then informed by the framework, seems to be a promising approach to finding the right balance and to get synergies between various methods/tools.

In line with the above, there will be a growing need for research on how to add existing methods/tools to an integrated supporting framework for sustainable development. Such theoretical studies will also need to be complemented with practical case studies identifying real-life requirements for the development of new methods/tools. Intensified co-operation with businesses and other organizations will take place. The aim is to more closely see how they work with strategic planning for sustainability today and then to suggest how they might move forward with complementing methods/tools. The latter will include LCA, TSPDs, SMS, and other potentially suitable methods/tools like investment calculus, multi-criteria decision support, and eco-labelling.

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# Paper A

## Sustainability Constraints as System Boundaries. An Approach to Making Life-Cycle Management Strategic

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# Sustainability Constraints as System Boundaries. An Approach to Making Life-Cycle Management Strategic

Ny, H., MacDonald, J.P., Broman, G., Yamamoto, R. and Robèrt K.-H.

## Abstract

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.

***Keywords:*** *backcasting, life-cycle assessment (LCA), materials management, The Natural Step (TNS), strategic life-cycle management, sustainable product development*

# Introduction

## A Troubled History

Historically, many “safe” materials have been commercialized, followed by a 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. Lessons that should have been learnt for future planning are 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 (MIPS) and Factor 10 (Schmidt-Bleek 1997); cleaner production (Aloisi de Larderel 1998); natural capitalism (Hawken 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 towards the relationship between sustainability issues and life-cycle thinking in practice (e.g. Wrisberg et al. 2002 and Heinrich et al. 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 whereby a successful outcome is imagined, followed by the question, "What shall we do today to get there (Dreborg 1966; 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 (i) highlight the need for management of materials and products through a lens of basic principles for sustainability, and (ii) 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 towards 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 on 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 sustainability 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, is 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 towards sustainability should follow strategic guidelines, which, in turn, require…
5. *Tools* for systematically monitor 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, 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 socio-ecological *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 for 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, insurances, taxes, bad publicity, etc (Holmberg and Robèrt 2000).

The parts of the planning process are (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 C-list that not only take care of the short term challenges but also prepare for coming actions to eventually make society comply with the SPs.

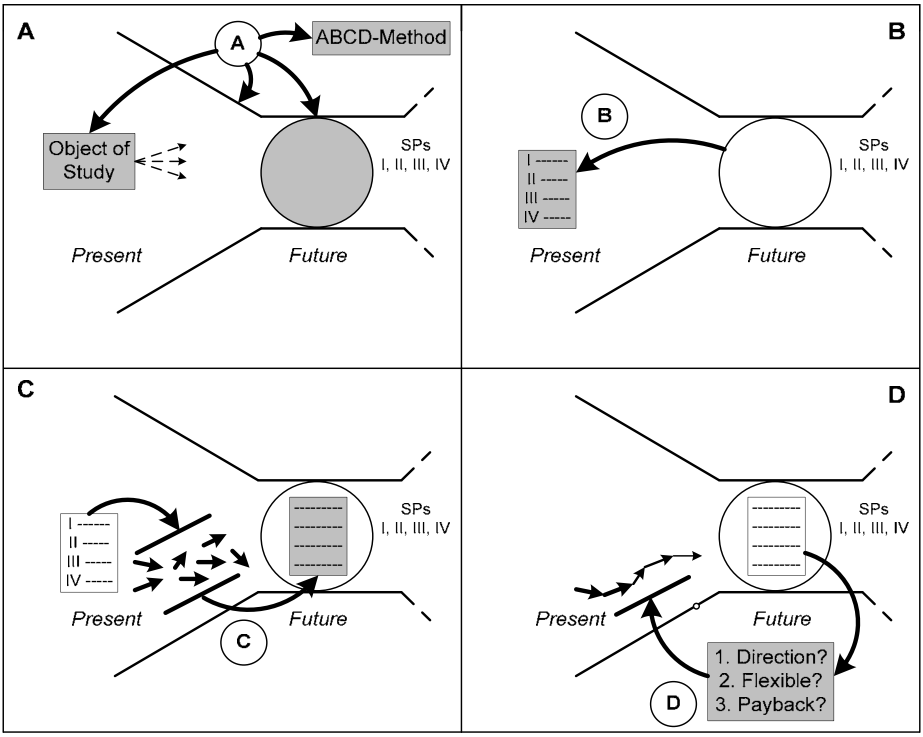


***Figure 1. Backcasting from Principles as illustrated by A-B-C-D-Planning.*** *A. Agree on (1) the object of study, (2) the sustainability challenge (a funnel of declining opportunity), (3) the future sustainable landing place for planning (defined by compliance with Sustainability Principles [SPs, 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.*

# 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 divided 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 at 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 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 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-Neef 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. 1998a). 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 assured 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 non-dissipative 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 function, those may be preferred.

Economic relationships also exist between dematerialization and substitution/change. Sometimes economically viable dematerialization is insufficient, because involved materials are relatively non-degradable (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 destruction potential. HCFCs, though, just like CFCs, are relatively non-degradable 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 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. A reliable CFL with max. 3 mg Hg (mercury)/lamp – comparable to the EU environmental labelling system requirement 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 (figure 2). Sustainability issues should be dealt with more urgently and 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 gray areas) is generally a rationale for undertaking proactive measures, as dealt with by the so-called precautionary principle.

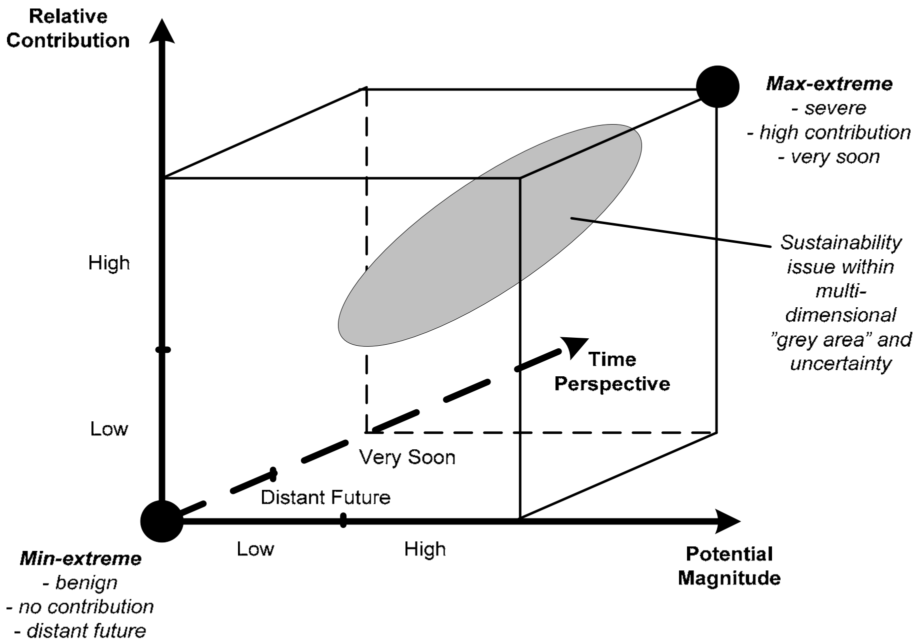


***Figure 2. Gray Areas of Ambiguity for Prioritization Criteria for Sustainability Issues.*** *Competent decision making often relies on strategic trade-offs where sustainability issues are evaluated against criteria such as potential magnitude, relative contribution to issue, and time perspective. 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 favour 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.*

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 comprehensively accomplish this 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 gray 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 (figure 3).

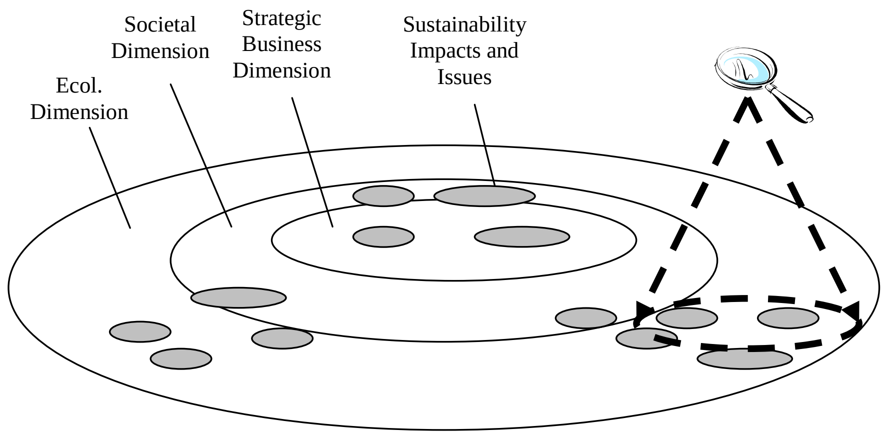


***Figure 3. System Boundaries in Traditional Life-Cycle Assessment (LCA) - Based on Selected Known Issues.*** *The sustainability arena of a company starts with the strategic business dimension under company control, and continues with the surrounding societal and ecological dimensions that the company 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.*

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 on the implementation of environmental management systems in Swedish companies concluded that only 10% of corporations have allowed the results from LCAs to influence the measures taken (Zachrisson 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 of ecosystems, and unsustainable emissions of compounds with 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 not only related 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 towards 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 getting experienced in seeing the big picture goals and selecting stepping-stones in that direction. Once the need for more sophisticated tools, like multi-dimensional decision support (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).

***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 then detailed analysis, as required. | Potential socioecological and economic problems from a full systems perspective. | To identify strategic pathways towards sustainability. |

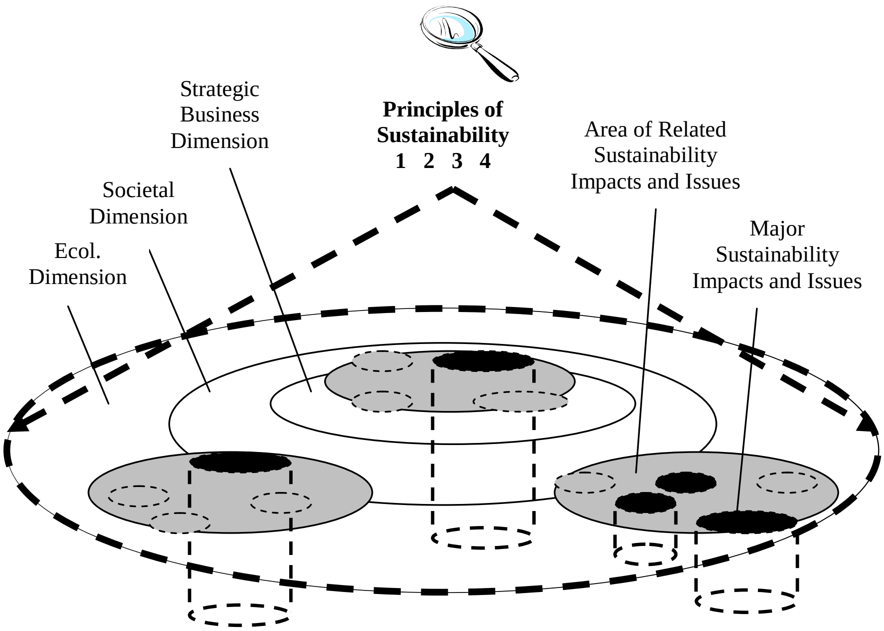


***Figure 4. Strategic life-cycle management (SLCM) – sustainability principles as system boundaries.*** *This approach starts with an overview of the whole system through the lens of the four Sustainability Principles (SPs). The large gray areas denote related hot spots, that is, impacts and issues 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 in context. Some of these impacts and issues may be sufficiently described from the overview, while 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.*

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 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 assure 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 already upfront 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 other system boundaries but the ones that apply for the whole biosphere. This means asking how a certain organisation 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 information on priorities. Morevoer, 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 includes areas where society's violations of basic SPs are 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 towards 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 14040:1997; ISO 14043:2000), 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.

***Table 2:*** *How a framework for sustainability can add to traditional 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 to not only fix problems, but avoid yet known 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 (that are particularly useful at this stage) to ensure that the full context of sustainability, including the strategic business/economic dimension, is taken into account. |

## Introductory Steps towards 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 (1998b) use an approach similar to the one put forward in this article. They also state that this perspective would open up for a more strategic approach to

LCA, but they do not elaborate 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 ten small- and medium-sized enterprizes (SMEs) were exposed to guiding questions under each SP and under 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 for any product category. The method encompasses problem-related questions referring to the B-step with its current flows and practices (figure 1), and solution-related questions referring to the C-step (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 B and C are listed, and smart early moves from C are selected to form a strategic plan (D). Each question may trigger further extensive/quantitative analysis and the creation of indicators that would be suitable to monitor the phase out of critical flows and practices. Examples of B-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 TVs, 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 TVs, refrigerators and for their recycling plant (METEC) in an effort to produce sustainability reports for those items (Matsushita Electric Group 2002). The TV case study is described in detail by Ny and colleagues (submitted). Both new ideas and potential hot spots requiring incorporation into strategic planning and future detailed assessments (e.g. by LCA) were identified.

## Future Steps towards 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 (figure 5).

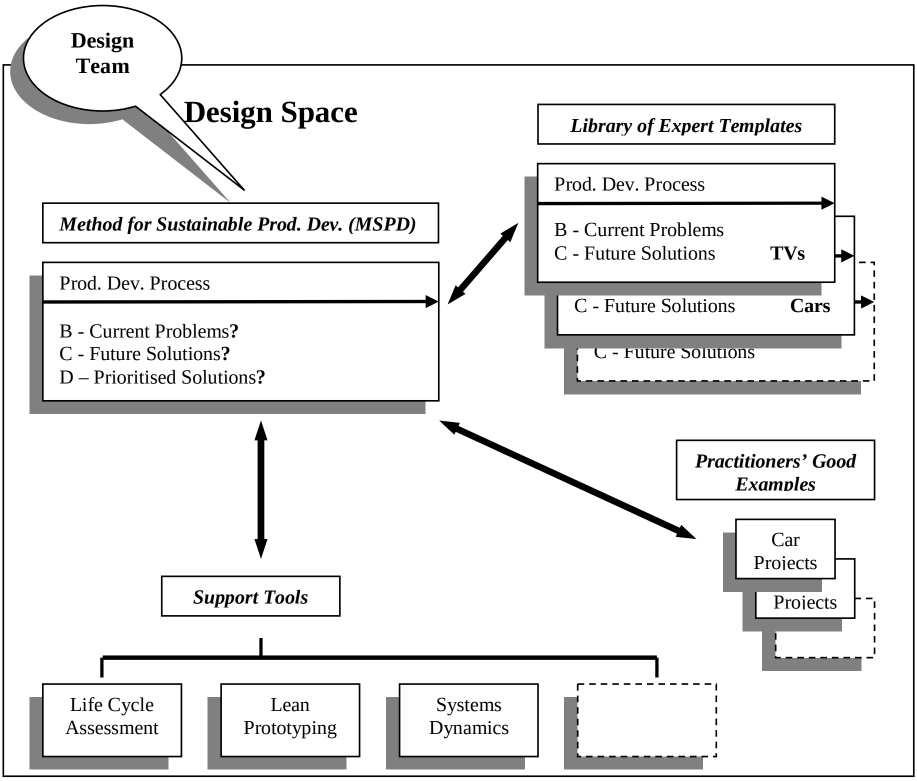


***Figure 5. A future design space.*** *Tools and concepts that are all informed by the strategic life-cycle management (SLCM) perspective constitute the design space. Tools that are already under development are the method for sustainable product development (MSPD), a library of expert templates for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

# 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 trade-offs towards 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 continuously 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 birds-eye perspective.

## Acknowledgements

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# Paper B

# Introducing Templates for Sustainable Product Development through a Case Study of Televisions at the Matsushita Electric Group

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# Introducing Templates for Sustainable Product Development through a Case Study of Televisions at the Matsushita Electric Group

Ny, H., Byggeth, S.H., Robèrt K.-H., Broman, G and MacDonald, J.P.

## Abstract

Backcasting from basic sustainability principles has been helpful for dealing with complexity in a strategic way. This approach has previously initiated development of a method for sustainable product development (MSPD). We here introduce an idea of “templates” for sustainable product development (TSPDs) as a complement to the MSPD. We also present an analysis of a case study at the Matsushita Electric Group, in which this TSPD approach was first used as the format for an expert-guided sustainability assessment of TVs.

We analyze the potentials of the TSPD approach to (i) help bridge the competence gap between the sustainability expert and the client, (ii) facilitate sustainability-related decisions both for top management and product developers, (iii) facilitate communication between these organizational levels, and (iv) influence the organization’s longer term ability to find product improvements that are relevant for strategic sustainable development.

Our findings indicate that the TSPD approach is a relatively simple and manageable, yet not simplistic, method that captures essential sustainability aspects of the life-cycle of product categories and that it has the above potentials.

# Introduction

## A Method for Sustainable Product Development

The early part of the product[1] innovation process is a critical intervention point for the transformation of society towards sustainability. Once a product design has been set its sustainability attributes are largely fixed. It is therefore imperative to develop rigorous and operational methods and tools for sustainable product development (Charter and Chick 1997; Ritzén 2000). A general method for sustainable product development (MSPD) has previously been proposed (Byggeth et al. 2006), with the aim of integrating social and ecological aspects of sustainability with a strategic business perspective in product development. When testing the MSPD, some Swedish businesses expressed a desire for some kind of guidance for specific product categories and for improved interaction with other methods and tools (Byggeth 2001; Byggeth et al. 2006).

## The Matsushita Case – Templates for Sustainable Product Development

Matsushita wanted to uncover overall gaps in their activities when viewed from a sustainability perspective and find out ways to strategically develop its services to people. A sustainability expert from nongovernmental organisation (NGO) The Natural Step (TNS)[2] was engaged to lead a sustainability assessment for TVs. In this case, time constraints did not favour the MSPD approach. Drawing from the MSPD experience, the sustainability expert suggested a new related approach with product category specific templates for sustainable product development (TSPDs) as the format for the assessment. The idea was to rapidly increase the ability of product experts to see and apply the overall sustainability picture as an aid for dealing with the complexity of various dematerializations, substitutions and management routines. The idea was also to give the product experts a means for communication to top management to receive support for actions.

[1] Hardware, software, process, service, or combinations of those.

[2] TNS is a Swedish-based international non-profit NGO, advising organizations on strategic sustainable development. Their approach, known as The Natural Step Framework, builds on the Strategic Sustainability perspective described in this paper.

## Article Purpose

The essence of the new TSPD approach and its potential for aiding sustainable product development is discussed and analysed in context of the Matsushita case study.

More specifically, the following research questions are addressed:

i. Did the template approach help bridge the competence gap between the sustainability expert and the client, and if so, how?
ii. Did the template approach facilitate decisions both at the top management level and at the more detailed product development level, and if so, how?
iii. Did the template approach facilitate communication between the top management and the product development levels, and if so, how?
iv. Did the template approach influence the organization's longer term ability to find product improvements relevant for strategic sustainable development, and if so, how?

# Methods

## A Framework for Strategic Sustainable Development

The template approach is based on a framework for strategic sustainable development that aims at clarifying how our future society must be constituted on the most basic level to be sustainable (as defined by sustainability principles, SPs). This framework also suggests how organizations can plan and act to make society approach that principle goal while their own organizations are strengthened, avoiding financial risks associated with unsustainable practices and foreseeing new business opportunities (strategic guidelines). This planning challenge is dealt with by distinguishing between five different but interacting levels (Robèrt 2000; Robèrt et al. 2002):

1. the system (in this case the organization within society within the biosphere),
2. success in the system (in this case sustainability as defined by sustainability principles),
3. strategic guidelines to arrive at success in the system,
4. actions aligned with the strategy to arrive at success in the system,
5. methods, tools and indicators designed to help prioritize and monitor actions that are strategic to arrive at success in the system.

This framework is developed into a concrete planning method called backcasting from sustainability principles (BSP) (Robèrt 1994; Holmberg 1998; Holmberg and Robèrt 2000; Broman et al. 2000). In order to describe the structure that the template approach is partly based on, the current wording of the sustainability principles (level 2) and a brief description of the backcasting procedure, including the main strategic guidelines (level 3), are given below.

Socio-ecological sustainability principles (Holmberg 1995; Broman et al. 2000; Ny et al. 2006):

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.

The backcasting procedure starts by discussing the framework as such, to reach acceptance for it as a shared mental model for the work to come (A). Then an iterative process of brainstorming commences, describing current practices in relation to the sustainability principles (B) and alternative future principal solutions or visions that are likely to support societal compliance with these principles (C). A gap analysis is then translated into a set of early actions that are strategically prioritized (D). The main guidelines for the prioritization are that the actions (investments) should: (1) support society's transformation towards sustainability (right direction), (2) be flexible platforms for the organization's coming investments (avoiding blind alleys), and (3) give proper return on investment (pay-back) soon enough to ensure a continuation of the process. (figure 1).

Previous studies have repeatedly shown how this framework can assist businesses and municipalities in grappling with the complexity of the sustainability challenge and turning what is often perceived as a cost into an opportunity for innovation and cost savings (Broman et al. 2000; Nattrass and Altomare 2002; James and Lahti 2004).

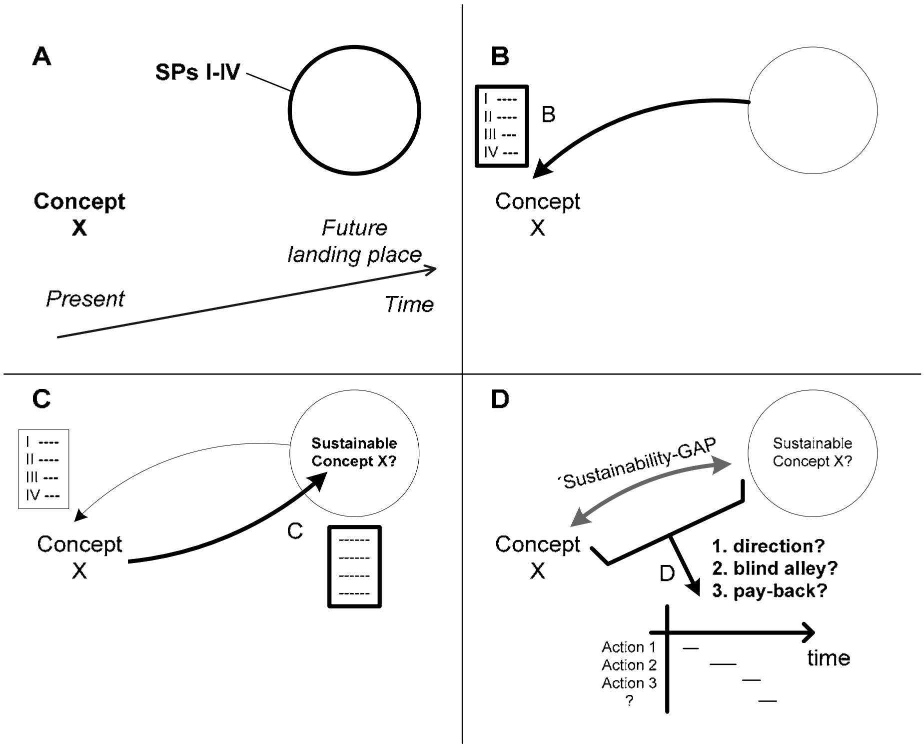


***Figure 1. Planning with Backcasting from Sustainability Principles (BSP).*** *A. Discussing the framework and defining the object of study (e.g., concept X). B. Identifying present problems and strengths in relation to the sustainability principles. C. Envisioning future solutions. D. Prioritizing actions based on the Sustainability–GAP arrived at through several iterations of steps B and C.*

## Sustainable Product Development

A previous study has begun to address a lack of methods and tools for sustainable product development (SPD) (Byggeth and Horschorner 2006). More specifically, it is suggested that product development should not only aim at improvement of products regarding a specific selection of impacts from current flows and practices. Product development should also aim at preventative life-cycle thinking and creation of viable paths of opportunities in a sustainability-driven business perspective. The historic lack of such systems overviews has led to many unforeseen and unintended negative impacts. One example is the relatively non-toxic and non-bio-accumulative Freons (CFCs) that were originally introduced as more efficient and less expensive refrigerants, while their negative effects on the ozone layer were not detected until decades later (Geiser 2001). Although this problem was very difficult to predict because of the complex mechanisms behind it, it should have been possible to avoid it by more principled reasoning. Since CFCs are foreign to nature and have low degradability, they require special attention as regards SP II. The risk of increasing concentrations of such substances in nature is high at large scale use without rigorous control.

To support prevention and proactivity, a method for sustainable product development (MSPD) has been proposed (Byggeth et al. 2006) in which the above mentioned framework is integrated with a concurrent engineering development model. Several descriptions of such models are found in the literature (Olsson 1976a; Roozenburg and Eekels 1995; Ulrich and Eppinger 2003).

The overall purpose of the MSPD is to:

- Provide basic knowledge about strategic sustainable development
- Provide basic knowledge about product development methodology
- Rise awareness of product-related sustainability issues and link to additional basic information
- Stimulate creativity and initiate relevant investigations and measures with a life-cycle perspective
- Aid identification and clarification of trade-offs and prioritization of short and medium term actions
- Aid structuring and documentation

This is done by an introduction manual (A), a modular system of probing questions to stimulate brainstorming (B and C), and a prioritization matrix to aid decisions about which solutions to carry forward to the next stage (D). The probing questions are derived by considering basic sustainability principles and a life-cycle perspective, and thus function as creative constraints and facilitate multi-disciplinary problem solving and decision-making. More detailed investigations by analytical methods and tools, initiated from the MSPD, should also be informed by this overview. A well-structured overview is not an alternative to detailed knowledge and detailed methods and tools. It is their combination that is so potentially powerful. Ideas of how to inform life-cycle assessment (LCA) by this same overview has previously been published (Ny et al. 2006).

## The Expert-Guided Template Approach

***Why?***

Sometimes top management, as well as product development teams, may need to get a quick overview of the sustainability performance of a given product category. Templates for sustainable product development (TSPDs), a sustainability expert-guided approach, is therefore introduced as a complement to the MSPD, to relatively rapidly facilitate:

- Bridging of the competence gap between sustainability experts and product experts
- Bridging of the top management level and the product development level in the company
- Reuse of general ideas at development of other products in the same category

The TSPDs should be able to serve as benchmarks for the analysis of existing products´ sustainability performance, or provide planning support for a specific new product concept. The most essential sustainability aspects should be highlighted in a format that is easily accessible to others without a prior need to learn in depth how the MSPD works. Top management, for example, should be able to identify resemblances and differences between the sustainability expert’s input on the one hand, and their own product policy and product plans on the other. Bringing the most essential sustainability aspects to the attention of the top management probably also increases their willingness to allocate resources when needed for more in-depth sustainability assessments. Such assessments could then be conducted with other methods and tools like the MSPD and/or LCA.

***What?***

The final TSPDs consist of sustainability expert statements regarding a product category, top management and product expert responses to these statements, and sustainability expert feedback on their responses. Thus, the TSPDs reflect a dialogue between the sustainability expert, top management, and product experts from their joint production of the TSPDs.

To assist with bringing forward the intended aspects, some key questions are used (see table 1). There are three templates (columns), each including the B (current situation) and C (future solutions/visions) steps of the backcasting procedure (rows).

***Table 1. Master Template Matrix***

| Time | Templates<br>I. Needs | II. Concepts | III. Extended Enterprise |
|---|---|---|---|
| **B (current situation)** | **Current market desires addressed (product/business ideas):**<br>• What market desires are the product currently intended for?<br>• What services/utilities does the product currently provide to people in general?<br>• What are the current overall sustainability problems related to these desires and services/utilities?<br>• How do these desires and services/utilities relate to basic human needs? | **Conceptual design of today's product:**<br>• What critical flows and management routines are currently linked to the chosen product concept from a full life-cycle and sustainability perspective (i.e., from resource extraction through production, distribution and use, to final disposal or reuse/recycling)? | **Current stakeholder communication/cooperation:**<br>• What current preferences and conditions of society at large are opposing the introduction of more sustainable concepts, and is the company's external communication accepting/conserving or aiming at changing these preferences and conditions?<br>• What value-chain cooperation is currently agreed upon to assure a full life-cycle responsibility (what gaps could be identified)? |
| **C (future solutions/visions)** | **Likely future market desires to address (product/business ideas):**<br>• What market desires are likely to evolve in the future as responses to the sustainability challenges?<br>• Which of the currently provided services/utilities are likely to be emphasized in this context?<br>• Could the related basic human needs be fulfilled in a completely new way (through other services/utilities)?<br>• Are there any market trends that point in this direction? | **Likely conceptual design of future product:**<br>• Could the flows and management routines related to the current product concept be developed to help society comply with the basic sustainability principles?<br>• Could new product concepts more easily help society comply with the basic sustainability principles? | **Likely future stakeholder communication/cooperation:**<br>• What future preferences and conditions would be particularly favorable for the more sustainable concepts, and how could the company communicate externally to promote such change?<br>• What future strategic alliances would be particularly favorable for a full life-cycle responsibility, and how could the company develop such alliances? |

The chosen elements of the concurrent engineering process ("needs"and "concepts") and the societal stakeholder outlook ("extended enterprise") are considered to be the most relevant for the creation of an overview. The more detailed design and production preparation stages as well as the whole launch or realization (i.e., actual production, distribution, sale and use) involve very specific aspects for each individual development project. We assume that general reusable conclusions for a product category would be more difficult to reach in those stages. Similarly, step D (prioritization of solutions from C) is also excluded, since the templates' purpose is not to be prescriptive but to trigger creativity and act as input for later detailed priorities. The essence of the chosen elements is described briefly below.

Template I. Strict development of any product should be preceded by product planning (Roozenburg and Eekels 1995). This includes a continuous review of the company's product policy (overall goals and strategies) and search for new/modified product/business ideas. This includes asking what types of products the company wants to provide and what markets should be in focus. This is the primary task for top management, but all parts of the company should in some way be involved.

New ideas could be stimulated by feedback from the current use of the product in society, captured, for example, through the company's sales and service activities. New ideas could also be stimulated from the ongoing production and, of course, by the company's R&D activities in a wide sense. Predictions of consumers' future desires and the company's capabilities of meeting these are critical for success.

We argue that sustainability aspects are of increasing commercial significance on the global market. The market analysis should therefore thoroughly deal with the global sustainability challenge, as described above. The focus should be on the true service/utility that the product should provide (basic functions), and clarify what basic human needs that the company wants to fulfill with their products. Since Maslow's idea of a need hierarchy (Maslow 1943) many authors have tried to understand human needs. We draw especially from one author (Max-Neef 1992) that claims that a sustainable society needs to satisfy nine universal basic human needs (subsistence, understanding, protection, affection, idleness/leisure, creation, identity, participation and freedom). He goes on to say that what differs between cultural contexts is *how* such basic needs are satisfied, not the needs as such.

We believe that a thorough clarification of needs, desires, and functions in combination with a full sustainability perspective can stimulate creative solutions and sometimes completely new product/business ideas.

Template II. Once basic product functions have been established it is necessary to find out how, in principle, these functions could be realized. This is often called "Conceptual Design". The aim of this phase of the development process is broad solutions as points of departure for the more detailed design. In general, these principle solutions should be carried to a point where the means of performing each major function has been fixed, as have the spatial and structural relationships of the principal components. One should also establish broad ideas of the shape and the kinds of materials of the product and its parts (French 1985). Besides the technical-physical functioning, it should be possible to roughly assess aspects of the product concepts like use, appearance, production,and costs (Roozenburg and Eekels 1995). It is usually desirable to generate many concepts. Decisions on which of the concepts to bring ahead for more detailed design are based on agreed upon design constraints and evaluation criteria.

There is a general trend to do more and more of advanced simulation already in this conceptual phase. Besides technical simulation, this also increasingly involves simulation of risks and opportunities in business (Sandberg et al. 2005). We argue that this should also include risks and opportunities for related socio-ecological systems. We are working on developing and linking such methods and tools to the MSPD and possibly to the TSPD. However, for now, the TSPD approach emphasizes the overview perspective as regards reducing material consumption and substituting materials and activities.

We argue that sustainability aspects should play a major role in the concept phase, e.g. to stimulate creativity in concept generation and to guide evaluation. Here is a unique chance to prevent negative impacts on ecological and social systems throughout the life-cycle of the product, and to assure functions that contribute to a sustainable development of society at large.

Template III. In parallel with the market analysis and the conceptual design, an overall marketing plan (and rough ideas of a production plan) is normally developed. This includes simulation of commercial results and comparison of those with the business economic goal. Of course, this interacts mutually with technical simulation. Again, in this TSPD approach we emphasize overview assessments.

We argue that the possibility for the company to change customers' and other stakeholders' preferences, as well as market conditions such as legislation, taxes, subsidies, and other politically decided incentives, should be considered strongly in these early parts of the development process. This new perspective (extended enterprise) could therefore be seen as a natural development of the established term extended producer responsibility, originally presented by Lindhqvist (Lindhqvist 1992, 2000). It could accelerate the move of the market in a more sustainable direction and thus influence the market success of certain product concepts. We emphasize the importance of not underestimating the possibility of the company, likely in strategic alliances with other companies, to influence societal policy changes through communication. This could be, for example, lobbying for proactive incentives and disincentives. Judging probabilities and the timing of such market changes is important in deciding what product concepts to prioritize. Furthermore, since it is rarely possible for a single company to fully control the full life-cycle of its products, dialogues, and business agreements with other companies and stakeholders around extended producer responsibility should be considered strongly already within current market conditions.

***How?***

A sustainability assessment according to the TSPD approach includes the following items:

1. The sustainability expert leads a preparatory training of top managers and product experts supposed to take part in the assessment.
2. Triggered by key questions (see table 1), the sustainability expert generates generic statements and presents them to top managers and product experts.
3. Top managers and product experts respond, within their respective competence fields, to the sustainability expert's statements. Simple misunderstandings are sorted out. Acceptances of the statements as well as possible different opinions are clarified.
4. The sustainability expert gives feedback on the responses to top managers and product experts.

Items 3 and 4 are repeated until consensus is reached for this overview assessment. Then a final presentation is given in a common session and a report, including the templates, is produced.

This exercise should be completed based on everything that is theoretically possible, because the overall intent is to creatively identify short- and long-term options. Economic and other constraints are evaluated in later stages, and the TSPDs are then part of the input for the prioritization of actions.

In the next section we present the pilot case study where this TSPD approach was first used. The wording of the triggering questions in table 1 and the procedural description above were not exactly the same at the time of this pilot study. Our formulations have developed with this pilot case study and the subsequent analysis presented in this article. The essence of the approach was, however, the same and although some lack of clarity may have had some influence on the client's ability to respond as intended, we believe that this case study is a valid basis for some early general conclusions.

# Case study: The Template Approach for TVs at Matsushita

## About Matsushita

The Matsushita Group consists of over 300 companies globally, with 290,000 employees, and annual global sales of USD $67 billion .[3] The Matsushita Group operates mainly in four business domains, 60 percent of which is represented by TVs, camcorders, audio equipment, and mobile phones under the Panasonic, Technics, and Quasar brands.

## Before the Sustainability Assessment

Before this study Matsushita had eliminated the use of CFCs in both the manufacturing and operation of their refrigerators and eliminated the use of plasticizers with high contents of scarce metals in the polymers used in their TVs. Matsushita had also aimed for 55 percent recycling rates for their TVs by the year 2001 (Matsushita 2000). The question for the corporation was then whether they had missed any critical sustainability aspects that should be considered for future planning and that could trigger innovation. That is, they wanted to identify problems that may have been left out from a strategic sustainability perspective and find possible principal solutions, such as various possible combinations of dematerializations, substitutions, and changed ecosystem management routines. Matsushita therefore, in year 2000, asked external sustainability experts from the non-governmental organization The Natural Step (TNS) for advice (Matsushita 2002).[4] The sustainability expert suggested a process by which a Matsushita team should be educated on the MSPD approach and then, jointly with the sustainability expert, apply it in a sustainability assessment. Time constraints made this impossible, which lead to the development of the template approach described above.

[3] For further detail, see: http://www.matsushita.com
[4] The lead advisor was Karl-Henrik Robèrt, founder of TNS and adjunct professor at Blekinge Institute of Technology.

## The Sustainability Assessment

According to a leading Japanese TNS consultant (Takami 2006), the Matsushita sustainability assessment was conducted over several years. At first, two people from the Matsushita environmental division had some preparatory training in strategic sustainable development, including the backcasting from principles planning method (figure 1). Then they, in turn, instructed key technical staff from the TVs design groups. In the beginning of year 2002, this informed Matsushita team was then exposed to the sustainability expert's templates, designed specifically for TVs in response to questions similar to those presented in table 1. After that, they responded by confirming, rejecting, constructively augmenting or reflecting on these statements. Thereafter the Matsushita team responses were scrutinized by the sustainability expert to evaluate whether they had, in his opinion, considered all practices that were critical with regard to sustainability (B) and strategically addressed options to bridge the gaps in its product planning (C). This feedback was then at several occasions given to the top management and product developers, starting with vice President Miki[5] and 20 key technical staff from the TVs design group.

***Template I***

In table 2 below, we present some quotes of the sustainability expert and the client to illustrate the dialogue and learning process brought about by Template I.

[5] Sukeichi Miki, CTO, Senior Managing Director, Member of the Board in charge of technology, quality and environment at Matsushita Electric Industrial Co. Ltd.

***Table 2.*** *Excerpts from the Matsushita template sustainability assessment – Template I*

| Time | Triggering questions | Sustainability expert's statements | Matsushita's responses | Sustainability expert's feedback on B and C |
|---|---|---|---|---|
| **B (current situation)** | Which services does TV currently provide to people? | *"TV is a medium of communicating information and knowledge as a component of a larger human-machine interactive system."* | [Expert's statements applicable, and, in addition]: *"There are some minorities who can send and receive information with multilingual and sign services"* | [Congratulates Matsushita for being open to see TVs in a new light]: *"… TVs as a potential saver of resources in the modern society […], global communication to achieve a sustainable society and so on."* |
| | …and what are the overall sustainability problems linked to these services? | *"…IT in general, including TV, has not played a very clear role in saving societal resources or been part of a conscious strategy to reach sustainability."* | *"Recycling TV sets just started from April 2001 in Japan, and we have been making a lot of efforts for infrastructure, technology and design suitable for recycling. However, we have to admit that the amount of material recycled is still small [55%]."* | [More details needed on sustainability solutions]: *"...the plans for the future are to build all TVs on recycled materials, but no comments on the exact way of doing so are presented. Furthermore, there are no comments on rebound effects from the use of IT."* |
| **C (future solutions/visions)** | Could the application of TV above, or new applications of TV, be developed to support sustainability, in any way, for the future market and/or are there any trends in the market that point in that direction? | *"We can use TV for: video-conferencing, education, e-mail, web-surfing to save resources from transporting people or information, […], intensified communication between industrialized countries and developing countries.* | [Expert's statements applicable and Matsushita is]: *"Aiming for TV set production in which Reduction and Recycle is pursued thoroughly"* | [and…]: *"No comments at all about the business potentials of TV in the developing world are presented."* |
| | | *"…producing TV in new ways, through means of dematerializations and substitutions for each SP, seems to be a good idea..."* | [and…]: *"The most influential issue in the life-cycle of TV sets is to reduce its electrical energy consumption, and we will develop products with even higher energy efficiency."* | [and Matsushita claims to seek a new ambitious sustainability related business model, but…]: *"… We leave it to Matsushita to determine how far towards the boardrooms these plans have proceeded."* |

***Analysis of Template I***

From table 2 (and the complete Template I (Robèrt 2002a)) it is clear that:

- In line with the overall purpose of the TSPD approach, the sustainability expert tried both initially and in his feedback to shift the Matsushita perspective from focusing on historic and current improvements towards identifying basic product functions and how they relate to a global sustainability perspective and, to some degree, to basic human needs. We think that this could have been made even clearer by the sustainability expert.
- Anyhow, Matsushita opens up to see TVs in a new light. The perspective is widened beyond current market desires. The potential of TVs to function as a transition agent towards a sustainable society and a resource saver is discussed.
- The recycling achievements brought up by Matsushita actually belong to Template II, as do dematerialization and substitution regarding the product itself brought up by the sustainability expert. We think that the new triggering questions in table 1 will help avoid such misunderstandings.
- The sustainability expert correctly points out that Matsushita had not convincingly addressed rebound effects that increased efficiencies might trigger. In this case, rebound effects means that it is likely that more efficiently manufactured (and therefore also cheaper) TVs would be sold in greater quantities. The environmental benefits of reduced resource use per TV unit may therefore turn into a higher total resource use, and the lower price could also decrease the incentives for individual consumers to reuse and recycle. Again, this discussion would, however, belong better to Template II.
- Both the sustainability expert and Matsushita sometimes failed to include all dimensions of sustainability. The current and future wider potential societal functions of TVs were discussed but mainly covering the positive aspects. Current known problems like negative health effects due to obesity, passivity, lack of social interactions in person, etc., were not included. We would also have expected some discussion about potential future problems and how to prevent them.
- The focus in the sustainability expert's statements, Matsushita's responses and the sustainability expert's feedback is, as intended, mainly on the product policy level (overall goals and strategies). In particular this is true when the sustainability expert challenges Matsushita to demonstrate top management support for a new ambitious sustainability-related business model.

***Template II***

In table 3 below, we present some quotes of the sustainability expert and the client to illustrate the dialogue and learning process brought about by Template II.

***Table 3.*** *Excerpts from the Matsushita template sustainability assessment – Template II*

| Time | Triggering Questions | Sustainability expert's statements | Matsushita's responses | Sustainability expert's feedback on B and C |
|---|---|---|---|---|
| **B (current situation)** | What are the critical flows and management routines that are currently, and in general, linked to the above described types of TV services from a full life-cycle perspective? | [On dematerialization aspects]:<br>*"…wasteful methods of resource extraction for example in mining industry, using unnecessary large amounts of materials in the production of the heavy TVs."*<br><br>[On substitution aspects]:<br>*"SP I. Some non-ferrous heavy metals in the production of TVs (e.g. in main structure, glass, plastics electronics) are scarce in nature leading to high risks of increasing concentrations in the biosphere."*<br>*"SP II. TVs are often containing persistent unnatural compounds such as anti-flammables (bromine organic compounds), and plasticizers and other chemical additives such as PVC."* | [On dematerialization aspects]:<br>*"…the most effective [way to lighten] the weight of [the TV is to lighten the weight of the cathode-ray tube, and Matsushita is, in this regard, on the top level of competitors…"*<br><br>[On substitution aspects]:<br>*"SP I. Plastic: We focused on Mg [Magnesium] as a new option for plastic and started producing on a commercial basis from 1998. Mg is both light and tough, which enabled us to design more compact thanks to the toughness."*<br>*SP II. We have partially adopted "FR-1" and "FR-4" containing phosphorous compounds which replace bromine anti-flammable material contained in printed circuit board."* | [Most of Matsushita's actions are applauded but some alerts are also raised]:<br><br>*"SP I. …to utilize the full potential of Mg, it is essential that the current practices regarding this metal are critically assessed from a sustainability perspective so that critical flows and practices can be corrected."* |
| **C (future solutions/visions)** | Could the above described critical flows and management routines be developed into a state that could comply with the SPs, and help society at large to do so? | [On dematerialization aspects]:<br>*"…recycling the materials in the production into so pure fractions that they can be re-used on the same functional level for new TV production."*<br><br>[On substitution aspects]:<br>*"SP II. Plastics and polymers can be developed […] to not require heavy metals anywhere in the production cycle, or persistent compounds foreign to nature such as certain additives in PVC and anti-flammables."*<br>*SP III. Suppliers of wood from poorly managed forests can be exchanged for other suppliers, or supported to step-by-step improvements by Matsushita.* | [On dematerialization aspects]:<br>*"Lightening weight: Substitute PDP (plasma display panel) or LCD (liquid crystal display) and so on for conventional display."*<br><br>[On substitution aspects]:<br>*"SP I. We are aiming to replace all plastics with metal such as Mg."*<br>*"SP II. We are aiming to abolish the usage of anti-flammable materials containing bromine or chlorine by march 2006."*<br>*"SP. III. The meaning of "support from Matsushita for suppliers' improvements" is not concrete. We won't make any deal with suppliers, which are regarded as inadequate in accordance with our principles for green purchase and procurement."* | *"SP II. It is good that anti-flammables containing bromine are going to be phased out, and that such progress has already started in concrete terms. However, the replacement to phosphorous compounds need a thorough sustainability analysis and is at present to be regarded as a critical flow."* |

***Analysis of Template II***

From table 3 (and the complete Template II (Robèrt 2002a)) it is clear that:

- In line with the overall purpose of the TSPD approach, the sustainability expert tried both initially and in his feedback to shift the Matsushita perspective from focusing on historic and current improvements towards a new perspective in which the full sustainability gap regarding material flows and management routines is in focus.
- The sustainability perspective was clearly covered since all SPs are considered, but the life-cycle perspective is not systematically covered. This is true both for the sustainability expert's statements and the client responses.
- The focus in the sustainability expert's statements, Matsushita's responses and the sustainability expert's feedback is, as intended, mainly on the concept level. For example, Matsushita names material types such as phosphorous containing anti-flammables called FR-1 and FR-4 as substitutes for bromine anti-flammables.

In essence, this template seems to have worked as intended.

***Template III***

In table 4 below, we present some quotes of the sustainability expert and the client to illustrate the dialogue and learning process brought about by Template III.

***Table 4.*** *Excerpts from the Matsushita template sustainability assessment – Template III*

| Time | Triggering questions | Sustainability expert's statements | Matsushita's responses | Sustainability expert's feedback on B and C |
|---|---|---|---|---|
| **B (current situation)** | What are the critical aspects of the societal supply-flows and management routines of produced TVs on today's market? | [Points out a current lack of a coherent understanding of sustainability among societal stakeholders]:<br><br>*"Recycling is not at all time efficient in society, with too few and too disperse recycling plants, and without keeping recycled fractions pure enough to allow reconstruction of new products. […] Authorities are often not clear about the SPs, and how those ought to guide criteria for resource extraction, production, materials, products, transports and disposal of products."* | [Focuses on some recently implemented solutions to some of the challenges the expert brought up]:<br><br>*"We recognize our responsibility to accurately recycle plastics which we have used so far, and invented the technology to recycle plastics from the main structure of used TV set and produce halogen-free anti-flammable plastics, which we succeeded in introducing in our 2001 model."* | [Some existing measures are applauded]:<br><br>*"A very good example of outreach from Matsushita is the offered possibility to repair TVs."*<br><br>[Further outreach is also encouraged:<br><br>*"implementing […] leasing systems, cooperate with other [proactive] firms to push prices down on sustainable alternatives.* |
| **C (future solutions/visions)** | Could the above described problems on the market and in society at large be developed into a state that could support Matsushita's "ultimate" sustainability objectives? | [Focusing on stakeholders to promote leaner societal support systems…]:<br><br>*"…merge forces with other companies to either implement new possibilities on private ground or reduce the costs for utilizing already existing infrastructures."*<br><br>[Influence authorities to promote a sustainability and life-cycle perspective, by developing]:<br><br>*"…criteria for resource extraction, production, materials, transports and disposal of products that are guided by the SPs."* | [Lists, again, the recently implemented solutions from III B, above, but no new innovations that might bridge the gap to sustainability]:<br><br>*"…we have started not to use any lead for circuit board, and to adopt resinous materials which do not contain anti-flammable bromine and/or chlorine materials."*<br><br>[Lists current efficiency-related problems]:<br><br>*"Regarding transports our task is to improve efficiency in logistics for products and to change current transportation methods to other methods which have smaller impact on the environment."* | […and to make society at large implement actions like]:<br><br>*"…getting prices high enough on the depositing of scrap and on extraction of virgin materials and fossil fuels"* |

***Analysis of Template III***

From table 4 (and the complete Template III (Robèrt 2002a)) it is clear that:

- In line with the overall purpose of the TSPD approach, the sustainability expert tried both initially and in his feedback to shift the Matsushita perspective from focusing on historic and current improvements towards more systematically identifying and dealing with communication aspects of a life-cycle responsibility that involves a wider range of societal stakeholders.
- The focus in the sustainability expert's statements and feedback is, as intended, mainly on the possibility for the company to change stakeholders' preferences, as well as market conditions such as legislation, taxes, subsidies, and other politically decided incentives and disincentives. Matsushita's responses show that they to some degree have started to think along these lines, but that there is also much more that could be done.
- Matsushita repeats some dematerialization and substitution measures regarding their products as such, which belong better to Template II. This may be due to a desire to transfer the broader and more challenging general outreach to stakeholders into more familiar concrete engineering issues.

## After the Sustainability Assessment

At a meeting in 2002, vice President Miki gathered 100 technical people from the TVs area to present and discuss the results of the sustainability assessment. Questions and answers from that session were presented at the Matsushita Environmental Exhibition of that year. In this first loop of the present case study, considerable consensus was reached about the sustainability challenges for Matsushita's TVs.

Matsushita Electric Group later displayed the results of the assessment in their environmental sustainability report for 2002 (Matsushita 2002) and received the Environmental Ministry Prize for best sustainability report in Japan [6]. In

[6] The following information was gathered from a website in 2006-05-17 (http://www.japanfs.org/en/newsletter/200301.html): Of 293 entries for the "Environmental Reporting Award" in fiscal 2002, 28 reports received an award. The Grand Prix was awarded to Matsushita (Panasonic) for its Environmental Sustainability Report 2002. http://matsushita.co.jp/environment/en/index.html

2002, Matsushita also climbed at the Nikkei Shinbun (Japan's biggest business newspaper) ranking for sustainability reporting to position 5, compared to position 42 in 2001. In the following years they stayed among the top 8 and in 2005 they reached number one.

Mr. Miki later told representatives of TNS (Takami 2006) that the idea of a wider societal outreach that was suggested in the Extended Enterprise template was really helpful and, in the years to come, Matsushita did much to educate consumers about products with improved sustainability performance. Matsushita has also re-invited TNS to make yearly assessments of the company's sustainability performance (Matsushita 2003, 2004, 2005). These assessments indicate continuous progress in several key areas like "strategy/vision", "product development and lineup", "materials and substitution", "external communication", etc.

## Discussion and conclusions

We have analyzed a pilot case study in which the templates for sustainable product development (TSPD) approach introduced in this article was first used as the format for an expert-guided sustainability assessment of TVs at the Matsushita Electric Group.

Our findings indicate that the TSPD approach is a relatively simple and manageable, yet not simplistic, method that captures essential sustainability aspects of the life-cycle of a certain product category and that it to a high degree seems to have the abilities we looked for in our four research questions.

*(i). Bridging of competence gap.* We think that it is evident from the study that the TSPD approach has the ability to significantly bridge the competence gap between a sustainability expert and client people taking part of the assessment on an, as intended, overview level. The mechanisms for this are the introductory training and the oral and written dialogues facilitated by the templates. The sustainability expert cut through the complex sustainability challenges and led the client towards relevant sustainability problems and solutions. The sustainability expert encouraged the client to widen its perspective beyond environmental performance to deal with social sustainability aspects and societal stakeholders. This is exemplified in Template I. Here, the sustainability expert suggested that TVs could be used as a means to promote a sustainable society. Matsushita responded that they work hard to increase efficiency and recycling. The sustainability expert applauded these efforts but reminded them that there are more sustainability factors that need to be dealt with, like business implications in the developing world and the rebound effect of efficiency increases. Moreover, a dialogue in Template II shows how suggested improvements in terms of dematerializations and substitutions led to a response about replacing all plastics with metals such as Magnesium. The sustainability expert's feedback then urged the client to make sustainability assessments of any potential substitute materials, including Magnesium, so that one problem is not just replaced by another.

*(ii). Facilitation of decisions.* We think that it is evident from the study that the TSPD approach has the ability to facilitate sustainability-related decisions at both the top management and product development levels. The mechanisms

are the same as stated in (i). One example is the resulting policy statement by Vice President Sukeichi Miki (Matsushita 2002):

> *"Until now, we have promoted the development of Green Products (GP) in pursuit of environmental efficiency. As the next step, under the concept of Super GP, we are aiming to create products in pursuit of sustainability."*

The dialogue in Template II referred to above, led to acceptance also among the participating product developers that any substitution should be assessed from a complete sustainability and life-cycle perspective.

*(iii). Facilitation of communication.* We think that it is evident from the study that the TSPD approach has the ability to facilitate communication between the top management and the product development levels. This is not the least supported by the resulting top management commitment to support sustainability efforts in product development. The mechanisms are as in (i) and (ii) and the communication takes place primarily through Template I and Template III. (the dematerialization and substitution considerations in Template II mainly involve product developers). The wide mindset as regards market desires and human needs in Template I makes it important both for top management and the innovative functions within product development departments. The same can be said about Template III – both levels need to work with societal outreach and value-chain cooperation. However, the initial Matsushita responses in Template III were not in line with this template's visionary perspective but rather examples of isolated actions that have been successful recently. Therefore, in the feedback, the sustainability expert challenged the top management to bring in such perspectives.

Other template approaches have been used successfully to enhance the understanding of complex systems and to accelerate communication of that understanding. For example, in the study of organizations that seek to cultivate innovation, templates of management styles have been developed (Chu et al. 2004). An evaluation of a Cleaner Production project in New Zealand showed that two-way communications between top management and project team members were dependent on whether concrete channels for having this type of communication existed or not (Stone 2006). Our analysis of the template approach indicates that it could function as such a channel.

*(iv). Longer term influence.* We think that it is evident from the study that the TSPD approach has the ability to influence the organization's longer term ability to find product improvements relevant for strategic sustainable

development. Matsushita gained more sustainability knowledge and a better overview of the sustainability implications of the studied product type (TVs). They grew an urge to learn more, to study other product types in the same way, and to develop more comprehensive cooperation with societal stakeholders. This is obvious from subsequent award-winning sustainability reports and top management statements. Matsushita's earlier reports were mainly focused on environmental performance (Matsushita 2000, 2001) but the award-winning 2002 report (Matsushita 2002) that presented the results of the TSPD sustainability assessment contained significant top management commitment to a new wider focus on all dimensions of sustainability, and new yearly assessments have followed (Matsushita 2003, 2004, 2005).

We believe that some of the observed types of initial misunderstandings could probably have been avoided by more of introductory training, and by letting all client people involved in the assessment get this training directly from the sustainability expert (without internal "middle people"). This could probably reduce the total time for this type of assessment due to a smaller need for corrective feedback. We also think that the new formulation of the triggering questions in table 1 will help avoid misunderstandings.

In summary, the TSPD approach, an offspring of the MSPD, is developed for a fast and effective overview assessment of the sustainability gap for specific product categories. This opens for the possibility of using these approaches in combination. The TSPD can be used in the early phases of the product development process to create overviews of the current situation and future options (B and C of the backcasting procedure). Thereafter, the MSPD can be applied to go deeper into B and C as well as exploring prioritizations between the options (D of the backcasting procedure) (figure 2).

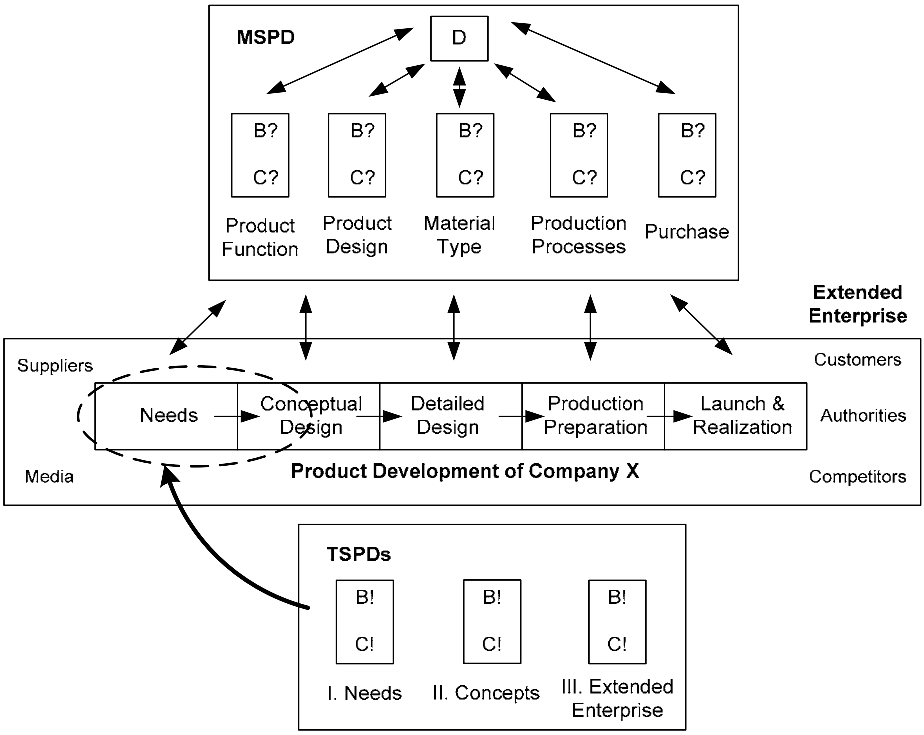


***Figure 2. The application of MSPD and TSPDs in a product development process.*** *The MSPD consists of several modules of questions on sustainability challenges (B?) and potential solutions (C?) that could be used as creative input to the product development team throughout the product development process. The MSPD also supports the prioritization between potential solutions (D). The templates include expert statements on expected sustainability challenges (B!) and potential solutions (C!) for product categories. The TSPD focus is on the early stages of product development and external stakeholders are to a larger extent taken into account.*

In future research, we plan to increase the accuracy of the assessment of the current situation (B) as well as of solutions and visions (C) by using support tools like systems analysis/dynamics to study the interrelationships between the mapped practices and flows under B and C, respectively, and also to support prioritizations (D) of initial actions. This will likely decrease the risk of omitting essential planning aspects, aid in discovering more creative solutions, and increase the sharpness of strategic choices.

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# Paper C

# Systems Modeling and Simulation within Sustainability Constraints

## Paper C is a manuscript in preparation:

Ny, H., Haraldsson, H.V., Robèrt K.-H. Broman, G. and Sverdrup, H. Systems Modeling and Simulation within Sustainability Constraints. Manuscript. In preparation.

# Systems Modeling and Simulation within Sustainability Constraints

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## Abstract

In response to the unsustainable development of the global society, a range of approaches have been developed to aid better understanding and handling of the complexity of the ecological and social systems, and their interrelations.

In this study we suggest that two of these – "systems modeling and simulation" (SMS) and "backcasting from sustainability principles" (BSP) – could be combined to better support strategic planning towards sustainability, and we present some initial ideas of how this could be done.

SMS is a research area studying the detailed functioning of a system with the purpose of trying to predict its future behaviour and effects from manipulation of it. Not being focused on strategic planning for sustainability, it has not, in itself, a robust definition of sustainability nor generic guidelines for strategic planning in relation to such a definition. This has typically been compensated by intuition amongst the users. The risk of arriving at strategically sub-optimised measures is then substantial. BSP is a research area framing strategic planning towards a rigorous principled definition of sustainability with the purpose of informing the most relevant case-specific support tools to identify critical sustainability aspects. However, the interrelationships between the aspects thus discovered have typically not been thoroughly investigated through modeling and simulation. Rather, intuition amongst the users has been employed. The risk of missing potentially important feedback loops, delays, hidden problems, counterintuitive effects and suitable intervention points in the system is then substantial.

We suggest that an integrated approach should start with framing the planning, utilizing BSP to create lists of critical present-day flows and practices, ideas of long term solutions and visions, and a first rough idea about prioritised early investments. After that, SMS should be applied to study the interrelationships between the listed items, in order to create more robust and refined analyses both of the problem at hand, the possible solutions and the possible investment paths, while constantly coupling back to the definition of sustainability and the generic guidelines for strategic planning of BSP. In this way only such scenarios are further elaborated that are likely to ultimately end up within the overall frame of a future sustainable society.

***Keywords:*** *strategic sustainable development, The Natural Step (TNS), systems science, systems analysis, systems dynamics, modeling*

# Introduction

## The Sustainability Challenge

Society is currently on a long term unsustainable course (Meadows et al. 1972; Steffen et al. 2004; MA 2005). Most responses to this challenge have dealt with particular aspects from the perspectives of established research fields. While proven successful for the study of isolated fields, reductionism is not likely to succeed when dealing with complex systems such as the human society in the biosphere (Robèrt et al. 2002; Ny et al. 2006). In such cases trans-disciplinary, trans-sector and other interactive approaches are necessary.

## Systems Science

A system consists of interrelated components. Some systems contain so many components and relationships that it is impossible to get a robust overview of their behaviours without scientific approaches and sophisticated tools. Systems science is a field that has emerged to face such challenges and as a result we can, for example, now say quite a lot about both short-term local weather and long-term average weather (climate) of different regions. Systems science uses a trans-disciplinary approach to build understanding of complex causal relationships and feedbacks between system components. Systems science embeds other terms like game theory, network science, systems analysis (SA), systems dynamics (SD), etc. Most systems scientists agree that the two latter terms are partly overlapping. One of them suggests that SA takes problems apart, building and studying conceptual models, while SD moves on to making simulations of model behaviour over time (Haraldsson 2005). In this article, when referring to SA and SD taken together, the term "systems modeling and simulation" (SMS) will be used.

## Planning Approaches for Sustainability

In order to plan strategically in a complex system, it is not enough to be able to simulate its dynamic behaviour. We also need a principle idea of the goal of the planning to set a desired direction of change, and the better understanding of the underlying basic rules of the system we have, the larger the probability that we will be able to influence it in that desired direction (Meadows 1999). A planner can draw from the rich research fields of strategic business planning (Montgomery and Porter 1991; Mintzberg et al. 1998), and military planning and conflict (Clausewitz 1832; Tzu 2001). A planning framework has been suggested that is based on such generic historical experiences - the “Five Level Framework” (Robèrt 2000). It is designed to develop plans through a thorough understanding of how to define the goal at the basic principle level, and how to apply logical guidelines and tools to systematically approach compliance with the principles of the goal. This Framework has been successfully applied by a variety of companies (Nattrass 1999; Robèrt 2002b) and municipalities (James and Lahti 2004; Gordon 2004) in planning for how to become part of a future sustainable society and is often called “backcasting from sustainability Principles” (BSP) (Holmberg and Robèrt 2000) or “The Natural Step (TNS) framework” – from the international NGO promoting it.

## A New Integrated Approach?

The global sustainability challenge has been tackled in similar ways in SMS and BSP. Both fields are applying knowledge from the larger realm of systems science in order to manage complexity and avoid reductionism. There are also differences that intuitively speak in favour of that the approaches may complement each other. SMS provides a rigorous approach to determine interdependencies in complex systems and to foresee outcomes that follow from the interdependencies and from manipulation of those. BSP provides a rigorous approach for the overall framing of the planning by strict basic principles for the desired outcome of the planning. From a strategic planning perspective, these two approaches have complementing strengths. We therefore think that a closer look at the potential links between these two fields could pave the way for a new integrated approach for strategic planning towards sustainability.

## What is Systems Modeling and Simulation?

Systems modeling and simulation (SMS) is often done in teams. The purpose is to agree between different stakeholders on the problem of study and its related questions and the conceptual and/or mathematical models that can appropriately deal with these questions. The overall goal with the exercise (what you want to achieve) is usually not made clear upfront but is rather left to the group to discover during the process. The focus is on the problem at hand and relevant assumptions needed to deal with this problem are supposed to be stated upfront. The group members should then map out causal links between different aspects of the problem, thus using their combined skills and experiences to create a common model of the problem. The model is then to be used to predict the behaviour of the system(s) of study over time and to invent suitable intervention strategies. Models are first ”verified” by checking their abilities to replicate observed historical trends and then they are used for forecasting from those trends.

In the literature there are many competing descriptions of the actual or desired workflow of SMS (Randers 1980; Richardson and Pugh III 1981; Roberts et al. 1983; Wolstenholme 1990; Sterman 2000) (see table 1)

***Table 1.*** *Some alternative workflow phases of SMS (Luna-Reyes and Andersen 2003)*

<table>
<tr><th>Randers</th><th>Richardson and Pugh III</th><th>Roberts and colleagues</th><th>Wolstenholme</th><th>Sterman</th></tr>
<tr><td rowspan="2">Conceptualization</td><td>Problem definition</td><td>Problem definition</td><td rowspan="2">Diagram construction and analysis</td><td>Problem articulation</td></tr>
<tr><td>System conceptualization</td><td>System conceptualization</td><td>Dynamic Hypothesis</td></tr>
<tr><td>Formulation</td><td>Model formulation</td><td>Model representation</td><td rowspan="3">Simulation phase (stage 1)</td><td>Formulation</td></tr>
<tr><td rowspan="2">Testing</td><td>Analysis on model behavior</td><td>Model behavior</td><td rowspan="2">Testing</td></tr>
<tr><td>Model evaluation</td><td>Model evaluation</td></tr>
<tr><td rowspan="2">Implementation</td><td>Policy analysis</td><td rowspan="2">Policy analysis and model use</td><td rowspan="2">Simulation phase (Stage 2)</td><td rowspan="2">Policy formulation and evaluation</td></tr>
<tr><td>Model use</td></tr>
</table>

Another author, has suggested that there are four overall group model building innovation phases (definition, clarification, confirmation and implementation) that are connected to up to eight iterative practical modeling steps (Haraldsson 2005). Generic to all the workflow descriptions is the idea, put forward by several authors within fields like organizational learning (Senge 1990) and product development (Roozenburg and Eekels 1995), to build understanding through *learning loops* (figure 1). With each learning loop iteration we move closer to properly formulate what we want to find out and what the answer might be.

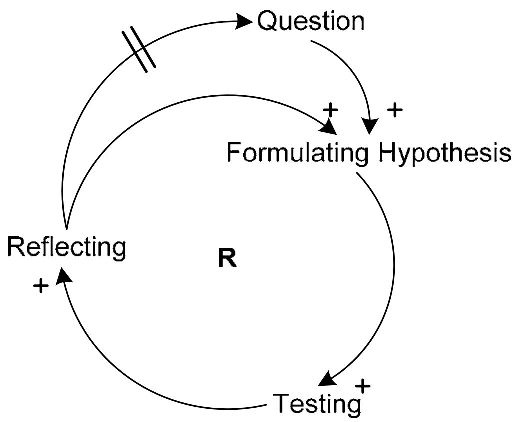


***Figure 1. A basic learning loop.*** *Each variable in this reinforcing loop (R) strengthens the one that follows. This means that a question initiates a reinforcing iterative learning process including hypothesis formulation, testing and reflection. The learning process may, with some delay, result in reformulation of the question and increasingly credible hypotheses.*

The SA procedure involves some key concepts (figure 2). It deals particularly with *system structure* - as described through *causal loop diagrams (CLDs)*. Before a CLD can map out a system it is necessary to pose the *question* that should be answered. This question implicitly defines what is relevant to include in the system mapping. These implications are then translated into concrete *system boundaries*, defining which *variables* and *cause-effect relationships (causalities)* to include in the system and which to exclude. These relationships are divided into two categories. A positive arrow (denoted +) from one variable to another implies that they change in the same way. When one grows or declines, the same is true for the other. A negative arrow (denoted -) from one variable to another implies that they are reversely related. When one grows the other declines and vice versa.

There are several complicating factors that make it difficult to create and interpret CLDs. Firstly, a growing number of variables and relationships add complexity. Secondly, some causalities - like the environmental effects from gradual increases of chemicals from industrial emissions – may be unknown and/or take place first after considerable *delay*. The causal mechanisms behind such delays may also be unknown. Thirdly, the variables may be connected in more or less complicated *feedback loops***.** When a change in one variable (A) causes such a change in another variable (B) that causes further change of the first variable (A), it is called *reinforcing (R)*. The opposite is called *balancing (B)*. The latter case is exemplified in figure 2 by a lake water volume that is connected with a lake water outflow. Should the water volume increase (because of increased water inflow), the water outflow also increases. Through this balancing feedback loop the lake volume will level off at a volume in which the water inflow matches the water outflow.

There are systematic ways to estimate complex and even counter-intuitive system behaviour from CLDs (figure 2). It is done by focusing on some key *output variables* and then consecutively reading each relationship of the CLD to see how those variables are in principle expected to change over time. The resulting graph is called a *reference behaviour pattern (RBP)*. This theoretical variable behaviour can then be compared to the real historical measured or *observed behaviour pattern (OBP)*.

The SD procedure includes some key concepts (figure 3). It deals particularly with the actual simulation of *system behaviour* over time, i.e. forecasting based on mathematical quantification of the CLD that resulted from the SA procedure. Such quantification includes definition of *differential equations* (including values of their coefficients) that describe how the system variables relate to each other over time. It also includes definition of initial values and boundary conditions. Also the full set of relevant output variables is defined and the quantified model is implemented into computer simulation software and is verified against historically observed system behaviour. This quantified model and simulation procedure is then used to make forecasting scenarios of future system behaviour, including studying how various intervention in the system affects such future behaviour. It is common to run at least three scenarios; best case, worst case and business as usual.

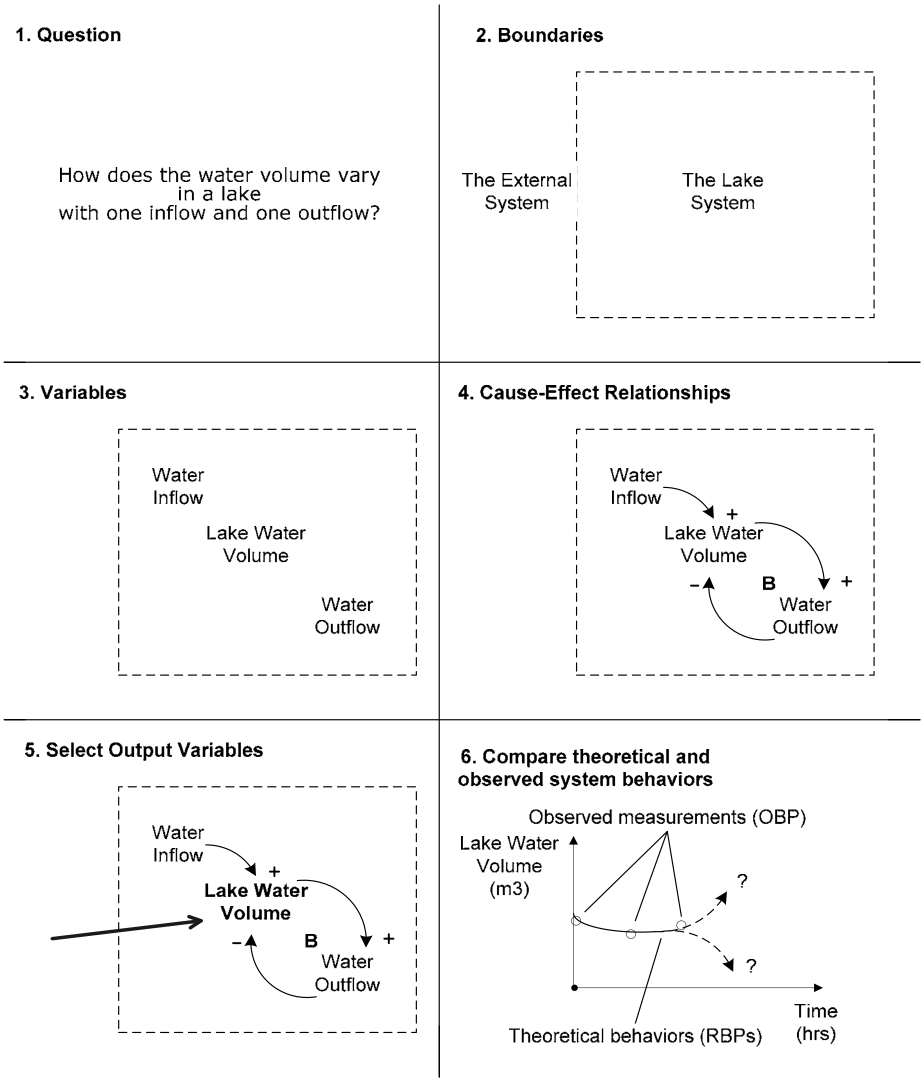


***Figure 2. Systems Analysis – Mapping Systems Structure.*** *This method maps out the problem and includes (1) identifying the question, (2) identifying the systems boundaries, (3) selecting relevant variables and (4) identifying cause-effect relationships. After that, the theoretical model is tested by (5) selecting some key variables and (6) comparing observed measurements (OBPs) with theoretical reference behaviour patterns (RBPs) of how the model would in principle predict that these variables behave over time.*

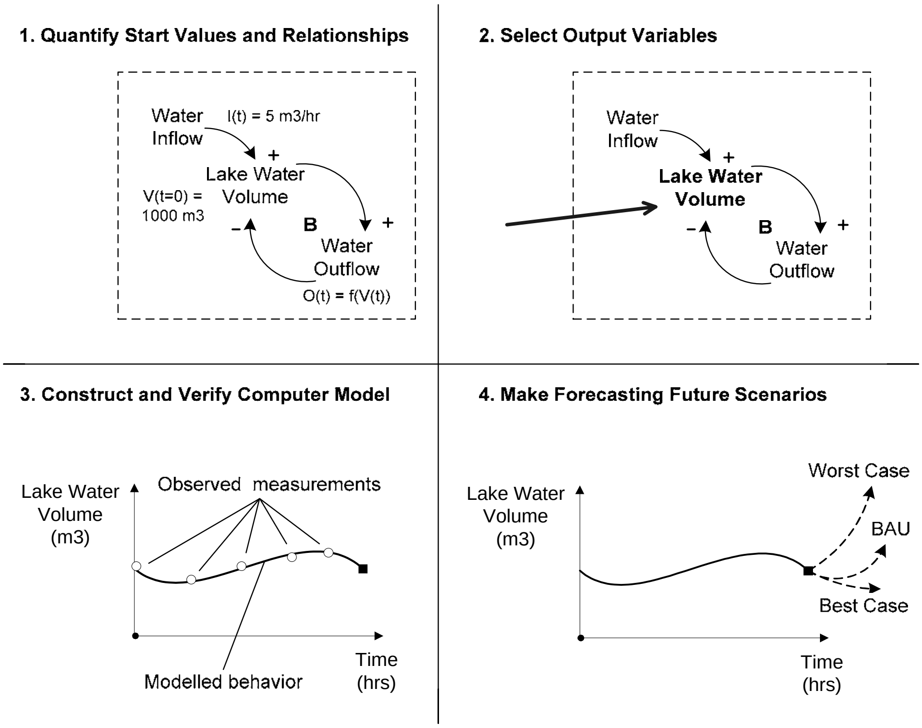


***Figure 3. Systems Dynamics – Simulating System Behaviour.*** *This method simulates system behaviour over time and includes (1) definition of differential equations describing relations and definition of initial values and boundary conditions, (2) selection of relevant output variables, (3) creation and verification of a computer simulation procedure and (4) forecasting of future system behaviour. This often includes business as usual (BAU) and a best and worst case.*

## What is Backcasting from Sustainability Principles?

Backcasting from sustainability principles (BSP) is a key part of a five level framework for strategic sustainable development (Robèrt 1994; Holmberg et al. 1996; Holmberg and Robèrt 2000; Broman et al. 2000; Robèrt 2000; Robèrt et al. 2002; Ny et al. 2006). This framework is generic to planning in any complex system. A chess game is an example of such planning and in table 2 it is compared to BSP.

***Table 2.*** *Chess vs. Backcasting form Sustainability Principles (BSP) on five planning levels*

| **Five level planning framework**<br>**- for success in any complex system** | **Chess planning framework**<br>**- for personal success in chess** | **BSP planning framework**<br>**- for success of organization X within society within the biosphere** |
|---|---|---|
| 1. System | Players, chess board, pieces and how they are allowed to move around the board | Individuals, within organisation X, within society with its laws, market, social fabric, etc., within the biosphere with its natural laws, basic resources, etc. |
| 2. Success | Compliance with principles for checkmate | Organization X in compliance with basic principles for its vision within basic principles for sustainability. |
| 3. Strategic Guidelines | With each move, (i) strive to strengthen your platform for coming moves that are likely to take you towards success as defined above. As a basic mindset, (ii) seek the most ”direct way” and (iii) strive to be “economic” with pieces. However, in the decision regarding an individual move, (ii) and (iii) need to be assessed in a dynamic interplay between each other and the abilities to support longer-term plans (i). | With each investment, (i) strive to strengthen the organisation’s platform for coming investments that are likely to take it towards success as defined above. As a basic mindset, (ii) seek the most “direct way” and (iii) strive to be ”economic” with organizational resources. However, in the decision regarding an individual investment, (ii) and (iii) need to be assessed in a dynamic interplay between each other and the abilities to support longer-term plans (i). |
| 4. Actions | Individual chess moves | Individual investments/measures |
| 5. Tools | Chronometer, standardized play patterns, statistics, etc. | Environmental management systems, Indicators, life-cycle assessments, investment calculus, etc. |

The BSP approach came about in response to the fact that the complex multidisciplinary sustainability challenge had been addressed by a series of promising but fragmented approaches and support tools that did not manage to explain how different approaches were related to strategic progress towards sustainability or to each other. A starting point was that strategic progress towards sustainability could probably not be achieved by a sole focus on gaining ever more knowledge about the system as such (level 1) – in this case ”society within the biosphere”. Instead, the idea was to study the system level *enough* to approach a principled definition of sustainability (level 2), and to allow “purpose” (vision within sustainability constraints) to act as functional system boundaries when strategic (level 3) actions are implemented (level 4) and monitored (level 5).

This approach recognizes that there are principled flaws of societal design upstream in cause-effect chains that systematically undermine the ecosystem and the social fabric – the two ”commons” on which the whole human society relies. The ecosystem provides services like fresh water and natural resources while the social fabric provides services like personal safety and help from fellow human beings (Capra 1996; Hayashi et al. 1999; Ostrom 1999; Folke et al. 2002). Metaphorically speaking, as the two commons are eroded more and more, we are moving deeper and deeper into a declining window of opportunity for long term prosperity of civilization (figure 4) (Robèrt 2000). The environmental and social problems we have already seen are serious, but the most serious problem is that such problems are bound to systematically increase due to the basic design and operation of today’s society. This is the meaning of unsustainability.

The sustainability principles (SPs) of the five-level framework (level 2) were developed with the following criteria in mind. The set of SPs should be:

- *science based*, that is compliant with relevant scientific knowledge available to date
- *necessary* for sustainability, that is, failure to comply with either SP would make sustainability impossible
- *sufficient* for sustainability, that is, the SPs taken together should cover all relevant aspects ´
- *general*, that is, people from various societal sectors and scientific disciplines should be able to understand and use them
- *concrete*, that is, capable of guiding actions and problem solving, and preferably

- *distinct*, that is, mutually exclusive to facilitate comprehension and monitoring

After several revisions the current wordings of the principles are (Ny et al. 2006):

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.

A minimum requirement for a "sustainable organisation" is to not contribute to society's violation of any of those SPs. However, it is non-prescriptive in that it does not imply any certain predefined conclusions. Like in chess, there are many possible patterns on the board that correspond to check mate, but they all comply with basic principles for checkmate. The SPs only define the overall frame within which a sustainable organisation has to operate. As such, these principles are creativity stimulating constraints for thinking up numerous potential ways to operate organisations in a sustainable society. Another advantage is the possibility to correct basic flaws of societal design thereby dealing with both presently known downstream impacts and related impacts that have not yet surfaced (Waage et al. 2005). The practice of large-scale use of Freons (CFCs), for instance, inherently leading to systematically increasing concentrations of "left over" CFCs in the biosphere (and thereby violation of SP II) could have been avoided already before we knew about their effects on the ozone-layer.

In the backcasting procedure, basic strategic guidelines (level 3) on how to systematically approach success are used. Just as it in chess may sometimes be smart to lose a piece if it creates interesting options for the longer term, it could sometimes be smart to temporarily increase an organisation's resource consumption and/or contribution to society's violation of some SP if that is a necessary early step to get a long term proactive reduction plan started (the dynamic interplay between (i), (ii) and (iii) in table 2). An example could be that a government sends delegates, by fossil fuel driven airplanes, to an international conference aiming at agreement of long term reduction of $CO_2$ emissions on the global scale.

In practice, BSP is performed in four main steps (figure 4) (Ny et al. 2006):

The first step (A) is to share and discuss the suggested framework with all participants of the planning exercise and translating the generic success definition into a case-specific one. The next step (B) is to identify the current situation from the perspective given by the success-principles. What are, from this standpoint, the critical flows and practices and what are the assets? The next step (C) is focused on brainstorming visions of a sustainable future, including solutions to the challenges identified in B, again applying the principled success-perspective. Finally, in step (D) the attention is shifted towards turning the solutions/visions from C into prioritized actions in a strategic plan, by applying the above described strategic guidelines (see (i), (ii) and (iii) in table 2). On top of those three core logical strategic guidelines there are also “soft” process-oriented guidelines like transparency, accountability and honesty.

Steps B, C and D are performed iteratively until no more significant problems and solutions can be identified. This process is called backcasting as opposed to “forecasting” and it has been developed from scenario planning (Robinson 1982, 1990) and is still under development (Robinson 2003). The special version of backcasting that we use in this article, though, is done from basic and generic principles rather than from specific scenario outcomes (Holmberg and Robèrt 2000). Rather than defining problems and futures in relation to past trends, as forecasting does, backcasting from sustainability principles defines them in relation to a principled definition of a desired future.

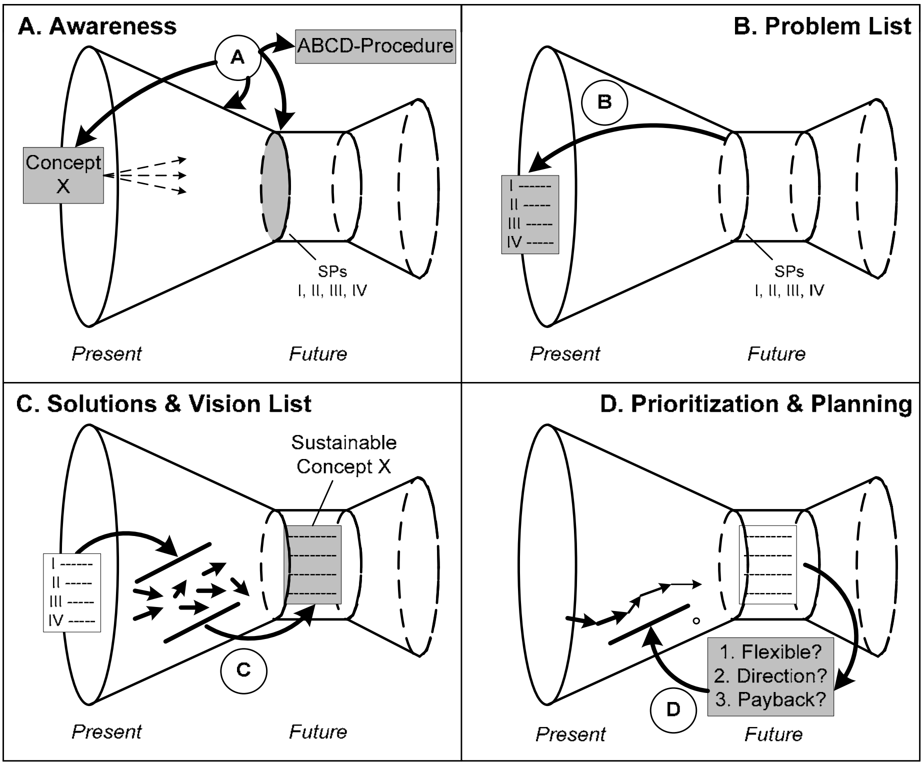


***Figure 4. The ABCD Procedure of Backcasting from Sustainability Principles (adapted from (Ny et al. 2006)).*** *Start by defining the concept of study (Concept X) and sharing knowledge about the challenge (decreasing window of opportunity, the funnel), the SPs and the ABCD procedure as such (A). Then identify present practices that are problematic with respect to the SPs (B). Continue with brainstorm to list potential solutions to the problems and envision new sustainable concepts (C). Based on the C-list and strategic guidelines, prioritize actions into a strategic plan (D).*

BSP has demonstrated its feasibility for providing strategic direction both within business (Electrolux 1994; Robèrt 1997; Anderson 1998; Nattrass 1999; Broman et al. 2000; Leadbitter 2002; Matsushita 2002; Nattrass and Altomare 2002; Robèrt 2002a; Robèrt 2002b) and policy (Rowland and Sheldon 1999; Cook 2004; Robèrt et al. 2004; James and Lahti 2004; Gordon 2004).

BSP has also been used to study and inform several other methods, tools and concepts from a full systems perspective on sustainable development and sustainability (Robèrt et al. 1997; Holmberg et al. 1999; Broman et al. 2000; Holmberg and Robèrt 2000; Robèrt 2000; Robert et al. 2000; Robèrt et al. 2002; Korhonen 2004; MacDonald 2005; Byggeth et al. 2006; Byggeth and Horschorner 2006; Ny et al. 2006; Ny et al.).

## BSP scrutinized from an SMS Perspective

BSP is an approach focused on framing strategic planning in complex systems. As such, BSP does not in itself contain rigorous tools for aiding understanding of the dynamics of the systems of study. The idea is that a facilitator that knows the method well and a well-composed group (with representatives from various stakeholders) will, by sharing one and the same mental model for how to frame the planning, be able to apply intuition, suitable support tools, and group dynamics to arrive at relevant early actions. Though experience speaks in favour of that this may work quite well in some situations (Robèrt 1997; Nattrass 1999; Broman et al. 2000; Leadbitter 2002; Robèrt 2002b; James and Lahti 2004), we know from systems science that many essential aspects and mechanisms may be hidden, or counterintuitive (Senge 1990; Meadows 1999). This means that by complementing BSP with a thorough scrutiny with SMS tools, problems, solutions, prioritised actions and trade-offs may be better founded.

## SMS scrutinized from a BSP Perspective

SMS is an approach focused on the study of complex systems and not necessarily for strategic planning in such systems. As such, SMS does not in itself contain a rigorous definition of the overall goal – in this case sustainability. When SMS tools are used for planning it is typically traditional forecasting planning, or adaption to predicted change from the current situation with its trends. The idea is that a facilitator that knows the method well and a well-composed group (with representatives from various stakeholders) will, with the aid of SMS tools, be able to apply intuition and group dynamics to map out system behavior in relation to a given problem. In this way the problem or the goal of the exercise is, so to speak, re-invented for every new study. This means that if SMS would be used to plan for sustainability there is no built-in assurance that the planning goal is sufficient for sustainability.

Furthermore, SMS builds on the assumption that predictions of the future behaviour of the studied system are 1) possible and 2) desirable. This is not uncontroversial in the sustainability discourse in for example social sciences. We argue that when planning in the system ”society in the biosphere” the complexity is too high to rely on the prediction approach alone. However, if a creative planning exercise would use an SMS approach, complemented with a principled definition of sustainability and basic strategic guidelines, the risk of essential elements being left out and the related risk of sub-optimization, would probably be significantly reduced.

We argue that when planning strategically it is better to first try to define on a principled level were we want to go and thereafter, with the aid of SMS tools, create and search, among many potential pathways, for pathways that are most likely to take us to the goal in a strategic way.

## An Integrated Approach – Systems Modeling and Simulation within Sustainability Constraints

Based on the two previous sections we suggest that BSP is used to set the overall frame of the planning, in line with the ABCD procedure (figure 4), while integrating different SMS tools to support the creation and assessment of alternatives throughout the B-C-D steps (Robèrt et al. 2004). By being able to model relations between items on both the B-list and the C-list and by being able to simulate their interaction it should be possible to create more robust lists. By being able to predict probable implications of preliminary prioritized actions, those that were first thought to be optimal but which due to counter-intuitive effects are actually not optimal, could be excluded at an early stage. In this way, financial and other risks could be reduced. This could also be expressed as a significant reduction in the feedback time from planning through theoretical testing and learning and back to new planning. This means that the five levels of the BSP framework could be displayed in a generic learning loop. A schematic illustration of this is provided in figure 5 and an expansion of the Test stage of the learning loop is provided in figure 6.

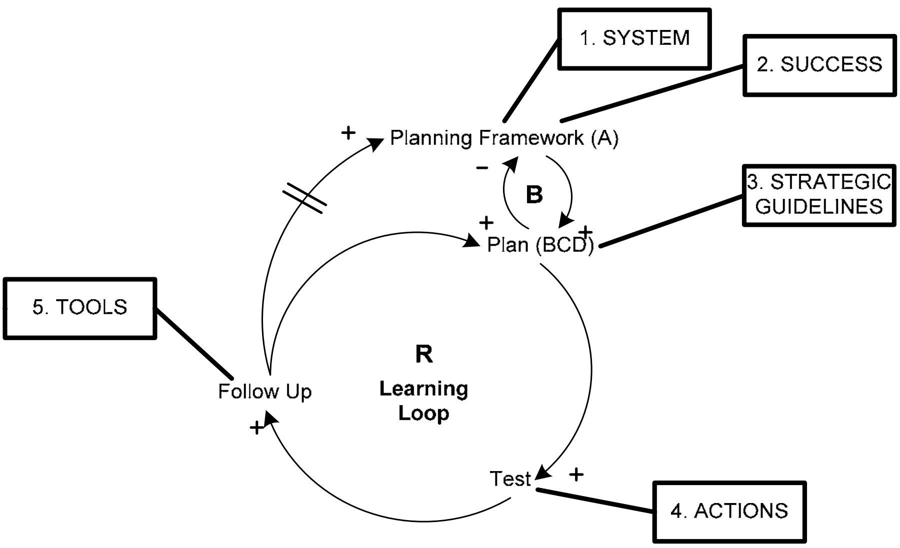


***Figure 5. The Backcasting from Sustainability Principles in a Learning Loop.*** *The planning framework (A) helps teams to build a common mental model of the system (level 1) and success in the system (level 2). Thereafter, the case specific planning (B-C-D) takes place,(level 3). Then the plan is tested, in reality or by simulation (level 4) and the results are followed up (level 5).*

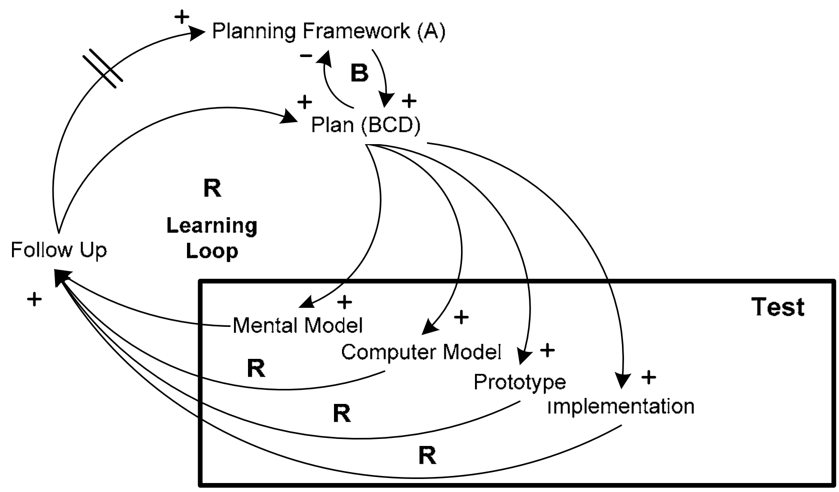


***Figure 6. The Testing Step from Idea to Implementation.*** *The learning loop will be run in several cycles, making the testing increasingly realistic. Experience from testing the mental model will feed into the construction and testing of a computer model and so on. In the end the final plan will be implemented. In the case of product development this corresponds to launching the final product.*

As an example, consider a municipal government that wants to make a sustainability assessment of its energy supply. Assume that it is presently almost entirely based on imported fossil coal and oil. What type of energy mix should they go for and what would be a preferable investment pathway towards it? We will go through the steps of this fictive sustainability assessment, and show the added potential benefits of an integrated approach (figure 7).

**Step A**. The municipality appoints a multi-disciplinary planning team to build a shared mental model of the global sustainability challenge and how it relates to the task at hand – creating a sustainable energy policy for the municipality. SMS tools can contribute with systematically clarifying basic interrelations in the studied system.

**Step B**. The planning team scrutinizes the present energy mix against the SPs and reveals contributions to sustainability problems like increasing atmospheric $CO_2$ concentration and resulting climate change (SP I), increasing concentration of $NO_x$ and resulting eutrophication (SP II), strip mining of coal and resulting loss of natural habitats (SP III) and unfair trading conditions with resulting damages to the social fabric of local indigenous communities in the mining areas (SP IV).

**Step B’.** With SMS tools the list of isolated sustainability aspects could be transformed into CLDs, differentiating between causalities and correlations (i.e. indicating how different aspects relate to each other) and identifying otherwise hidden factors, feedbacks, delays, etc. These improvements are likely to create a more complete B-list, as a better input to the C-step.

In the present example, a CLD may, for example, reveal a less apparent but still significant sustainability problem. Even though fossil fuel import may be the cheapest option right now, any further investments put in infrastructure around the fossil fuel import may turn into “dead ends” as fossil fuel (especially oil) prices are expected to permanently follow an upward trend within a decade (Heinberg 2003; Campbell 2005). If the municipality in such a situation would be “locked” into a fossil fuel infrastructure they would either have to pay the high fossil fuel prices or invest heavily to quickly switch to another fuel infrastructure. In either case, the municipal government could spend less money on social satisfiers of human needs like healthcare services, education and recreational facilities. This means that a policy of delaying the substitution from fossil fuel import to more sustainable and potentially locally generated energy would increase the risk of future troubles.

**Step C.** The planning team identifies potential solutions to the problems listed in B and visions for the municipality in a sustainable society.

**Step C’.** SMS tools could then lend support in a similar way as in B. The team could use CLDs to create a deeper understanding of the relationships between the different proposed solutions and visions. These improvements are likely to result in a more informed input to the D-step.

In the present example, a CLD may clarify some alternative ways to break the dependence on fossil fuels. One could, for example, focus on energy efficiency and using the right type of energy for the right purpose by introducing a local tax model that punishes wasteful activities and subsidizes efficient ones. Incomes from the tax could also be spent on building new infrastructure for renewable energy. The renewable energy could, for example, come from imported biomass. However, it is then also important to consider the risk of putting external ecosystems and other local communities in jeopardy. On the other hand, a CLD might also clarify how the municipality could turn itself into a renewable energy supplier and get incomes from neighbouring communities. Such income could then be spent on social satisfiers. And so on.

**Step D.** In a traditional D-step, aiming at prioritizing investments (actions), the dynamic interplay between the basic strategic guidelines discussed above is dealt with mainly by intuition.

**Step D'.** With SMS tools, the implications of different alternative investment paths could be simulated, which could significantly improve the quality of prioritization, especially when the solutions and visions from C are interrelated in complex ways and result in counterintuitive effects.

In the present example, one would, among other things, like to know a beneficial timing of the phase-out of fossil fuels that takes into account the time necessary for building the infrastructure for the new renewable energy supply. One would also like to know suitable timing and size of economic disincentives (e.g., taxes on fossil fuels) and how alternative renewable energy sources might influence the social satisfiers of the community.

The ABCD procedure should be repeated at least yearly to give a regularly updated strategic plan. In this way, real life feedback from its implementation can be used to adapt the plan (adaptive management) and to improve the models and simulation procedures.

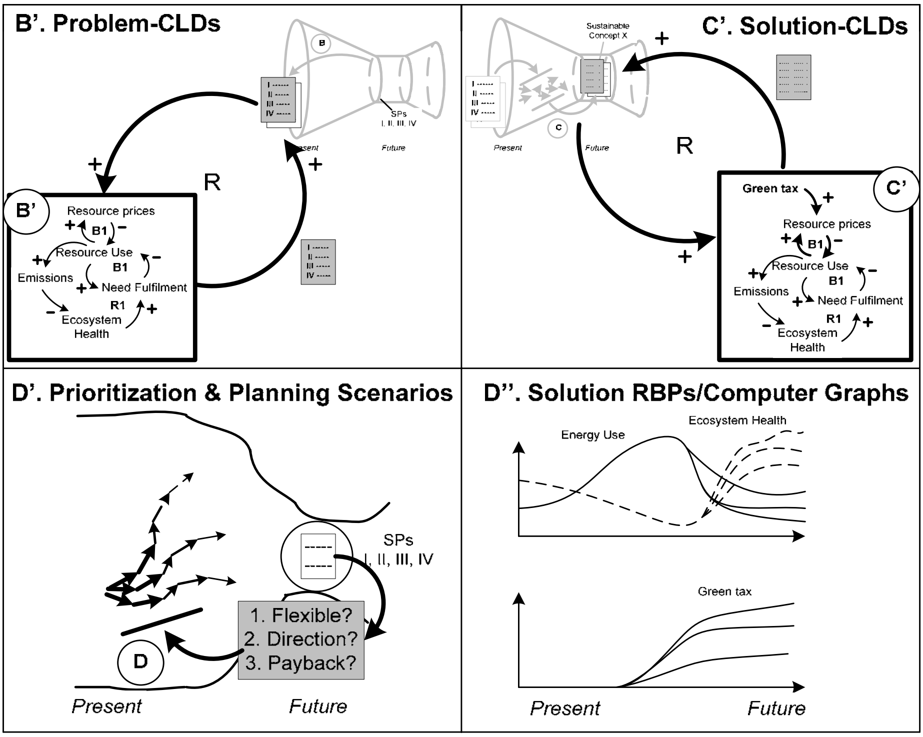


***Figure 7. Systems Modeling and Simulation in an ABCD Procedure.*** *First make CLDs of both the problems (B') and the solutions/visions (C'). Then let knowledge on these interrelations and simulations of their implications for different investment paths aid more sophisticated prioritization and planning scenarios (D'). Finally, study user-friendly graphic illustrations of scenario outcomes over time (D'').*

## Discussion and Conclusion

This article is a theoretical study that suggests a new approach to strategic planning towards sustainability. The idea is to integrate two current approaches: systems modeling and simulation (SMS) and backcasting from sustainability principles (BSP).

BSP is an approach focused on framing strategic planning in complex systems, informing suitable support tools in every specific case. Explicit modeling of interrelations and simulation of their implications are not included in traditional BSP, but is dealt with through intuition among the people in the planning group. This approach therefore typically produces lists of relatively isolated problems and solutions/visions, meaning that without proper choices of complementing tools there is a risk of potentially missing some important feedback loops, delays, hidden problems and suitable intervention points in the system. BSP could be seen as the planning step of a generic learning (a core concept of SMS) loop that also includes action implementation and follow-up. This overlap facilitates integration with the SMS approach.

SMS is an approach focused on the study of complex systems and not necessarily on strategic planning in such systems. When SMS tools are used for planning, though, it is typically traditional forecasting planning, or adaption to predicted change from the current situation with its trends without a robust principled definition of the goal. The goal is reinvented in each planning exercise and thus relies on intuition among the people in the planning group, thereby potentially missing aspects that are inherently essential for a desirable outcome. This, and the fact that we do not know about all current problems, imply a significant risk of sub-optimization. Furthermore, not maintaining continuous sight of the overall goal deprives in itself the creative process of its ultimate driver (Ny et al. 2006). However, SMS tools can aid understanding of the detailed functioning of a system (first step of BSP) and reveal interesting interrelations and implications (following steps of BSP). This overlap facilitates integration with the BSP approach.

From the above comparison of the two approaches, it is clear that they are strong in potentially complementing areas. We therefore suggest a new integrated approach - tentatively called systems modeling and simulation within sustainability constraints. This approach starts with framing the planning exercise in relation to a principled rather than a detailed goal. This means that BSP is used to create lists of critical present-day flows and practices, ideas of long term solutions and visions, and a first rough idea about prioritised early investments. This is also a counter measure against potential reductionism as it does not prematurely exclude critical sustainability factors. After that, SMS tools are applied to study the interrelationships between the listed items, in order to create more robust and refined analyses both of the problem at hand, the possible solutions and the possible investment paths, while constantly coupling back to the definition of sustainability and the generic guidelines for strategic planning of BSP. In this way only such scenarios are elaborated that are likely to ultimately end up within the overall frame of a future sustainable society.

In the future we will test the suggested integrated approach through several case studies and action research. As a preparation for this we are currently studying several companies to see how they presently make strategic decisions in relation to sustainability.

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## ABSTRACT

Decision makers are challenged by complex sustainability problems within the socio-ecological system. In response, a vast range of sustainability-related methods/tools have been developed, each focusing on certain aspects of this challenge. Without a unifying theory it is, however, unclear how these methods/tools can support strategic progress towards sustainability and how they relate to each other. This need for clarity and structure urged some sustainability pioneers to start develop an overarching framework for strategic sustainable development (SSD), often called "The Natural Step (TNS) framework", from the NGO that has facilitated its development and application, or the "backcasting from sustainability principles (BSP) framework" from its main operational philosophy.

The aim of this thesis is to study if, and in that case how, this framework can aid coordination and further development of various sustainability-related methods/tools, specifically to increase their capacity to support sustainable product development (SPD). Life-cycle assessment (LCA), "templates" for SPD and systems modeling and simulation (SMS) are the methods/tools in focus.

A new strategic life-cycle management approach is presented, in which the main sustainability aspects, LCA "impacts", are identified through socio-ecological sustainability principles. This creates new opportunities to avoid the reductionism that often follows from traditional system boundaries or from a focus on specific impacts. Ideas of how this approach can inform the studied tools are given. This may eventually lead to a whole integrated toolbox for SPD (a "Design Space"). As part of such a Design Space, a new "template" approach for SPD is developed. A case study of a sustainability assessment of TVs at the Matsushita Electric Group indicates that this approach can create a quick overview of critical sustainability aspects in the early part of the product development process and facilitate communication of this overview between top management, product developers, and other stakeholders. A potential integration between BSP and SMS is also discussed. It is suggested that this should start with BSP to create lists of critical present-day flows and practices, ideas of long term solutions and visions, and a first rough idea about prioritized early investments. After that, SMS should be applied to study the interrelationships between the listed items, in order to create more robust and refined analyses of the problems at hand, possible solutions and investment paths, while constantly coupling back to the sustainability principles and guidelines of the BSP framework.

Decision makers seem to need more of an overview and of simplicity around sustainability issues. A general conclusion is, however, that it is important that this is achieved without a loss of relevant aspects and their interrelations. Over-simplifications might lead to sub-optimized designs and investments paths. Combining the BSP framework with more detailed methods/tools seems to be a promising approach to finding the right balance and to get synergies between various methods/tools.


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