A FOUNDATION FOR SUSTAINABLE PRODUCT DEVELOPMENT

Sophie Hallstedt

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Karlskrona, April 2008,

Sophie Marie Lilian Hallstedt

Abstract

Product development is a particularly critical intervention point for the transformation of society towards sustainability. Current socio-ecological impacts over product life-cycles are evidence that current practices are insufficient. The aim of this thesis is to form a foundation for *sustainable product development* through the integration of a sustainability perspective into product development procedures and processes.

Literature reviews and theoretical considerations as well as interviews, questionnaires, observations, testing and action research through case studies in various companies have indicated gaps in current methodology and have guided the development of a new general Method for Sustainable Product Development (MSPD). This method combines a framework for strategic sustainable development based on backcasting from basic sustainability principles with a standard concurrent engineering development model. A modular system of guiding questions, derived by considering the sustainability principles and the product life-cycle, is the key feature. Initial testing indicates that this MSPD works well for identification of sustainability problems as well as for generation of possible solutions. However, these tests also indicate that there is sometimes a desire for a quick overview of the sustainability performance of a specific product category. This is to guide early strategic decisions before the more comprehensive and detailed work with the MSPD is undertaken, or, alternatively, when an overview is sufficient to make decisions. In response, a Template for Sustainable Product Development (TSPD) approach is presented as a supplement to the MSPD.

To generate products that support sustainable development of society it is necessary to combine sustainability assessments with improvements of technical product properties. An introductory procedure for such sustainability-driven design optimization is suggested based on a case study. For maximum efficiency of a company in finding viable pathways towards sustainability, it is also necessary to coordinate different methods and tools that are useful for sustainable product development and integrate them into the overall decision-making processes at different levels in companies. To find gaps in the sustainability integration in a company's decision system, an assessment approach is suggested based on case studies.

A general conclusion from this research is that the support needed for making sustainability-related decisions are not systematically integrated in companies today. However, this thesis also indicates that it is possible to create generic methods and tools that aid the integration of sustainability aspects in companies' strategic decision-making and product development. These methods and tools can be used to guide the prioritization of investments and technical optimization on the increasingly sustainability-driven market, thus providing a foundation for competitive sustainable product development.

Keywords: *backcasting, decision processes, ecodesign, integrated, product development, sustainability principles, sustainable product development, strategic sustainable development*

Thesis

Disposition

This thesis includes an introductory part and appended papers I-VI[1]. The papers have been reformatted from their original publication into the format of this thesis but the content is the same.

Paper I

Byggeth S.H. and Broman G.I. 2001. Environmental aspects in product development - An investigation among small and medium-sized enterprises, in: *Proceedings of SPIE, Environmentally Conscious Manufacturing*, Surendra M. Gupta, Editor, vol. 4193, 261-271. ISBN: 0-8194-3858-8.

Paper II

Byggeth S. H. and Hochschorner E. 2006. Handling trade-offs in Ecodesign tools for sustainable product development and procurement. *Journal of Cleaner Production,* vol. 14, issue 15-16, 1420-1430.

Paper III

Byggeth S. H., Broman G. and Robèrt K.-H. 2007. A method for sustainable product development based on a modular system of guiding questions. *Journal of Cleaner Production,* vol. 15, issue 1, 1-11.

Paper IV

Ny H., Hallstedt S., Robèrt K.-H. and Broman G. 2008. Introducing templates for sustainable product development through an evaluation case study of televisions at the Matsushita Electric Group. *Journal of Industrial Ecology* (In press).

[1]The author of this doctoral thesis has changed her name from Byggeth to Hallstedt during the research period.

Paper V

Byggeth S.H., Ny H., Wall J., Broman G. and Robèrt K.-H. 2007. Introductory procedure for sustainability-driven design optimization, in: *Proceedings of the International Conference on Engineering Design, ICED' 07*, Cite des Sciences et de l'Industrie, Paris, France, 28-31 August. ISBN 1-904670-02-4.

Paper VI

Hallstedt S., Ny H., Robèrt K.-H. and Broman G. 2008. An approach to assessing sustainability integration in strategic decision systems. Submitted for publication.

Abbreviations

CE	Concurrent Engineering
DfE	Design for Environment
DPD	Dynamic Product Development
FSSD	Framework for Strategic Sustainable Development
LCA	Life-Cycle Assessment
MSPD	Method for Sustainable Product Development
SP	Sustainability Principle
SME	Small and Medium-Sized Enterprise
SPD	Sustainable Product Development
TNSI	The Natural Step International
TSPD	Templates for Sustainable Product Development
RoHS	Restriction of the use of certain Hazardous Substances in Electrical and Electronic equipment
WEEE	Waste Electrical and Electronic Equipment
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
EMAS	Eco Management and Audit Scheme
EPD	Environmental Product Declaration

Table of Contents

Appended Papers

1 Introduction

This chapter gives a background to the research in this thesis, presents the aim and scope of the research and describes the research design as well as the thesis structure.

1.1 Background

Global sustainability problem

There is a growing consensus among scientists of various fields that society is currently on a long-term unsustainable course (Meadows et al. 1972; Steffen et al. 2004; Millennium-Ecosystem-Assessment-(MA) 2005; Gore 2006; Stern 2006; Intergovernmental-Panel-on-Climate-Change 2007). A transition to a sustainable society requires companies, governments, institutions and individuals to make strategic decisions based on a thorough understanding of the challenges and opportunities of this transition.

Product contribution to the sustainability problem

Product development is a particularly critical intervention point for the transformation of society towards sustainability. Socio-ecological impacts of resource extraction, production, distribution, use and disposal of products are evidence that current practices are insufficient. A product's impacts - positive and negative throughout its life-cycle - are largely determined by decisions during product development (Roozenburg and Eekels 1995; Charter and Chick 1997; Ritzén 2000). Thus, it is imperative to integrate a sustainability perspective in methods and tools for product development. Businesses taking a leading role in this development are likely to become increasingly more competitive. They will more clearly see the business case in systematically diminishing their contribution to society's un-sustainability (Holmberg and Robèrt 2000). This includes improved brand value, improved control of costs, increased efficiency and loyalty of staff, and better anticipation of new market opportunities (e.g. Willard 2005).

Measures for a change

There are many early signs of ecological sustainability considerations becoming part of strategic decision making in business. Many countries have implemented recycling and product-oriented regulations that emphasize an extended producer responsibility. Meanwhile consumers have become more aware of sustainability problems. This has led to that many companies have implemented Environmental Management Systems (EMS), performed Life-Cycle Assessments (LCAs), launched cleaner production and ecodesign initiatives (de Caluwe 1997; van Weenen 1997; Tischner et al. 2000; Robèrt et al. 2002; Byggeth and Hochschorner 2006), started to use ecological indicators like eco-efficiency and begun to eco-label products. The recent emergence of concepts such as ‘Corporate Social Responsibility’ (CSR) and ‘Triple Bottom Line’ indicates that companies now also have started to take the social sustainability dimension into more professional consideration.

Measures of today are not enough

In spite of all these promising market interventions, society in general still remains on an un-sustainable course. In relation to a relatively slow progress in the actual “greening” of products, suggestions have been made that certain types of ecodesign tools are in fact unsuitable (Baumann et al. 2000). Related reasons for the slow progress may include limitations in time and economic resources for an effective development and application of ecodesign tools (Hanssen 1996; Hanssen 1999), or there may be a lack of incentives implying that the expected environmental benefit would not be enough (van Hemel and Cramer 2002).

Sustainable product development

Without integrating a framework for strategic decision making in relation to societal development towards the full scope of socio-ecological sustainability in the future, it is supposedly difficult to consider the most relevant aspects of sustainability, to identify the interlinked strategic business opportunities and to inform appropriate methods and tools. In this thesis, the focus is on product development with a full systems perspective on socio-ecological sustainability, a process which will be referred to as “sustainable product development” (SPD). Tools and methods for sustainable product development differ from today’s 'design for environment'-tools. These 'design for environment'-tools can be criticized for; (i) aiming at environmental “improvement” of products from a limited perspective (given by various kinds of impacts that occupy the public and industrial discourse), (ii) not considering how incremental improvements fit into a viable strategy towards sustainability and (iii) for not stimulating ‘out of the box’ solutions based on, for example, assessments of true future resource potentials rather than constraints given by today’s technologies. The difference between SPD and concepts such as 'ecodesign' and 'design for environment' has also been emphasized by, for example, van Weenen (1997); Roy (1997); Simon & Sweatman (1997); and Byggeth and Hochschorner (2006). The aim of this thesis, elaborated in the next section, is an attempt to start filling these methodology gaps.

1.2 Aim & Scope

Purpose
The overarching research question of this thesis is; *how can a strategic sustainability perspective be integrated into product development procedures and processes?* The aim is to form a methodological foundation for sustainable product development, applicable for any business and all product types. The concept of product comprises the physical artefact, software, processes, services or combinations of these in systems. The main basic approach is to combine a framework for strategic sustainable development built on backcasting[2] from basic socio-ecological sustainability principles with a standard concurrent engineering development model. The new methodology is supposed to promote identification of sustainability problems and stimulate and guide generation of possible solutions. The wider purpose of all of this is to support pro-activity and transformation of society at large towards sustainability.

Delimitations
It is not within the scope of this thesis to directly investigate regulations *(e.g. "Restrictions of the use of certain Hazardous Substances in Electrical and Electronic Equipment (RoHS)", "Waste Electrical and Electronic Equipment (WEEE)" and "Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)")*; standards and management systems *(e.g. "Eco Management and Audit Scheme (EMAS)", "ISO 14001", "Environmental Product Declaration (EPD*)"); or procurement and labeling systems *(e.g. the "Nordic Swan", "Bra Miljöval", "Krav")*. However, these are all important aspects of product development and are the subject of other, related, studies. Furthermore, they are all indirectly related to the perspectives developed in this thesis.

Long term outcomes from using the new methodology are not investigated since the developed methods and tools are not yet fully implemented in companies and since follow-up times are still insufficient. However, indications of positive impacts from prototype versions of the suggested methods and tools have been found in a number of case studies.

[2] Backcasting is a concept that will be explored more in detail later. In short: "looking back from an imagined point in the future in order to explore strategies to get there"

1.3 Research Design

Research methods
This thesis is based on ten years of research (1997-2007). Six projects have been undertaken, whereof five include industrial case studies to assure relevance. Nineteen companies of various sizes and with different products have participated.

The research includes six main planning steps that have been followed throughout the research; (i) defining the goal and purpose, (ii) describing the conceptual framework, (iii) formulating the research questions, (iv) deciding on the research methods, (v) selecting case sites and (vi) identifying how to deal with validity threats (Maxwell 2005).

The research has been of a theoretical, exploratory and descriptive nature. Theoretical as it has anchored methods and tools in a scientific context, based on product development theories and basic knowledge of the functioning of ecosystems, technical systems and social systems. Exploratory as it has found out what has happened when testing the new methods and tools and thereby generated new insights and new questions (papers: I;III;IV;V). Descriptive as it has included; studies of support tools (paper II), and, case studies of established routines in organizations (paper VI), to provide base-line knowledge for further improvements.

The theoretical studies in various areas (ecological, societal, industrial, business, etc.) have lead to attempts to design logical structures of methods and tools, and the testing of these in relation to (i) previously published methods and tools, and, (ii) through experiments and real life applications. Data have been collected through several surveys, including interviews, questionnaires and observations. The case study is the main research method used with the purpose to concentrate on how product development is managed in one or a few companies and with the attempt to investigate these situations in detail.

For the exploratory surveys of paper I and III, interviews and questionnaires were used in parallel. In these cases, the same set of open questions were given in the questionnaires and then followed up with in-depth interviews. The main reason was to give the interviewed persons preparation time to answer the questions and also the ability for the researcher to explain, if necessary, any uncertainties of the questions. The data from these interviews were written down immediately afterwards and also compared with the answers in the questionnaire in order not to miss any details and to avoid any misunderstandings. Also the working materials from the companies, collected in a database, were reviewed in parallel to the analysis of the interview questions.

For the descriptive survey presented in paper VI, a standard set of open interview questions were given to all six participating organizations. In addition, semi-structured interviews were given to investigate the interviewed person's view of specific questions within the research area. In a semi-structured interview, the researcher has a strong influence on what, and how much, is taken up on each topic. The data from these questions were used as additional material for the discussion of the main results. For the survey presented in paper VI, participation observation was also used as a research method. An advantage of using observation as a complement to interviews is that it reveals what people do rather than what they say they do.

In the case studies presented in paper IV and V, data was collected from the testing of methods and tools on some sample products. Theoretical analyses and elaboration of the results were done afterwards. Also in paper II a theoretical analysis was conducted and the main research method was a literature review on different ecodesign tools. To explore the research area, to be able to discuss the research achievements of others, to bring together work from other disciplines, and identify gaps in knowledge, literature reviews have been done in all research projects and used throughout the thesis period.

Reliability and validation

Reliability of the interview studies is a weak point as interviews cannot be evaluated through repetition. The situation of each interview is unique. In one of the research surveys (paper VI) two researchers carried out the interviews, analyzed the data and reported the result in order to decrease subjective interpretation of the results from the interviews. More specifically, this meant that the researchers used the same question template and reported the result separately. Thereafter the report results from both researchers were compared with each other and merged into one report result. In two other surveys (paper I and III), interviews, questionnaires and working materials from the companies were reviewed in parallel to the analysis of the interview questions to decrease subjective interpretation of the results. Research interviews give limited opportunities for generalization. However, the case studies give a narrow but deep view and can give an increased understanding of the research area and show indications of certain results. In this respect, it can be judged valuable even if the reliability of the results is a weak point. Validation, defined as a measure of how well the investigation undertaken actually investigates what is intended to be investigated, has been secured through direct feedback during the interviews on the interpretation of the answers. Results have also been reported to companies for feedback.

1.4 Thesis Outline

This thesis consists of six studies, reported in papers I-VI. As a general background to the appended papers, an overview discussion of sustainable product development and related theories about sustainable development, sustainability principles, product development and ecodesign, is given in chapter 2. A summary of the appended papers is provided in chapter 3. Thesis contributions, concluding discussions and areas of future research are finally described in chapter 4.

2 Sustainable Product Development

This chapter gives an overview of the theories and research areas within which this research was centered and also relates to previous research studies in this field.

2.1 Strategic Sustainable Development

Definitions of sustainability and sustainable development
Humans have made unprecedented changes to ecosystems in the recent century to meet growing demands for, for example, food, energy and products in general. This has improved the quality of life for many, but it has been done at the expense of a weakening of nature's long term life supporting capacity. Natural resources are currently overused and nature's waste assimilation capacity is exceeded (Steffen et al. 2004; Millenium-Ecosystem-Assessment-(MA) 2005). Socio-economically, a strong polarization between industrialized and developing nations has also developed and this has weakened the social fabric of many societies (O'Neill 2002). Such symptoms of un-sustainability are rooted in the very design and operation of the modern society. To set this right, the first task is to develop the society towards sustainability. Then the society must evolve within the boundaries of sustainability. To accomplish this, a definition of sustainability and methodology for development within sustainability constraints are necessary.

With the Brundtland report 'Our common future' the concept of sustainable development received increased attention. The report stated that:

> *"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 can be interpreted as a definition of both sustainability and sustainable development. Although principally correct, the definition is too general to be useful for strategic planning of actions towards sustainability in business and society.

In this thesis the following sustainability principles (SPs)[3] are used as a definition of sustainability. For references, see for example (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 (e.g. fossil carbon or metals),

II …concentrations of substances produced by society (e.g. nitrogen compounds, CFC's, and endocrine disrupters),

III …degradation by physical means (e.g. large-scale clear-cutting of forests and over-fishing),

and, in that society. . .

IV…people are *not* subject to conditions that systematically undermine their capacity to meet their needs (e.g. from the abuse of political and economic power).

These principles can be seen as a concretization of the Bruntland definition. They make possible an analysis of present activities in business and society as well as of solutions and visions, from a sustainability perspective. The first three principles give a frame for ecological sustainability, and the fourth for social sustainability. These principles are basic, meaning that they *cover* all relevant aspects of sustainability, that is, can be used to structure but not *contain* all such aspects.

The reason for choosing this set of sustainability principles in this thesis, in favor of several alternatives (e.g. Daly 1990, 1992; Daily and Ehrlich 1992) is that they have been designed to be (Robèrt 2000; Ny 2006):

- *science-based:* that is, compliant with relevant scientific knowledge available to date;
- *general:* that is, generic and applicable to all sectors of any society;
- *necessary:* that is, failure to comply with any one of the SPs would make sustainability impossible;
- *sufficient:* that is, taken together they cover all relevant aspects of sustainability;
- *concrete:* that is, capable of stimulating and guiding problem-solving and actions in practice;

[3] These principles are sometimes also called system conditions for a sustainable society.

- *distinct:* that is, complementary to facilitate comprehension and development of indicators and tools needed to monitor progress towards sustainability.

These sustainability principles, having the above combined qualities, make it easier to identify causes of current and potential problems at their origin, and thus to structure, solve and prevent problems upstream rather than fixing symptoms downstream as they appear. Such principles are therefore considered valuable for a foundation for sustainable product development.

A framework for strategic sustainable development
It is important to state upfront that the above principles are not better than other sets of sustainability principles. But they are specifically designed for backcasting, which relies on the bulleted characteristics above (Ny et al. 2006). They describe a principle future goal. This definition of the goal, and the backcasting procedure to get there (described below), are key elements of a Framework for Strategic Sustainable Development (FSSD)[4]. This framework is intended to help organizations plan and act in a structured and systematic way to support their own and society's transformation towards sustainability while avoiding financial risks associated with unsustainable practices, foreseeing new business opportunities and improving on image and brand value. In this way the framework brings together socio-ecological and economic dimensions over time. This is also of fundamental importance for sustainable product development, including maintained or improved competitiveness for the organization.

The FSSD is structured in five different and interacting levels (Robèrt 2000; Robèrt et al. 2002):

1. *The Systems level* describes the overarching system with the organization, within society with stakeholders, laws, etc., within nature with its natural laws, basic resources, etc.
2. *The Success level* describes the overall principles that are fulfilled in the system (1) when the organization is in compliance with its vision, within basic principles for socio-ecological sustainability.

[4] Sometimes referred to as The Natural Step framework.

3. *The Strategic level* describes the strategic guidelines for planning and acting towards the goal (2). The most basic guidelines are: (i) With each investment, strive to strengthen the organization's platform for coming investments that are likely to take it towards success as defined in (2). In doing so, strike a good balance between (ii) direction and advancement speed with respect to the sustainability principles and (iii) return on investment.
4. *The Action level* describes what actions that are planned and carried out in line with the strategic guidelines (3) to achieve the goal (2) in the system (1). For example; designing a more efficient engine, that will pay off early and therefore make it more economic later on to invest in a renewable energy source for the company.
5. *The Follow up/Tools level* describes the methods, tools and concepts used to measure, manage and monitor the activities (4) so that these are chosen in a strategic way (3) to arrive at success (2) in the system (1). For example; ecodesign tools and environmental management systems.

The SSD framework in practice - the A-B-C-D procedure

An A-B-C-D procedure (see also figure 1) is a practical application of the FSSD. The steps are:

A. Discussing and agreeing upon the FSSD, including the sustainability principles and the backcasting procedure, as a relevant approach to sustainable development.

B. Analyzing present activities in relation to the principled goal by answering the overall questions: "In what way do the product and its accompanying flows and practices contribute to society's violation of the sustainability principles?" and "What specific assets does the product, or more generally the competence of the organization, provide for a systematic planning towards sustainability?"

C. Brainstorming of possible solutions to the problems identified in B, ideas for utilization of advantages listed in B, and perhaps creating a vision at large of how the organization may fulfill its customer needs in a sustainable way in the future. Answers are searched for the overall question: "Which product (properties/functions), and accompanying flows and practices, could fulfill the specified needs and could in principle fit within a sustainable society, and which design changes and other initiatives could in principle serve as intermediate stepping stones?" Also 'unrealistic' solutions and ideas are allowed and noted in this step.

D. Forming strategies towards sustainability, that is, specifying a program of prioritized actions that are likely to systematically take the organization from today's situation to the future vision. This means that each investment, at least if it is large and binds resources for relatively long time periods, should (i) strengthen the organization's platform in a way that is as flexible as possible for coming investments that are likely to take it towards success as defined by the SPs (and other goals set up by the organization). As a basic mindset, the organiszation 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 in relation to the longer term plans (i).

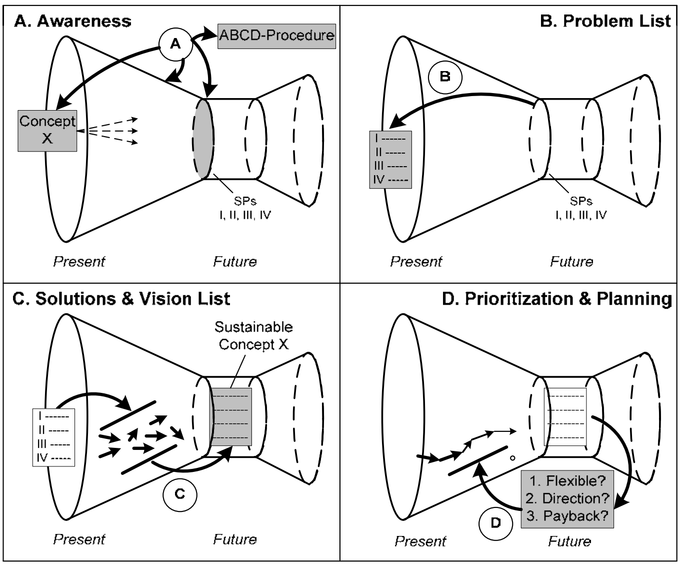

Figure 1. *The A-B-C-D procedure of backcasting from sustainability principles (Reproduced from Ny et.al., 2006.* ***Step A:*** *Start by agreeing on a mental model of the concept of study (Concept X), the sustainability challenge (a decreasing window of opportunity, the funnel), the Sustainability Principles (SPs) (I-IV) and the ABCD procedure as such.* ***Step B****: Then identify present practices that are problematic with respect to the SPs and assets for solving the problems.* ***Step C****: Continue with brainstorming to list potential solutions to the problems and envision new sustainable concepts.* ***Step D****: Based on the B- and C-list and strategic guidelines, prioritize actions into a strategic plan.*

Experience with the SSD framework
Many previous studies have reported how the FSSD has been implemented and used by both policy makers (e.g. Rowland and Sheldon 1999; Cook 2004; Robèrt et al. 2004; James and Lahti 2004; Resort-Municipality-of-Whistler-(RMOW) 2007; Purcell and Baxter 2007) and business leaders (e.g. Electrolux 1994; Robèrt 1997; Anderson 1998; Nattrass 1999; Broman et al. 2000; Leadbitter 2002; Matsushita 2002; Nattrass and Altomare 2002; Robèrt 2002; TNSI 2002).

A general experience is that the FSSD seems to support problem-solving and decision making in complex situations. Using a wide enough perspective and clarifying upstream causes of problems mean less risk of forgetting essential aspects as well as of sub-optimized strategies and even 'blind alleys'. It empowers cooperation between people from different sectors and disciplines who seek to design problems out of the system and to prevent new problems. The FSSD has also been shown to stimulate creativity and community building. Departing in planning from robust basic principles makes it easier to identify out-of-the-box solutions that are based on true constraints and resource potentials, rather than on restrictions that follow from current norms, practices and technologies. This mode of procedure also makes it easier for people from different sectors and disciplines to agree on a common vision of the future.

Many of these benefits of the FSSD are related to the use of backcasting as a supplement to traditional forecasting and the use of a principled description of the goal rather than a detailed scenario description. This is discussed briefly below.

Backcasting versus forecasting
Backcasting means imagining success in the future and then looking back to today to assess the present situation through the lens of this success definition and to explore ways to reach that success (Robinson 1990; Dreborg 1996). Another, commonly used, planning methodology is forecasting, that is, applying what we know of the current situation, and the trends that brought us there, as a basis for the planning. This makes it possible to foresee some opportunities as well as problems, which can be considered in the planning process (Holmberg and Robèrt 2000; Robèrt 2000). However, forecasting alone has several disadvantages. Though it can be useful for avoiding known problems and problems that can be predicted directly from those problems, forecasting alone is insufficient. If there is no well-defined end-goal in mind, based on a systems perspective, there is a risk of over-emphasizing problems

that are currently given much public and political attention and under-emphasizing or missing other relevant problems and future problems that are difficult to foresee in detail. These under-emphasized problems might be a contributing reason to the current general unsustainable development path. However, within a backcasting planning exercise, forecasting can be used as a supplement when considering short-term priorities and the pace of change (Ny 2006).

Principles versus scenarios

Typically, scenarios are based on envisioning a simplified, yet rather detailed future from which backcasting is performed (Robinson 1990; Dreborg 1996). Although backcasting from scenarios is a more strategic method than forecasting alone and has the potential of encouraging people to merge forces around shared visions, it also has some potential shortcomings (Ny et al. 2006). For example, given people's different values, it may be difficult for large groups to agree on relatively detailed descriptions of a desirable distant future. Also given technological and cultural evolution, it may be unwise to lock the mind into overly specific assumptions about the future. In addition to that, if basic principles for sustainability in the whole biosphere are not explicit and brought to inform the scenario, it is difficult to know whether any given scenario is really sustainable or not.

Listing violations of the sustainability principles

Sometimes simplistic lists of unsustainable versus sustainable materials, products, and activities are requested. However, it follows from the above that neither sustainability, nor unsustainability, can be described in simplistic terms.

Firstly, it is unlikely that detailed lists can replace training and analysis of complex systems from a decision-maker or planner. When decision-makers choose between various strategic options for sustainable development there are many categories of criteria (e.g. certainty of current data and information, seriousness, urgency) in play simultaneously (Waage 2003). Each situation is likely to be more or less unique.

Secondly, whether or not materials or products are contributing to society's violation of the basic sustainability principles, is something which is attributed to the *management* of the materials or products during their full lifecycles rather than to certain characteristics of the materials and products per se (Ny et al. 2006). For example, the use of wood can be highly unsustainable if the wood is harvested from poorly managed forests and painted with lacquers with chemicals that are accumulating in natural systems.

And conversely, heavy metals can be sustainably managed if they are maintained in technical loops tight enough to comply with the sustainability principles. However, the use of metals that are very scarce in natural systems (e.g. Mercury, Cadmium) and chemicals that are foreign to nature and relatively persistent (e.g. CFC's and Bromine organic anti-flammables) is linked to a relatively high risk of contributing to society's violation of the first two sustainability principles. Since it is difficult and costly to achieve close to 100 percent recycling, a large scale use of such materials is consequently "more" difficult (and probably expensive) to contain within sustainability constraints.

It follows from this, that certain materials and products may be more difficult (technically, economically, socially) to maintain within sustainability constraints, whereas others are much simpler. Renewable materials, easily degradable chemicals (into naturally occurring substances) and metals that are relatively abundant in nature can be used with a relatively low risk of contributing to society's violation of the sustainability principles. However, even the use of such substances may violate these principles when emissions are so large that the assimilation and regeneration capacity of the ecosystems are exceeded.

From the above it is clear that it would be difficult, and unwise, to provide a general list of "sustainable materials" or "unsustainable materials". From a sustainability perspective the question is rather about sustainable management of materials.

2.2 Product Development

Definitions of product development and product innovation
In the area of product development there are many terms and definitions. Here only a few definitions are given to provide some background and different views of the terminology. According to Ulrich and Eppinger (2003) product development means:

> *"The set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product".*

Roozenburg and Eekels (1995) state that product development is the early part of an industrial *innovation process* comprising:

> *"all activities that precede the adoption of a new product in a market (or the implementation of a new production process), such as basic and applied research, design and development, market research, marketing planning, production, distribution, sales and after sales service."*

This is illustrated in figure 2.

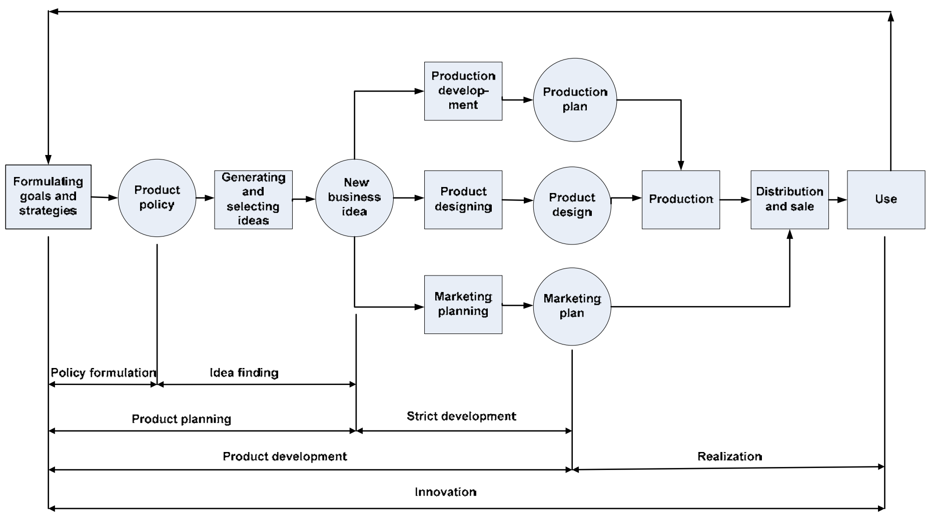

Figure 2. *The product innovation process. (Reproduced from Roozenburg and Eekels (1995), p 13.)*

So, a first conclusion is that the terminology is not entirely distinct. What Roozenburg and Eekels call *product innovation* is in actual terms very close to what Ulrich and Eppinger call *product development*, whereas the latter is only a part of the *product innovation* process according to Roozenburg and Eekels (proceeding the product realization process).

In this thesis, the terminology of Roozenburg and Eekels (1995) and figure 2 is adopted. The main focus is on the *product development* part. It is important to integrate sustainability aspects as early as possible, considering the whole innovation process and product life-cycle, to avoid sub-optimizations and high costs later on for "fixing" what was wrongly planned from the beginning.

Strategies for product development

Traditionally the development of products has been carried out in a sequential process, also called Serial Engineering, meaning that each design stage starts when the previous one is completed. The main disadvantages using this strategy are:

- risks of delays and additional costs, which are likely if a change is required in a later stage;
- risks of poor communication between the various phases, which results in little attention to manufacturability issues of the product at the design stage;
- risks of not meeting the customer needs due to insufficient product specification; and
- risks of high time-consumption due to waiting periods between the various phases in the process.

(Ottosson 1999; Syan 1994)

To minimize the time for product development serial engineering evolved to "integrated product development" (Barkan 1988; Evans 1988; Winner et al. 1988). Integrated product development or Concurrent Engineering (CE) means that people with different competence and often from different departments in a company, such as marketing, design, and production, work at the same time with the same project. A commonly used definition is:

> *"A systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life-cycle from*

conception through disposal, including quality, cost, schedule, and user requirements." (Winner et al. 1988).

CE allows creativity and has the advantage of the workers' power of initiative and knowledge. In addition to that, CE can facilitate to work with customers and suppliers at an early stage of the product development process. One of the main benefits of CE is reduction in engineering changes, which results in decreased cost and decreased time to market. In addition, the quality is meant to be inherent in the product design rather than being an afterthought (Prasad 1996).

Integrated product development forms a framework for design activity. Integrated product development models are presented by, for example, (Olsson 1976; Andreasen and Hein 1987; Pugh 1991; Ullman 1997; Ulrich and Eppinger 2003). Fredy Olsson is considered to be one of the pioneers of integrated product development and the models developed after his work of 1976 do not differ considerably from his model. His model includes the whole product development process from recognition of a need to a useful product (figure 3). It is structured in four parallel business areas and in five phases, each intended for a certain issue. The model is easy to follow, and flexible since it is possible to choose different starting points depending on the project at hand. These characteristics were the main reason why the MSPD (see papers I and III) was based on the model described by Olsson (1976). However, in the MSPD the parallel areas of expertise are not strictly pre-defined. Instead, the company is free to define its own group of expertise for each project, since different expertise can be relevant for different companies and projects.

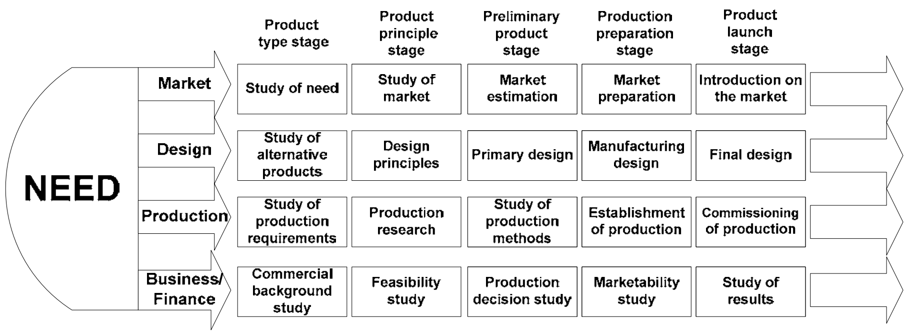

Figure 3. *Integrated product development model. (Reproduced from Olsson, 1976).*

In the phases, many working steps are required such as collecting information, searching for solutions, calculating and evaluating. Although several activities are taking place concurrently in this model, the division of the process into phases, in which certain decisions are supposed to be made, indicates that it is to some extent still a serial process. However, a product development model is a theoretical view of the product development process, providing guidance for, for example, when, who and how to use different methods and tools during the product development phases (Lindahl 2005), but strict borderlines between the phases are not always upheld in practice. For a product developer the attention is not entirely within a specific phase and responsibility area at the time. The main focus may be in the present phase and the given responsibility area, but flashes of thoughts are all the time going both backwards and forwards in the process and between different responsibility areas, as well as to experience from prior projects. An experienced product developer is, so to say, more or less thinking of everything at the same time, but with different emphasis or level of detail depending on the status of the project. The theoretical model can be seen as a help to grade the emphasis and enlighten important aspects that should be considered at the phase in which they are included. In practice, several company-specific product development models also exist. With the above in mind, the sustainability product assessment in the MSPD was organized into a separate modular system, applicable to all phases and even company-specific product development models (see paper III).

To further promote CE, Ottosson (1999) suggests a so-called Dynamic Product Development (DPD)-strategy. He argues that the established models for integrated product development are suitable mostly for re-engineering of existing products and seldom result in totally new and groundbreaking products. The DPD-strategy does not follow defined phases, it encourages flexibility and it is focused on the use-orientation. During the whole process many minor decisions are made, depending on situations and not on schedules or checklists, to achieve the major goals (Ottosson 1999). To integrate sustainability into the company's whole decision support system is then important (see paper VI).

Importance of early phases

According to Roozenburg and Eekels (1995), product planning should precede strict development of any product. This includes a continuous review of the company's product policy (overall goals and strategies) and search for new/modified product/business ideas. Among other things, this means asking what types of products the company wants to provide and what markets should be in focus. This is the primary task for the 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 products in society, captured, for example, through the company's sales and service activities. New ideas could also be stimulated by the ongoing production and, of course, by the company's research and development activities in a wide sense. Predictions of consumers' future desires and the company's capabilities of meeting these are critical for success. The rapidly increasing significance of sustainability on the market adds aspects to consider and puts special demands on integrating a socio-ecological sustainability perspective in this early product planning phase.

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 conceptual 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 involved components. One should also establish broad ideas of the shape and the kinds of materials of the product and its parts (French 1985). It should also be possible to roughly assess aspects like 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 design constraints and evaluation criteria. Sustainability aspects over the full life-cycle of the product should play a major role in the concept phase, for example, to stimulate creativity in concept generation and to guide evaluation (see papers III and IV). This is a way of avoiding financial risks and identifying new opportunities that would otherwise be difficult to note or realize in later stages.

Parallel to 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 and in all these simulations it is critical to include sustainability aspects (see paper V).

In summary, this means that it is important that business leaders and product developers develop competence also in the sustainable product development field and have sufficient methodological support for handling the future sustainability challenges. Some previous attempts at developing such methodology are discussed in the next section.

2.3 Ecodesign & Sustainable Product Development

Environmental aspects in product development

Traditionally many environmental problems caused by the industry have been addressed by end-of-pipe strategies to fix current problems rather than to apply a sustainability perspective for the redesign of products and processes. In the long run this often turns out to be costly and inefficient because it mostly does not provide solutions to the problems from a systems perspective. In recent decades focus has turned more towards avoiding problems before they arise. Furthermore, the main sources of pollution in industrialized countries have for many substances changed from point sources to diffuse emissions from products (Bergbäck 1992) and (Holmberg and Karlsson 1992). This has increased the efforts to identify the potential environmental impact from products already during product development.

Several approaches have been proposed to integrate environmental aspects into product development. Some examples are cleaner production, pollution prevention, ecodesign, design for environment (DfE), design for recycling, life-cycle design, green engineering and sustainable product development (van Weenen 1997). The ones mainly discussed in this research are ecodesign, design for environment and sustainable product development.

Ecodesign is a common term used to denote the work of developing environmentally adapted products. The overall meaning is:

> *"of minimizing a product's environmental impact throughout its life-cycle by taking preventive measures during product development."* (Johansson 2001).

Another definition is:

> *”design which addresses all environmental impacts of a product throughout the complete life-cycle without unduly compromising other criteria like function, quality, cost and appearance.”* (Poyner and Simon 1995).

Design for Environment is a synonym and is defined as:

> *"systematic consideration, during new product and process development, of design issues associated with environmental and human health and safety over the full product life-cycle."*(Fiksel 1993).

Methods and tools

Many investigators have identified the need for methodological support for integrating environmental aspects into product development, (e.g. Ehrenfeld and Lenox 1997; Ritzén 2000). Many different support methods and tools exist today, for example, matrices, spider webs, checklists, guidelines, and comparison tools. These have been developed for different purposes, such as for assessment of environmental impacts, identification of environmental critical aspects, comparison of environmental design strategies, comparison of product solutions and prescription of improvement strategies (Ryding 1995; Fiksel 1996; Brezet and van Hemel 1997; Luttorp 1997; Graedel 1998). Examples of different types of ecodesign tools can be found in the reviews by de Caluwe (1997), van Weenen (1997) and Tischner et al. (2000). Many of these aim at implicating a way of thinking and acting for companies when developing a product in order to minimize the potential negative environmental impacts of the product. One of the most rigorous and frequently used tools is Life-Cycle Assessment (LCA), with the objective of evaluating impacts of materials and products from the "cradle" (resource extraction), through transport, production, and use, to the "grave" (after end use) (International-Organization-for-Standardization-(ISO) 1997).

The MSPD (see paper III) was developed to support the wider aim of *product development guided by a framework for strategic sustainable development based on backcasting from basic sustainability principles* (as discussed in the introduction). This method combines an *inventory analysis* with an *impact assessment*, to systematically notify and organize data of materials and other resources used directly or indirectly for the product analyzed. In addition, an *improvement assessment*, to facilitate generation of proposals that support societal transformation towards sustainability is included. The MSPD is not intended to replace other methods and tools, but rather to make better use of them. For example, if, on an overarching level, some issues are suspected to be critical with respect to the SPs, this could be further investigated by a comprehensive LCA (informed by the overarching life-cycle assessment of the MSPD).

Approaches for real changes

Methods and tools are important but not enough for real change of product development practices. Often the senior management's responsibility of setting the main direction for product development, of assuring that suitable methods and tools are actually used, of allocating resources appropriately, and of assuring communication through all levels of the organization, is emphasized (McAloone 1998; Ritzén 2000; Lindahl 2005). Thus, to actually realize sustainable product development, it is important to go beyond pure methods and tools development and also consider how the strategic decision system, at all levels of a company, could integrate sustainability aspects (see paper VI).

3 Summary of Papers

3.1 Paper I

Byggeth S.H. and Broman G.I. 2001. Environmental aspects in product development - An investigation among small and medium-sized enterprises, in: Proceedings of SPIE, Environmentally Conscious Manufacturing, Surendra M. Gupta, Editor, vol. 4193, 261-271. ISBN: 0-8194-3858-8.

The present author's contribution
Took part in the planning and writing of the paper. Led the writing process. Provided most of the method development and carried out the surveys.

Research questions

- What product development procedures are typically used in Small and Medium-Sized Enterprises (SMEs) and how are sustainability aspects taken into considerations?
- What are some desired characteristics of a Method for Sustainable Product Development (MSPD), according to SMEs?

Research approach and results
This study presents the results from two surveys in ten SMEs and includes a brief description of an early computerised version of an MSPD.

An initial survey registered their product development procedures and environmental work as well as their need for, and desired characteristics of, a new method for integrating sustainability aspects into the product development process. The survey was performed parallel to, and gave an additional basis for, the development of the first structure of an MSPD. For the SMEs in this investigation the question is not whether environmental aspects need to be considered, but rather what should be considered and how. There is a wish for a computer-based method/tool that, during the ordinary product development process, assists them in identifying potential risks for environmental problems related to their products. A second survey registered additional desired characteristics and improvement suggestions when testing the early computerised version of the MSPD.

In summary, the surveys pointed out that for the SMEs a method for integrating ecological and social aspects into product development should:

- be possible to use without too much expertise,
- be inexpensive, both to buy and to update,
- preferably be computerised as the companies are used to other computerised tools (such as CAD) when designing products, and
- have results that are readily communicable to sub-contractors and customers, but not necessarily as a quantitative measure (a number).

The SMEs found appealing the strategy of first raising a few “most relevant” questions from a sustainability perspective, combined with the possibility of successively going into more detail if necessary for a decision. However, even though it was possible to bring in a large and comprehensive perspective on sustainability in concrete product development, the original method applied was experienced to be relatively cumbersome to work with. This was partly because of the complexity and organization of the so-called “Sustainability Product Assessment (SPA)-matrix”. A structure that better aligns with, and supports the logic of, the Product Development Process (PDP) was desired.

How to analyze materials and substances with the MSPD was a problem of special interest to the companies. A need for better guidance to find substances with minimal environmental load, and to become aware of the choices, was declared.

Main contribution to this thesis

The initial survey registered the company’s product development procedures and environmental work. From this survey, together with a literature study, a generic model of a product development process was identified and then used as one part of the MSPD. Both surveys identified desired characteristics from potential user groups of an MSPD, which gave input to a next version of the MSPD presented in paper III and its supplement presented in paper IV.

3.2 Paper II

Byggeth S. H. and Hochschorner E. 2006. Handling trade-offs in Ecodesign tools for sustainable product development and procurement. Journal of Cleaner Production, vol. 14, issue 15-16, 1420-1430.

The present author’s contribution
Took part in the planning and writing of the paper. Led the writing process. Carried out approximately half of the analysis of the ecodesign tools and was responsible for the sustainability analysis.

Research questions

- In what way do some ecodesign tools provide support in different types of trade-off situations?
- Do these ecodesign tools also give support from a sustainability perspective?

Research approach and results
An assessment of some ecodesign tools was carried out to find out the potential support with respect to valuation and sustainability in three different trade-off situations.

A selection of fifteen different types of ecodesign tools was studied. These tools have been developed for different purposes, for example, assessment of environmental impacts, identification of environmental critical aspects, comparison of environmental design strategies, comparison of product solutions and prescription of improvement strategies. The selected tools were all intended to be simple to use, did not require comprehensive quantitative data and were not too time-demanding to use (at most a few days).

Each tool was analyzed with respect to the following:
(i) *is valuation included to support trade-off decisions? And, if so,*
(ii) *in what way does the tool provide such support? Three situations were studied: trade-offs within one environmental aspect, between different environmental aspects, and between environmental aspects and other criteria.*
(iii) *does the tool provide decision support from both a social and ecological sustainability perspective?*

The ecodesign tools that included a valuation were analyzed and related to the framework for strategic sustainable development described in chapter 2 to ascertain how they might contribute to strategic progress towards sustainability.

Nine of the fifteen tools included a valuation and were able to give support in a trade-off situation, but the support was not sufficient. The valuation should include a life-cycle perspective and a framework for strategic planning towards sustainability. If not, it can lead to strategically incorrect decisions with concomitant risks of sub-optimized investment paths and blind alleys. However, all the analyzed tools can in principle be complemented with methods and tools based on strategic planning towards sustainability.

Main contribution to this thesis
This study confirmed some suspected gaps in current ecodesign tools and methodology available in the literature and provided further guidance for the development of the MSPD presented in paper III and its supplement presented in paper IV. This study also generated ideas for an approach to assess sustainability integration in a company's strategic decision system, described in paper VI.

3.3 Paper III

Byggeth S. H., Broman G. and Robèrt K.-H. 2007. A method for sustainable product development based on a modular system of guiding questions. Journal of Cleaner Production, vol. 15, issue 1, 1-11.

The present author's contribution
Took part in the planning and writing of the paper. Led the writing process. Responsible for most of the method development and carried out the surveys.

Research questions

- Can potential sustainability problems of current products be identified and does the new suggested MSPD provide guidance in finding alternative solutions to the present or planned products?
- How user-friendly and flexible is the new suggested MSPD, and what are the needs for further research and development?

Research approach and results
A restructured and enhanced Method for Sustainable Product Development (MSPD), including a modular system of guiding questions, was developed and tested during a one-year period in two different types of companies in Sweden. This was followed up with a questionnaire and an in-depth interview with specific questions designed to frame the above research questions.

The results indicate that the overall purpose of the MSPD can be fulfilled, that is, to:

- Provide basic knowledge about sustainability from a full systems and life-cycle perspective
- Provide a strategic approach to sustainable product development
- Provide basic knowledge about product development methodology
- Raise awareness of product-related sustainability issues and point to sources of more detailed information needed to address these issues
- Initiate relevant investigations and link traditional design considerations with sustainability considerations to stimulate creativity
- Aid identification and clarification of trade-offs and prioritization of short and medium-term actions
- Aid documentation in line with the above structure

This is achieved by an introduction manual, a modular system of guiding questions to stimulate brainstorming, and a prioritization matrix to aid decisions about which solutions to carry forward to the next stage. The guiding questions are derived by considering basic sustainability principles and a full 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 such as Factor analyses, Footprinting or LCA, but a way of making better use of these.

Main contribution to this thesis

Asking guiding questions derived by considering basic sustainability principles and a full life-cycle perspective is a key feature of this thesis. This study also confirmed a desire from product developers for some kind of sustainability-expert support for getting a quick overview of the main sustainability aspects of a given product category before continuing with the MSPD work on their own. This is part of the background for the “templates” approach described in paper IV.

3.4 Paper IV

Ny H., Hallstedt S., Robèrt K.-H. and Broman G. 2008. Introducing templates for sustainable product development through an evaluation case study of televisions at the Matsushita Electric Group. Journal of Industrial Ecology (In press).

The present author's contribution
Took part in the planning and writing of the paper. Took part in the development of the new theoretical concepts.

Research questions

- Does the TSPD approach have the ability to help shifting focus from gradual improvements of a selection of aspects in relation to past environmental performance of a certain product category, to a focus on the remaining gap to a sustainable situation?
- Does the TSPD approach have the ability to facilitate a common understanding among different organizational levels of major sustainability challenges and potential solutions for a certain product category?
- Does the TSPD approach have the ability to facilitate a continued dialogue with external sustainability experts, identifying improvements that are relevant for strategic sustainable development?

Research approach and results
An idea of "templates" for sustainable product development (TSPDs) was to increase the ability of company in-house product developers to see and apply the overall long-term sustainability picture as an aid for identifying a suitable mix of dematerialization and substitution investments. The idea was also to give them a means for communication to top management in order to receive support for actions.

Whether the TSPD approach has the desired qualities was investigated in an evaluation case study at the Matsushita Electric Group. The effect of the template approach was evaluated in three steps.

a. What was the sustainability performance of the Matsushita TVs before the approach was introduced?
b. Was the template approach applied as intended?

c. What indications of resulting product-related sustainability improvements could be found?

This study indicates that the TSPD approach captures overall sustainability aspects of the life-cycle of product categories. The TSPD approach has in the Matsushita case demonstrated to be a functional basis for dialogue about sustainability-related issues within the company and thereby facilitating sustainability-related decision making later on.

Furthermore the TSPD approach:
- has the ability to shift the focus of the client organization towards its sustainability gap. The mechanisms for this were the introductory training and the oral and written dialogues facilitated by the templates.
- has the ability to facilitate a common understanding among different organizational levels of major sustainability challenges and potential solutions. It is mainly Templates I and III that facilitate communication between organizational levels.
- has the ability to facilitate a continued dialogue with external sustainability experts, identifying improvements that are relevant for strategic sustainable development. In this case study, Matsushita gradually deepened their dialogue with external experts and showed progress in relation to the sustainability requirements identified in the initial sustainability assessments.

Main contribution to this thesis
The TSPD approach, an offspring of the MSPD (paper III), was developed for a fast and effective overview assessment of the sustainability gap for specific product categories. The TSPD approach was also used as part of a procedure for a sustainability-driven design optimization, discussed in paper V.

3.5 Paper V

Byggeth S.H., Ny H., Wall J., Broman G. and Robèrt K.-H. 2007. Introductory procedure for sustainability-driven design optimization, in: Proceedings of the International Conference on Engineering Design, ICED' 07, Cite des Sciences et de l'Industrie, Paris, France, 28-31 August. ISBN 1-904670-02-4.

The present author's contribution
Took part in the planning and writing of the paper. Led the writing process. Carried out and took part in the sustainability assessment.

Research question

- What would be a suitable procedure for combining sustainability- and technical assessments in order to facilitate design optimization informed by a societal perspective?

Research approach and results
Basic ideas for an iterative optimization procedure that combines a sustainability assessment with a technical assessment are presented. The procedure is introduced through a case study of a water jet cutting machine.

For the sustainability assessment, general backcasting from sustainability principles was first used. Among other things, this showed that electricity use could be a concern relative to other properties due to current use of unsustainable energy systems. This led to recommendations like buying electricity from renewable energy sources and mapping out and reducing energy and material use.

The templates approach (TSPD) was then used to identify product development consequences of the overarching sustainability problems/benefits and solutions from the assessment of the company. These results were also later used as input to a Causal Loop Diagram (CLD) and Reference Behavior Patterns (RBP), giving a systems description of water jet cutting in a sustainability context. The TSPD added to the sustainability assessment, among other things, a concrete recommendation to focus on reducing the weight of the moving parts in the water jet cutting machine without reducing its manufacturing accuracy and speed. This would reduce the energy use throughout the machine life-span, which would in turn reduce the impacts of unsustainable energy systems. Other ways to reduce energy use were also identified such as improved jet efficiency.

For the technical assessment, a finite element model of the machine was used in a parameter study to sort out, for the specific design criteria, influential design parameters. A virtual machine was then used that contained several sub-models; a finite element model simulating the flexibility of the moving mechanical parts, a motor model, and a multi-body model of the transmission. Given the input from the sustainability assessment, all major moving machine components were identified and parameterized in the virtual machine.

The result of this study revealed a significant potential for design improvements. The weight of the main moving components can be reduced by more than 30 per cent, at the same time as the cutting accuracy can be improved by more than 60 per cent at maintained cutting speed. The water jet case shows the potentials for an integrated sustainability- and technical assessment. The working procedure is interactive and iterative in order to finally suggest what design variables have the most significant socio-ecological impacts. The integrated assessment procedure needs to be repeated several times before a satisfactory solution from both the technical and the socio-ecological perspective is reached. This is because different parameters are dependent upon each other.

Main contribution to this thesis

This study contributed with a possible working procedure able to add information about socio-ecological impacts of product properties and influence design criteria used in prioritization situations during product development. This procedure facilitates well-informed decisions early in the product development process and reduces risks of costly and difficult changes in later phases.

3.6 Paper VI

Hallstedt S., Ny H., Robèrt K.-H. and Broman G. 2008. An approach to assessing sustainability integration in strategic decision systems. Submitted for publication.

The present author's contributions
Responsible for planning and writing the paper. Carried out and took part in the surveys, the analysis and the writing.

Research questions

- By what approach can sustainability integration in a company's strategic decision system be assessed?
- At *what organizational level* should *what type of support* be used to facilitate decisions that effectively take the company towards sustainability?
- What would be some generic guidelines for improving a company's strategic decision system?

Research approach and results
A two-stage assessment approach based on guiding questions was developed and tested in two small and medium-sized companies and two large companies. The strategic capabilities of their decision systems were studied – both in general and in relation to sustainability. The results were validated against the experiences made by two management consultancies with a large number of clients.

The two assessment stages were:

1. **Inventory** of current general and sustainability-oriented strategic decisions systems.
2. **Strategic Capability Assessment** of these decision systems – both in general and in relation to sustainability.

The result of this study presents a new assessment approach with the ability to identify a list of key improvements for how a company could integrate sustainability in its strategic decision system. These recommendations are:

(i) creating an overarching supporting organizational context, including senior management awareness and commitment to a widely adopted definition of sustainability, sustainability integration in business goals and policies, and, to that end, adequate resource allocation,

(ii) institutionalizing internal company capacity building and communication on sustainability,

(iii) introducing integrated methods, tools and indicators for both senior management and product development teams that focus on how to close the gap between the present situation and long-term socio-ecological sustainability.

The study indicates that the assessment approach could be used as a generic template to assess the current state of sustainability integration in company decision systems.

Main contribution to this thesis

In paper I-V the focus has been on support methods and tools for integration of sustainability aspects in product development. This study widens the perspective to include processes and methods and tools for communication and cooperation across organizational levels. It shows that SPD methods and tools are important but not enough for implementing sustainability in companies. It provides guidance for how to systematically integrate sustainability in companies' strategic decision systems to support the development of more sustainable products.

4 Concluding Discussion

A general conclusion from this research is that the support needed for making sustainability-related decisions is not systematically integrated in companies today. However, this thesis also indicates that it is possible to create generic methods and tools that aid the integration of sustainability aspects in companies' strategic decision-making and product development.

A unique contribution is the combination of a framework for strategic sustainable development (FSSD) based on backcasting from basic sustainability principles with a concurrent engineering product development model. The resulting method for sustainable product development (MSPD) has as a key feature a modular system of guiding questions, derived by considering the sustainability principles of the FSSD and the product life-cycle.

The FSSD has a number of qualities that make it particularly attractive when studying and aiming to improve product development methodology. It covers the full scope of sustainability and can therefore be used, as in this thesis, both for evaluating existing methods and tools and to support development of new methods and tools. It supports the ability of the new methods and tools to facilitate identification of causes of current and potential problems at their origin, and thus facilitates structuring, solution and prevention of problems upstream. Using such a perspective also means less risk of sub-optimized strategies and provides good chances of foreseeing new business opportunities. The FSSD empowers cooperation between people from different sectors and disciplines and stimulates creativity, community building and innovation. The basic sustainability principles make it easier to identify out-of-the-box solutions that are based on true constraints and resource potentials, rather than restrictions that follow from current norms, practices and technologies. Such a perspective is especially important to employ in the early phases of product development.

The main idea of using guiding questions is to avoid detailed rules and prescriptive guidelines. The purpose is instead to raise the awareness and knowledge about product-related sustainability problems and opportunities among business leaders and product developers and to open up for a creative dialogue and innovation within basic sustainability constraints. In each module the questions are divided into inventory/impact questions and improvement questions. Initial testing indicates that the MSPD works regardless of product type and thus utilizes the above mentioned qualities of the FSSD in the product development context. However, these tests also indicate that there is sometimes a desire for a quick overview of the sustainability performance of a specific product category, to guide early strategic decisions before the more comprehensive and detailed work with the general MSPD is undertaken, or, alternatively, when an overview is sufficient to make decisions. This is the objective of the templates for sustainable product development (TSPD) approach presented in the thesis. It is also shown that TSPDs facilitate communication between top management and product developers and thus positively influence the company's capacity to find product improvements that are relevant for strategic sustainable development in the longer term. The TSPD approach is lead by a sustainability-expert, providing statements about sustainability-related issues for the product category in question. Such an expert-led approach could be seen as a weakness in the short term as it depends on persons with certain competences. On the other hand, with the increasing education for sustainable development there will be more and more people that can lead a TSPD assessment, and the marginal effort of creating a template for a new product category will decrease as the number of existing templates increase (because of commonalities between product categories).

The MSPD includes an evaluation matrix intended to facilitate multi-criteria evaluation of generated solutions. This combines sustainability aspects with more classical aspects of product development. A four-level color grading is used to facilitate illustration and communication. However, future research should investigate in more detail which criteria should be used for evaluation and how these should be weighted against each other. Also, it should be examined how quantitative and qualitative data can be better considered together in the evaluation and how the consequences of the different alternatives can be better described or illustrated.

Finally, an important conclusion from this work is that to reach maximum efficiency in finding viable pathways towards sustainability, it is necessary to coordinate different methods and tools that are useful for sustainable product development and integrate them into the overall decision-making processes at different levels in companies. In order for these methods and tools to be used properly, a commitment from senior management is needed. This should include integration of sustainability aspects in business goals and appropriate resource allocation. A new strategic capability assessment approach is therefore also developed in this thesis, as well as guidance for how to systematically integrate sustainability in companies’ strategic decision systems.

In summary, the contributions of this thesis constitute support for prioritization of investments and technical optimization on the increasingly sustainability-driven market, thus providing a unique foundation for competitive sustainable product development. The wider contribution of all of this is to support societal transformation towards sustainability.

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Paper I

Environmental aspects in product development - An investigation among small and medium-sized enterprises

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Environmental aspects in product development - An investigation among small and medium-sized enterprises

Sophie H. Byggeth and Göran I. Broman

Abstract

Small- and Medium sized Enterprises (SMEs) represent a large part of industry. Environmental considerations during product development in SMEs therefore imply a large potential for reducing society's environmental impact. Implementing environmentally adapted product development among SMEs has been considered difficult and is uncommon. Our approach is to develop a qualitative Method for Sustainable Product Development (MSPD) that relates both to a framework for sustainability and to the ordinary product development process. The aim is to guide the user to avoid problems related to social and ecological non-sustainability without demanding extensive expertise knowledge. Two surveys in ten Swedish SMEs have been carried out. An initial survey registered their product development procedures and environmental work as well as desired characteristics of a new suggested method for integrating environmental aspects into the product development process. A second survey registered additional desired characteristics and improvement suggestions when testing an early version of our MSPD. The surveys and the structure of our MSPD are presented, and the desired characteristics for a workable method in SMEs, found in our investigation and in literature, are discussed.

Keywords: *Sustainable Product Development, Small- and Medium Sized Enterprises (SMEs), Ecodesign.*

1. Introduction

Traditionally many environmental problems caused by the industry have been addressed by end-of-pipe strategies. In the long run this often turns out to be costly and inefficient because it does mostly not provide “real” solutions to the problems. In recent decades focus has turned more towards avoiding problems before they arise, which has increased the efforts for identifying potential environmental impact from products already during product development. It is especially beneficial to make such efforts early in the product development process [1].

Because of increased environmental awareness among customers and tougher competition on the market environmental adaptation of products has become more and more important for companies [2, 3]. While many larger companies have started to take a more systematic approach to considering environmental aspects during product development, this is still unusual among Small and Medium sized Enterprises (SMEs). For example, educating employees in the environmental field as well as implementing an environmental management system is uncommon for SMEs compared to large companies [4].

About 99 percent of Swedish companies belong to the SME sector (up to 500 employees). These companies employ 51 percent of all employees in Sweden, and their turnover is 68 percent of the total turnover for Swedish companies. In Europe around 90 percent of all enterprises are SMEs and they contribute to about 70 percent of the environmental pollution [5]. From the above information there seems to be a large potential for improvements in integrating environmental considerations into product development among SMEs. A problem however has been that each individual SME has experienced its own business as small and insignificant for the total societal environmental impact. They have so far also experienced that no clear environmental requirements from the market and the government have existed [4]. It is not until the 1990s that a more pronounced pressure to improve environmental performances has been put also on SMEs [6].

Today there seems to be an interest also in many SMEs to introduce so called Eco-tools. Many Eco-tools are available, for example matrixes, checklists, guidelines etc., with the purpose of analysing and improving environmental performances of products, processes or whole design strategies. Several references are given in de Caluwe [7]. Most of the tools and methods of today are however not suited for SMEs. They are experienced as too complicated and time consuming [8]. This is probably because most such tools have been developed for larger companies.

In section 2 we describe our survey among ten SMEs, in which we registered their product development procedures and environmental work as well as desired characteristics of a new suggested method for integrating environmental aspects into the product development process. For the SMEs in our investigation the question today is not weather environmental aspects need to be considered, but rather *what* should be considered and *how*. There is a wish for a computer based method/tool that, during the ordinary product development process, helps them to find the potential risk for environmental problems related to their products.

In section 3 we describe the structure of an early version of our MSPD tested in the SMEs. It contrasts to previous tools and methods in that we emphasise a connection both to a product development model and to overall conditions for sustainability. It is intended to be structured in a hierarchical way, successively focusing on the "most relevant" questions until a decision can be made. In this way we think that many detailed questions, most likely to have only marginal influence on the decision, can be excluded from the investigation.

In section 4 we describe the results from an initial test of our MSPD among the SMEs. They found our strategy of first raising a few "most relevant" questions from a sustainability perspective, and with the possibility of successively going to higher levels of detail if necessary for a decision, as appealing. For a general background discussion on this strategy of simplicity without classical reductionism we refer to Broman et al [9].

In section 5 we discuss our results from the initial survey and test in relation to results from other investigators as well as ideas for improvements.

2. An Initial Survey among Ten Small and Medium Sized Enterprises

The group of companies we are co-operating with in developing our MSPD is a mix of Swedish SMEs with different products or services. In Table 1, the companies are divided into three size categories with respect to their number of employees. In this table we also present their main products/services and indicate which one of the following three business types they belong to: *mass production of physical products* (MP), *special ordered physical products/one piece production* (SP), or *special ordered services* (SS).

Table 1. *Size categories, main products/services, and business types for the ten SMEs in the study.*

Number of employees	Company	Main product or service	Business Type
< 50 (small)	A*	Design- and calculation services	SS
	B	Lighting fittings	MP
	C	Special ordered production machines	SP
	D*	Air conditioner systems	MP
	E	Design- and calculation services	SS
50-199 (medium small)	F*	Cable- and pipe insulation	MP
	G*	Laundry service and textile consultant	SS
	H	Special ordered welded products	SP
200-500 (medium large)	I*	Heat exchangers	MP
	J*	Exhaust systems	MP

* The company has recently been included as a part of a large company but still consider itself as a SME.

Company A and E are design and calculation consultants. Their main business type is therefore special ordered services. However, these services often means participation in development of physical products on the behalf of their customers, sometimes for only a part of the development process and sometimes for a whole development process with a complete responsibility. How environmental aspects are considered and responsibility shared in this interaction between the consulting company and the producing company we consider of special interest for coming studies.

According to the Swedish Central Bureau of Statistics [10] 97 percent of all Swedish enterprises are *small* (1-49 employees), 2 percent are *medium small* (50-199) and 0.4 percent are *medium large* (200-500). The number of large companies is very small, although they employ many people. Among employees in Swedish companies 30 percent work in *small* companies, 12 percent in *medium small* companies, 9 percent in *medium large* companies, and 49 percent in *larger* companies. Of the total turnover for Swedish companies the percentages are 41, 16, 11, 32, for *small*, *medium small*, *medium large*, and *larger* companies, respectively. The profile of our SME-group does not match the national profile in that the proportion of the *small* enterprises is under-represented and the *medium small* and *medium large* companies are over-represented. The mismatch is much because we excluded companies that do not work with product development enough to be interesting for our investigation. Such companies often have only one or a few employees and represent a large fraction of the national *small* category.

Before introducing our ideas for a MSPD to the companies we studied if, and in that case how, they already worked with product development models and environmental issues. We wanted to know if the companies had a structured and documented product development procedure. If not, we asked for an oral description of how their product development is performed. We wanted to know what Eco-design tools the companies used, or have heard of, and what they think of them. We wanted to know how they experience environmental requirements from the market and legislation, what technical and environmental competence their product developers have, etc. We also wanted to know if they thought there is a need for a (new) method for sustainable product development, and in that case what desires they have for the characteristics of such a method. Written questions were followed up with interviews and visits at the ten companies. The main findings from this initial survey are described and discussed below.

2.1 Integrated Product Development in the SMEs

None of the *small* and only one of the *medium small* companies had their product development process documented. However, most of the companies had a fairly structured procedure for product development anyway, which is maintained within the company by tradition (the behavior has grown into the walls). The *medium large* companies and one of the *medium small* companies had a documented plan for their product development process. In most of the companies (8/10) people from different competence fields or responsibility areas, for example market, production, quality, manufacturing, design etc, are working together in a team. In the *small* companies one person often has more than one area of responsibility. There is a strive for parallel activities, so even for the *small* companies we could discern so called integrated product development or concurrent engineering, although not complete, not documented, or not originating from a theoretical insight.

The product development procedures described by the companies were compared to a theoretical model for integrated product development [11], see figure 1.

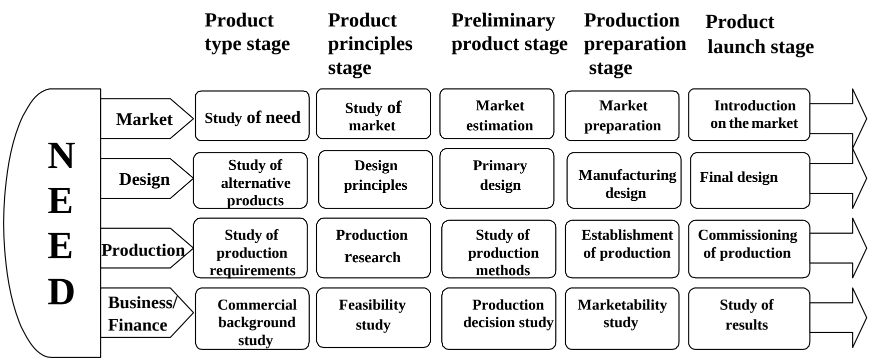

Figure 1. *Integrated product development model. Reproduced from Olsson* [11].

This model covers most aspects of our SMEs' product development activities. However, the survey confirmed our thoughts that in practise the phases are not as distinctly divided as they appear to be in the theoretical model and the parallel activities or responsibility areas are not always the ones given in the model. Both of these aspects are especially clear for the companies that have no documented procedures. For the companies that have documented procedures the product development phases are not exactly the same as in this particular theoretical model, but similar. In the latter companies formal and predefined meetings, where specified decisions are to be taken and various checklists filled in, mark the transition between phases. However, all companies, including those that have documented procedures, agreed also to our thoughts that in the mind of a product developer, the attention is not entirely within a specific phase and responsibility area at the time. Rather, as schematically illustrated in figure 2, the main focus may well be in the present phase and the given responsibility area, but flashes of thoughts are all the time going both backwards and forwards in the process and between different responsibility areas, as well as to experience from prior projects. An experienced product developer is so to say more or less thinking of everything at the same time.

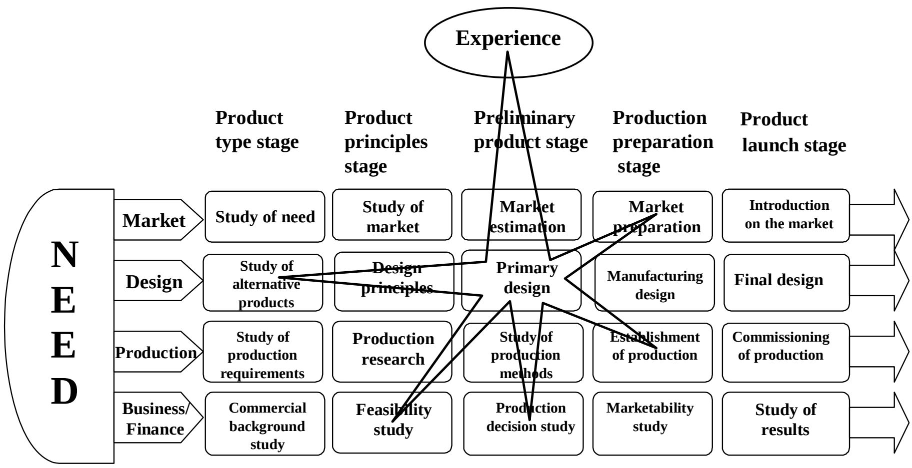

Figure 2. *Main focus of attention within one product development phase and given responsibility area. Flashes of thoughts to other phases and responsibility areas.*

2.2 Environmental Consciousness and Interest of a MSPD

The main reasons stated by the majority of our SMEs for working with environmentally adapted product development is demands from professional customers (larger companies) and the related risks of loosing market shares to competitors if they do not comply with these demands, and a general responsibility to contribute to sustainable development. Only one of the *small* companies in our investigation stated that it has not yet experienced any environmental demands on its products. This is the smallest company in our group (15 employees) and it has one piece production. The conclusion is otherwise that the question today is not weather environmental aspects need to be considered in product development in our SMEs, but rather what should be considered and how.

No systematic approach is used today among our SMEs to analyse their products life cycle or to minimise the environmental impact from their products. A few companies had heard of some tools or methods but they had not used them in practise. They expressed an interest in a method/tool that, during the ordinary product development process, could help them find potential risks for environmental problems related to their products. The method/tool should be possible to use without too much of detailed expertise knowledge. The method/tool should preferably be computerised as the companies are used to other computerised tools (CAD) when designing products. The result from using the method/tool should be possible to readily communicate to sub-contractors and customers, but not necessarily as a quantitative measure (a number). Another important characteristic is that the method/tool should be inexpensive, both to buy and to update.

The SMEs found our ideas for a method capable of first raising a few “most relevant” questions from a sustainability perspective, and with the possibility of successively going to higher levels of detail if necessary for a decision, as appealing. They expressed a great interest in participating in the development of such a method/tool. They were willing to contribute with their experience and to test and evaluate prototypes of the method/tool.

3. MSPD – A Method for Sustainable Product Development

We are developing a MSPD in co-operation with the ten SMEs, with the Department of Physical Resource Theory at Chalmers University of Technology, Gothenburg, Sweden, and with The Natural Step Foundation, Stockholm, Sweden. The main structure of the method is shown in figure 3. MSPD is a qualitative method that connects environmental aspects both to the "ordinary" product development process and to overall conditions for sustainability. It consists of three parts: an Integrated Product Development Model (IPDM) containing checklists with specific questions for each product development phase, a strategic planning process based on backcasting (ABCD-analysis), and a matrix containing hierarchically ordered and guiding questions. This Sustainability Product Analysis (SPA) matrix has conditions for sustainability along one axis and the life cycle of the product along the other axis.

Considering the results from our initial survey among the SMEs we choose not to specify in advance the parallel activities or responsibility areas in the IPDM. The integrated product development group is formed in each case to fit the company's special needs. Otherwise our IPDM is similar to the one in figure 1.

The steps in the planning process (ABCD-analysis) are:

A. Discussing conditions for sustainability and backcasting, that is, discussing the ABCD-analysis as a relevant framework for sustainability and sustainable development. This is repeated when new members enter the project group.
B. Discussing how the company relates to the conditions for sustainability in today's situation.
C. Creating a vision of how the company fulfils its customers' needs in the future when society is sustainable.
D. Specifying a program of actions that will take the company from today's situation to the future vision.

For a further discussion we refer to for example Holmberg [12] and Broman et al [9].

The conditions for sustainability suggested in our MSPD is stated below without further comments. For a background and discussion we refer to for example Robèrt [13], Holmberg [14], Holmberg et al [15] and Broman et al [9].

In the sustainable society, nature is not subject to systematically increasing…
1…concentrations of substances extracted from the Earth's crust.
2…concentrations of substances produced by society.
3…degradation by physical means.

And, in that society . . .
4…human needs are met worldwide.

The questions in the SPA-matrix originate from these system conditions and cover the product life cycle phases shown in figure 4. The aim is to identify substances and activities that have the potential risk of contributing to society's violation of the system conditions for sustainability. The result from answering the SPA-questions becomes a guide for solutions to the potential problems. The SPA-matrix is used in the ABCD-analysis, which in turn is used in the IPDM. Integrating the parts in this way and relating to overall conditions for sustainability is unique compared to other tools and methods we know of for design for the environment. In this way environmental aspects are included naturally in the "ordinary" product development process and the investigation starts at a basic level with a sustainability perspective. The method is meant to be general enough to be suitable for different types of companies. The method is also meant to be used for a whole product development process, but also for parts of the process. Being useful in only parts of the process without loosing perspective is especially important for consulting companies. For a further description of the method we refer to Byggeth et al [16].

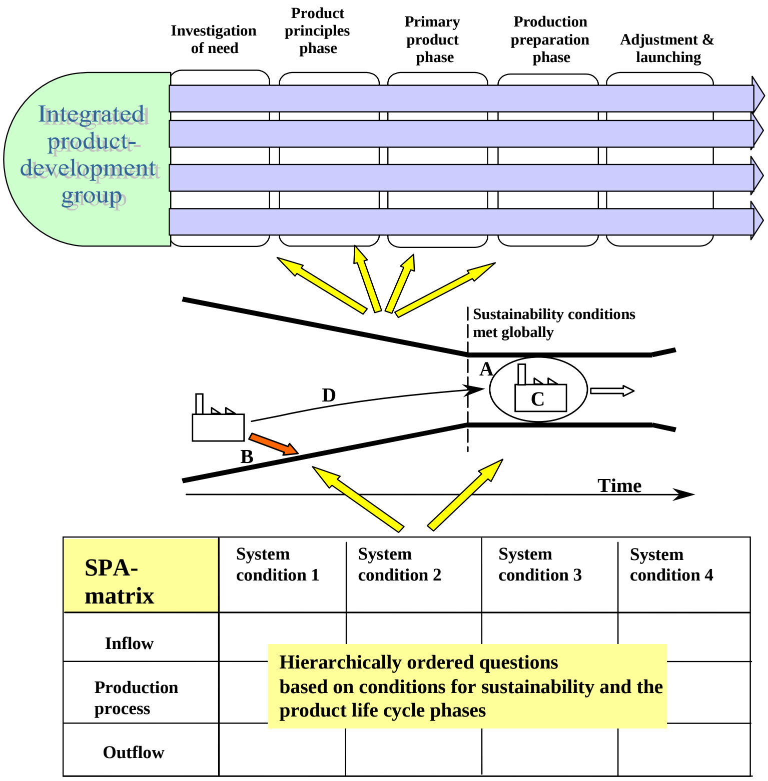

Figure 3. *MSPD and its three parts: an integrated product development model, a strategic planning process for sustainable development, and a sustainability product analysis matrix.*

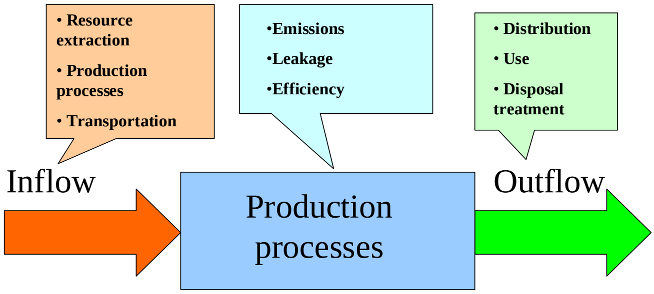

Figure 4. *Life cycle phases covered in the SPA-matrix.*

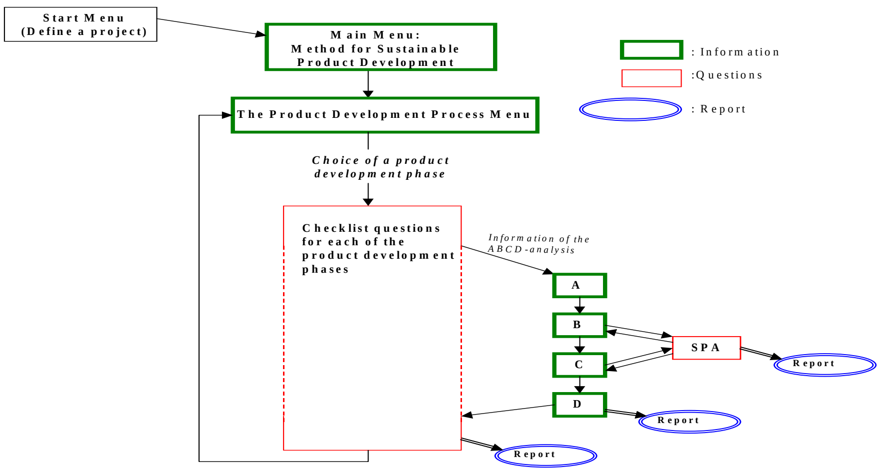

Figure 5. *Schematic description of the computerised MSPD.*

The present computerised version of our MSPD, schematically shown in figure 5, consists of a description of the method, menus, and instructions for the user, as well as questions and information. More details of the computerised version will be described in coming publications.

4. Results from Testing an Early Version of MSPD

The first prototype of our MSPD was tested in company A, B, F, G, H and J. No company tested the whole MSPD. The main reason for this was to keep down the workload for the companies, as this prototype was sometimes hard to work with. Another reason was that during the relatively short time of the test the companies only passed one or two development phases, and yet another reason was to see if the method could actually be used in only parts of the product development process. The companies tested the prototype first on their own and later with the support from a researcher.

4. 1The Structure of MSPD and its Organisation

The companies liked the overall structure of our MSPD (figure 3). In order to be used at all, the companies thought that any environmental tool must be a natural part of the ordinary development process. Our MSPD was considered to fulfil this characteristic in a good way.

The test confirmed that persons with different competence fields are working together in project teams. The teams were different in size and included different competence fields dependent on the business type, the size of the company, and the project at hand. It ranged from two persons to 10 persons. Having a flexible group in our IPDM, not specifying in advance the parallel activities or responsibility areas, was appreciated.

The ABCD-analysis, with its system conditions and backcasting methodology, was considered to give a good base for structured discussions on sustainability and sustainable development within the companies. They thought that the method was useful also for parts of the product development process, since this sustainability perspective is held throughout the method.

Hierarchical questions from the SPA-matrix were thought to have a good potential of keeping the workload within reason for including environmental aspects in product development in SMEs. However, clarification of this hierarchical structure and simplification of the questions were desired. Furthermore, the result from the SPA-analysis should be less voluminous and less complicated to interpret. It should be possible to more easily communicate to sub-contractors and customers for an improved discussion.

An important question is how to efficiently organise the use of MSPD among the team members. Integrating the method in a Product Data Management (PDM) system was considered as an interesting idea. This could increase effectiveness since many persons could then use MSPD at the same time and rights could be set for manipulation of shared data. To use MSPD in a PDM system a web-version of the method was desired. To have the method available on the Internet was preferred by the smallest companies, not having or planing for a PDM system. However, the question of data security must then be especially considered.

4.2 User Friendliness and Initial Assistance

A better transparency of the computerised method was desired, by for example an orientation frame in a part of the screen that indicate in what development phase and in what step in the ABCD-analysis the user is presently working. Better possibilities to move between the different parts of the MSPD were also desired.

Many of the users experienced the language as a problem as the text was written in English and not in their mother language (Swedish). However, the *medium large* companies found it important to have also an English version of the MSPD, as their international company language is English.

Initial assistance for how to use the MSPD was found necessary. An introductory education on sustainability and sustainable development when the method is first introduced in the company was also considered important for a successful implementation.

Better support for the D-step in the ABCD-analysis was desired.

4.3 From General to more Company Specific IPDM-questions

The phase specific questions in the IPDM for the different product development phases, which do not directly concern environmental issues, were considered interesting. There was a desire that these questions should be developed further, with more information linked to them. Also a connection to other tools, such as quality assurance tools and working environment restrictions, was asked for. Instead of a general set of such questions the companies found it interesting to be able to form more company specific questions in the IPDM.

4. 4 A Material Database

To choose materials for the products was considered as one of the hardest decisions. A need for a guide to find “dangerous” substances, to choose the “best” substances for the environment, and to become aware of the choices, was declared.

As a product often contains several materials and that each material may in itself be complicated to analyse, for example composite materials and alloys, it represents a large effort for the company. On the other hand, once such an investigation has been performed for a material often used by the company, the result should be possible to re-use without too much of extra work. A company database in which such results could be stored and linked to the MSPD was therefore desired.

5. Discussion

In our initial survey we found that there is a general interest among the SMEs in taking environmental impact into consideration. The driving forces are competition between companies, customer demands and their own responsibility to contribute to sustainable development. Similar results can be found elsewhere in the literature [6, 3].

Most companies had a fairly structured procedure for product development, which is maintained within the company by tradition if not documented, and they work in integrated development teams. The overall structure of their product development processes agrees well between the companies as well as to a theoretical integrated product development model. On a more detailed level however, differences between the procedures in the companies and the theoretical model are noticed, for example how the process is divided into phases and what checklist questions that are used in the different phases. This depends on for example the business type and the company size. That the way of manage product development depends on contextual factors has been stated also by others [17]. A general theoretical integrated product development model might not be suitable for all types of companies. Developing a module system with possibility to integrate the company's own phase specific questions and checklists will therefore be investigated further.

Many investigators have identified the need for support tools for integrating environmental aspects into product development [3, 18]. Existing support tools, mostly based on Life Cycle Assessment (LCA), have however not attracted any of the SMEs in our study. Such tools are often experienced as too complicated and time consuming by SMEs [8]. The companies found the strategy in our MSPD of first raising a few "most relevant" questions from a sustainability perspective, and with the possibility of successively going to higher levels of detail if necessary for a decision, as appealing. They had not seen this approach in other tools or environmental management systems. Improvements on this hierarchical structure as well as simplifications of the questions were however desired and will be focused on in the coming work. To facilitate further testing in the SMEs a Swedish version will also be developed.

The companies in our study stated that any environmental tool must be a natural part of the ordinary product development process, if it is to be used at all. Our MSPD was considered to fulfil this characteristic. Desired characteristics are also that the method/tool should be possible to use without too much of detailed expertise knowledge, it should be computerised and easy to handle, the results should be clear and possible to communicate, and it should be inexpensive to buy and to update. Our MSPD was thought to have the potential of fulfilling these desires but the present version needs improvements. Many of the desired characteristics that emerged in our study are general and applicable to other support tools for product development, and they agree with the findings of other investigators [19, 20]. Other common factors stated in the literature for a successful tool are that it should support collaboration, promote individual learning, highlight problems, and have a measurable effect on the results of the project work [3]. Furthermore, management commitment and support together with personnel education and training as well as to have an enthusiastic person inspiring the organisation to consider environmental issues have been identified as success factors for how Eco-design should be integrated into the product development process [21]. The SMEs in our study agreed that the above factors are important. Initial assistance for how to use the MSPD was found necessary and an introductory education on sustainability and sustainable development when the method is first introduced in a company was recommended. Not the least to engage management.

Integrating our MSPD in a Product Data Management (PDM) system was considered as an interesting idea. This could increase effectiveness since many persons could then use MSPD at the same time and rights could be set for manipulation of shared data. To use MSPD in a PDM system a web-version of the method was desired. A web-version of the method has been developed and how this can be included in a PDM system will be studied in coming work. To have the method available on the Internet was preferred by the smallest companies, not having or planing for a PDM system. This opportunity will be considered and the related question of data security studied.

Many materials and substances are used by a company and involved in its products. How to analyse these materials and substances and to what level of detail when using our MSPD was a problem at the companies. The method was not thought to give a good enough guide for this. A need for better guidance to find the “dangerous” substances, to choose the "best" substances for the environment and to become aware of the choices, was declared. If a company material database can be integrated into our MSPD to solve this problem, and in that case how, will be considered in coming work.

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Paper II

Handling trade-offs in Ecodesign tools for sustainable product development and procurement

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Handling trade-offs in Ecodesign tools for sustainable product development and procurement

Sophie Byggeth and Elisabeth Hochschorner

Abstract

Trade-off situations often occur in the product development and procurement processes when alternative solutions emphasize different aspects that have to be balanced against each other. Ecodesign tools can be used in both product development and purchasing, for example to prescribe design alternatives, assess environmental impacts or to compare environmental improvement alternatives. However, it is not always clear what should be chosen in trade-off situations. In this study, 15 different Ecodesign tools were analyzed to ascertain whether a valuation is included in the tools, in what way the tools give support in different types of trade-off situations and whether the tools give support from a sustainability perspective.

Nine of the 15 tools analyzed included a valuation and were able to give support in a trade-off situation, but the support was not sufficient. The valuation should include a lifecycle perspective and a framework for sustainability. Otherwise it can lead to strategically incorrect decisions from a sustainability perspective with concomitant risks of sub-optimized investment paths and blind alleys. However, all the analyzed tools can be complemented with other tools and methods based on strategic planning towards sustainability in order to include a framework for sustainability.

Keywords: *Ecodesign tools, trade-off, product development, purchasing, procurement, sustainability, sustainable development*

1. Introduction

In the product development and procurement processes, there are many elements to consider and frequently, trade-offs are necessary when choices have to be made between different alternatives. The product developer and the purchaser need to consider different criteria for each product or product concept, for example, price, quality, product life-span, materials, maintenance and the environmental performance characteristics, in order to take a decision. This often leads to trade-off situations, meaning compromise situations when a sacrifice is made in one area to obtain benefits in another. It is usually impossible to optimize them, all at once. For example in the case of a car, reducing material in the product might decrease safety for the passengers while at the same time increase the fuel-efficiency.

In Ecodesign, the trade-off can be a conflict between environmental targets. Improving a concept in one environmental area can give negative effects in another area. Some examples of different trade-off situations are presented below:

- *Material and material;* One material can be exchanged for another in a product and the trade-off can be between small amounts of a toxic material and more weight of a less toxic material.
- *Material and energy;* In electric power transmission, resistance in the cable causes losses which require utilization of more material in the cables in order to save electrical energy. Another example is insulation of houses, where relatively more insulation materials help to save energy in wintertime.
- *Material and cost;* One material can be exchanged for another in a product and the trade-off can be between lower performance of a cheaper material and higher performance of a more expensive material.

It is difficult to foresee potential winners or losers in trade-off situations. There may be different outcomes depending on different perspectives, e.g. the customers´, the companies´ or the environment. It is unlikely that a company will make a choice that is not primarily economically driven. Furthermore, it is of crucial importance that new products meet market requirements. Therefore, there is a risk that the environment will not be the highest priority in some trade-off situations.

However, in the longer term, and depending on factors such as image and political decisions, it is possible to bridge the gaps between different perspectives. In many cases when environmental aspects are integrated in product development, it leads to synergies with other business interests, like image improvement, new market opportunities and sometimes cost reductions, even in the short term [1]. If the synergy effect of some product criterion is identified and can be decided upon early in the product development process, it may be possible to improve the function of the product at the same time as reducing the environmental impacts [2]. In that way, it might also be possible to find, win-win-win situations for the company, the customer and for the environment.

To integrate environmental aspects into the product development processes, support tools are needed [3]. There are many so-called Ecodesign tools intended to facilitate an integration of environmental aspects into the product development process. Different types of Ecodesign tools can highlight potential environmental problems and facilitate a choice regarding different environmental aspects. In this article, the potential support with respect to valuation and sustainability from different types of Ecodesign tools is reviewed in three different trade-off situations. The authors selected 15 Ecodesign tools that are well documented and intended to be simple to use. All have been developed by different researchers and are described in previously published papers, reports and books. The choice of tools was based on a number of factors such as the level of documentation, their use in Sweden and the interests of the authors. These tools represent only a small proportion of all available Ecodesign tools.

1.1 Trade-offs in the Procurement Process

Environmentally preferable procurement has been steadily increasing in recent years, both in public and private organisations. This applies both to the “producers” of products and services as well as their customers (purchasers). Common reasons for public organisations to consider the environmental impacts of their products are mandates or regulations. For private organisations, long-term cost savings or other benefits, both directly (e.g. reduced costs over the life of purchased goods) and indirectly (e.g. goodwill among stakeholders or customers) are common reasons to purchase environmentally preferable products [4].

When deciding on environmental requirements for the product, trade-off situations can arise. Possible trade-offs can occur when the purchaser has to decide which environmental aspects are most important, e.g. recycled content, energy efficiency, water consumption or air pollution control [4], and how environmental requirements should be related to other requirements, e.g. legislation, quality and economy. One of the major difficulties with environmentally preferable purchasing is the lack of available and reliable information about the environmental characteristics of products and services.

1.2. Trade-offs in the Product Development Process

Trade-off situations in the product development process are often about choices among multiple factors that need to be weighed against each other in order to make a decision. During the design process, the design freedom decreases in relation to the product development process and time. It becomes increasingly costly and technically difficult to make changes in the later stages and this should be avoided [5]. Therefore, it is important that the product developer is aware, early in the product planning and development phase, of the different alternatives and the consequences of the choice in all trade-off situations.

It is impossible to say, in advance, when and which trade-off situations will occur in the product development process, as it is a complex and interactive process with different aspects to be considered. The question is, rather, how the product developer makes the choice and how the trade-offs can be identified and avoided. How can criteria with synergy effects and criteria with offsetting benefits be identified? When they are identified, is it possible to rank them in order of priority to facilitate decisions for or against certain alternative solutions?

In the early product development process there are examples of trade-off situations when deciding on the product requirement list. Functional requirements and costs usually have the largest influence and set the limits on other elements such as shape, material and production methods. The most important element largely, sets the framework for the other elements. Therefore, they should be integrated in order to reach the optimal solution [6].

Later in the product development process, the project team may have to choose between developing their own individual product details and buying components already developed and available on the market. Developing a new component may be optimized for the particular product, but takes time to develop and may therefore, be a more costly alternative. On the other hand, a product component that already exists on the market means an already tested product part with a documented mode of action and quality, but may not necessarily optimized for the particular product being developed.

Choice of materials for products is considered to be a hard decision for a product developer. A product may be composed of several materials and each material may, in itself, be complicated to analyze, for example composite materials and alloys. Trying to foresee future environmental problems of materials is difficult but of crucial importance in making strategic choices towards sustainability.

2. Method

Fifteen Ecodesign tools were analyzed in three steps (I-III), described below.

2.1 Step I: Is a valuation included in the tool?

In order to support a trade-off decision, our opinion is that a valuation has to be included in the tool. We use the term valuation in a broad sense to mean: implicit rating of the importance of ‘criteria’ or ‘strategies’ within each tool. By ‘criteria’, we are referring to such things as ’toxicity’, ‘air pollution’, etc. By ‘strategies’, we are referring to such things as ‘use raw materials that are locally or regionally available’, ‘select low emission production process’, etc. We do not mean that a specific valuation method is used in the tools. The results from the analyses are presented in Table 2.
Only tools including valuation were further analysed in steps II and III.

2.2 Step II: In what way does the tool provide support in different types of trade-off situations?

There are many types of trade-off situations and combinations of different and important elements, e.g. functions, costs, materials, service, market aspects and social aspects. In this study we concentrated on three different situations where Ecodesign tools can be useful. The definition of ‘environmental’ aspect in ISO 14040 [7] was used.

Guidance in the following three areas was studied:

1. *Within one environmental aspect.* For example, in what way(s) does the tool give guidance for a choice between different materials? Between different energy sources?
2. *Between different environmental aspects.* For example, in what way(s) does the tool give guidance for a choice between strategies that affect different environmental impacts, e.g. energy use and level of toxicity?
3. *Between environmental aspects and other criteria.* For example, in what way(s) does the tool give guidance between strategies that influence the environment and other aspects differently, e.g. material use in relation to costs?

We also studied whether the criteria in the tool are weighted. By weighting we mean that the criteria are evaluated on the same scale and therefore can be compared with each other, even if this might not be the tool's primary purpose.

2.3 Step III: Does the tool give support from a sustainability perspective?

Generally it is important to get an overview of the situation when making decisions in complex systems and this demands an understanding of how different things are connected. In order to have a consistent system for evaluation we used the System Level model as described and discussed in Robèrt et al. [8] and Robèrt [9]. This generic "Five Level Hierarchy" (described briefly below) emphasizes the need to inform the planning from an imaginary point in the future that complies with basic principles of social and ecological sustainability, and then 'Backcasting' from that. (For descriptions of Backcasting, see for example Dreborg [10,11]) This means defining the gap to sustainability and investigating various investment routes to fill that gap.

The Ecodesign tools that included a valuation were analyzed and related to the System Level model to ascertain how they might contribute to strategic progress towards sustainability [8]. To have a sustainability perspective, all five levels should be considered in the tools, according to the System Level.

2.4 The System Level Model

2.4.1. System level

The system level is a description of the overarching system in which we are planning and solving problems. In this case: the human society with the surrounding ecosystems.

2.4.2. Success level

The success level describes the overall principles that are fulfilled in the system when the goal is reached, in this case social and ecological sustainability. (Economy is dealt with below under the Strategy level). It is only when the goal is defined that it is possible to be strategic. A generic definition of social and ecological sustainability should rely on basic, complementary principles that allow the tackling of problems upstream in cause-effect chains that are concrete enough to guide thinking and asking of relevant questions. Four Socio-ecological principles (System Conditions) were designed for this purpose and were used in this study (for references, see [12], [13] and [14]):

In a sustainable society, nature is not subjected to systematic increases in:

1. Concentrations of substances extracted from the Earth's crust;
2. Concentrations of substances produced by society;
3. Degradation by physical means and,
4. In such a society people are not subjected to conditions that systematically undermine their capacity to meet their needs.

2.4.3. Strategy level

This level describes the strategic guidelines for planning towards the goal in the system (Success level). The overriding strategic guideline is to launch investments step-by-step that (a) are possible to further develop in line with the basic principles of sustainability while (b) being sound from an economic perspective so that the process does not come to an end due to lack of economic resources.

2.4.4. Action level

In the optimal situation, the actions are informed by the strategy level to achieve the goal (the success level) in the system (system level). Example, turning to more resource-efficient engines, which will make it more economically sound to change to renewable energy sources.

2.4.5. Tools level

The tool's level describes the tools used to measure, manage and monitor the (Action level) activities so that those are chosen in a (Strategy level) strategic way to arrive at a (Success level) success in the (System level) system. Example: Ecodesign tools, Environmental Management tools.

2.5 Presentation of the Tools

There are tools intended for analysis of environmental impacts; selecting potential environmental improvements; providing assistance for design and brainstorming; and evaluating environmental aspects with other important criteria. Examples of tools can be found in the reviews made by de Caluwe [15], van Weenen [16] and Tischner et al. [17].

We made a selection of 15 different types of Ecodesign tools i.e. matrices, spider webs, checklists, guidelines, cost accounting tools and comparing tools that have been presented by different researchers. These have been developed for different purposes, i.e. assessment of environmental impacts, identification of environmental critical aspects, comparison of environmental design strategies, comparison of product solutions and prescription of improvement strategies. These tools are all intended to be simple to use, do not require comprehensive quantitative data and are not too time-demanding (at most a few days to use the method). However, some environmental knowledge is required in order to monitor relevant data for the tool as well as understanding the answer that comes out. Each tool is briefly presented in Table 1.

In the presentation of the tools, we describe: the purpose of the tool; whether or not a life cycle perspective is considered; whether the approach is qualitative or quantitative, and if the tool includes general or concrete prescriptions for which environmental aspects should be considered. By 'life cycle perspective,' we mean the product life cycle from extraction of raw materials to recycling and management of the used product. No detailed analyses of the respective life cycle perspectives were made in this study. The tools are structured regarding their main characteristics in the three groups: ‘analysis’, ‘comparing’ and ‘prescribing’.

Table 1. *Fifteen Ecodesign tools described and assessed on the basis of the purpose of the tool, whether a life cycle perspective is considered, whether the approach is qualitative or quantitative and if the tool includes general or concrete prescriptions on which environmental aspects to consider.*

Tools	Presentation
Analysis tools	
ABC-Analysis (Tischner et al. [17] based on Lehmann [18])	*Purpose:* This tool can be used for assessment of environmental impacts of a product. The product is evaluated on eleven different criteria and classified in one of the following grades; A= problematic, action required, B= medium, to be observed and improved, C= harmless, no action required. *Life cycle perspective:* yes *Qualitative or quantitative approach:* qualitative *General or concrete prescriptions:* concrete
The Environmentally Responsible Product Assessment Matrix (Here called ERPA) (Graedel and Allenby [19])	*Purpose:* The matrix is used to estimate a product’s potential for improvements in environmental performance. Each life cycle stage (pre-manufacturing, product manufacture, product delivery, product use, refurbishment/recycling /disposal) is evaluated on five criteria (material choice, energy use, solid residues, liquid residues, gaseous residues). The environmental impact for each of the life cycle stages is estimated by grading each criterion from 0 (highest impact) to 4 (lowest impact). Checklists are developed to grade the criteria. *Life cycle perspective:* yes *Qualitative or quantitative approach:* The tool generates a quantitative result (from 0-100). But, no quantitative data are needed to perform the grading. *General or concrete prescriptions:* concrete

Table 1 (continued)

Tools	Presentation
MECO (Wenzel et al. [20], Pommer et al. [21])	*Purpose:* An estimation of the environmental impact for each life cycle stage (material supply, manufacture, use, disposal and transport) is made by estimations and calculations of the amounts of materials, energy and chemicals. Materials and energy are calculated as consumption of resources. Environmental impacts that do not fit into the other categories should be included in the category 'Other'. *Life cycle perspective:* yes *Qualitative or quantitative approach:* Quantitative data are needed to perform the assessment. Some parts of the results are qualitative and some parts are quantitative. *General or concrete prescriptions:* concrete
MET-matrix (Brezet and van Hemel [22])	*Purpose:* The purpose of the tool is to find the most important environmental problems during the life cycle of a product, which can be used to define different strategies for improvement. The environmental problems should be classified into the categories Material cycle (M), Energy use (E), Toxic emissions (T). *Life cycle perspective:* yes *Qualitative or quantitative approach:* The results and data can be both qualitative and quantitative. *General or concrete prescriptions:* general
Comparing tools	
Philips Fast Five Awareness (Meinders [23])	*Purpose:* The tool is used to judge and compare different product concepts towards a reference product. Five criteria are chosen; energy, recyclability, hazardous waste content, durability/reparability/preciousness, alternative ways to provide service. *Life cycle perspective:* yes *Qualitative or quantitative approach:* qualitative *General or concrete prescriptions:* concrete

Table 1 (continued)

Tools	Presentation
Funktionkosten (Schmidt-Bleek [24])	*Purpose:* The Funktionkosten tool identifies cost-effective product alternatives to be developed or can be used as an estimation of cost changes as a result of an implementation of an ecological design principle. General product functions are described and for each function a cost is calculated for each alternative solution. *Life cycle perspective:* no *Qualitative or quantitative approach:* quantitative *General or concrete prescriptions:* general
Dominance Matrix or Paired Comparison (Tischner et al. [17])	*Purpose:* The purpose of the tool is to set up a ranking of competing criteria or solutions, e.g. competing demands on a product or competing ecological requirements, by doing a systematic comparison between the different alternatives. Each individual alternative is compared qualitatively with all other alternatives. *Life cycle perspective:* no *Qualitative or quantitative approach:* qualitative *General or concrete prescriptions:* general
EcoDesign Checklist (Tischner et al. [17])	*Purpose:* The checklist helps to identify the main environmental problems along a product's life cycle. The user has to evaluate whether the solutions in the checklist are good, indifferent, bad or irrelevant. *Life cycle perspective:* yes *Qualitative or quantitative approach:* qualitative *General or concrete prescriptions:* concrete
Econcept Spiderweb (Tischner et al. [17])	*Purpose:* Econcept Spiderweb can be used for an estimation to decide between design alternatives. The user defines an appropriate set of criteria to be used for the estimation. For each solution a qualitative evaluation of the criteria is made and gives an environmental profile for each solution. *Life cycle perspective:* no *Qualitative or quantitative approach:* qualitative *General or concrete prescriptions:* general

Table 1 (continued)

Tools	Presentation
Environmental Objectives Deployment (EOD) (Karlsson [25])	*Purpose:* The purpose of the tool is to present the relationships between the `product's technical description´ (e.g. material, reparability, energy efficient) and the `environmental considerations´ (material usage, reduce weight, use recyclable materials). The environmental considerations are weighted and this is specified by the user. *Life cycle perspective:* no *Qualitative or quantitative approach:* qualitative *General or concrete prescriptions:* general
LiDS-wheel (Brezet and van Hemel [22])	*Purpose:* A tool to give an overview of environmental improvement potential to the designer. Eight environmental improvement strategies are utilized in the tool; selection of low-impact materials, reduction of material usage, optimisation of production techniques, optimisation of distribution system, reduction of impact during use, optimisation of initial lifetime, optimisation of end-of-life system and new concept development. Data from a reference product are entered into the diagram and according to the eight strategies; improvement options for the product should be identified. *Life cycle perspective:* yes *Qualitative or quantitative approach:* qualitative *General or concrete prescriptions:* concrete
The Morphological Box (Brezet and van Hemel [22])	*Purpose:* This is not considered to be a typical Ecodesign tool but can be useful in finding creative solutions. The existing solution is broken down into elements, e.g. product parts. For each element different proposals are described. Then alternative solutions for the product are created by combining the proposals for each element. *Life cycle perspective:* no *Qualitative or quantitative approach:* qualitative *General or concrete prescriptions:* general

Table 1 (continued)

Tools	Presentation
Prescribing tools	
Strategy List (Tischner et al. [17])	*Purpose:* The tool can be used to improve the environmental performance of a product concept or to compare different product concepts. The tool consists of a list of suggestions for each life cycle phase (product manufacture, product use, product recycling, product disposal, distribution) to improve the environmental performance. The suggestions are based on the criteria: optimise material input, optimise energy use, reduce amount of land use, increase service potential, reduce pollutants, reduce waste, reduce emissions, reduce health and environmental risks. *Life cycle perspective:* yes *Qualitative or quantitative approach:* qualitative General or concrete prescriptions: concrete
10 Golden Rules (Luttropp and Karlsson [26])	*Purpose:* The 10 Golden Rules is a summary of many guidelines that can be found in company guidelines and in handbooks of different origins. Before it can be used as a tool in a company, it should be transformed and customized to the particular company and its products. The tool can then be used to improve the environmental performance of a product concept or to compare different product concepts. *Life cycle perspective:* no *Qualitative or quantitative approach:* qualitative *General or concrete prescriptions:* concrete
Volvo' s Black List Volvo' s Grey List Volvo's White List (Nordkil [27-29])	*Purpose:* The purpose is to list chemical substances which must not be used (black list), should be limited in use (grey list) in Volvo's production processes, or chemical substances which may be critical from a health and environmental point of view (white list). The white list also suggests alternatives which, according to experiences and assessments made at Volvo, are potentially less hazardous. *Life cycle perspective:* no *Qualitative or quantitative approach:* qualitative *General or concrete prescriptions:* concrete

The tools described in Table 1 may be used in different phases in the product development or procurement processes. Some tools, e.g. checklists for choosing chemicals (Volvo's Lists) are useful, early in the design process. Tools that are used for comparing different alternatives (e.g. Philips Fast Five Awareness, Econcept Spiderweb) are intended for later stages of the design process, when there are different product concepts to be compared. Other tools can be useful in several phases of the product development or procurement processes, for example tools to compare alternatives (e.g. Environmental Objectives Deployment (EOD), Funktionkosten) or tools to identify environmentally critical aspects of products (e.g. the MECO Method).

3. Results from the Analysis

The studied tools differ in several ways: they have been developed for different purposes and they are structured in different ways. Some of the tools can be complemented with other tools, for example checklists, which make them more applicable for guidance (e.g. the MET Matrix and the Environmentally Responsible Product Assessment Matrix (ERPA)).

From the 15 tools studied, there were eight tools (ABC-Analysis, ERPA, MECO, MET-matrix, Philips Fast Five Awareness, Ecodesign Checklist, LiDS-wheel, and Strategy List) that had a lifecycle perspective, which gives an overall picture of the environmental impact from the product's lifecycle phases.

The results from the tools can be qualitative (ABC-Analysis, Philips Fast Five Awareness, Dominance Matrix or Paired Comparison, Ecodesign Checklist, Econcept Spiderweb, EOD, LiDS-Wheel and the Morphological Box), quantitative (ERPA and Funktionkosten) or both (MECO, MET-Matrix and EOD in the case when weighting factors are used to calculate improvement potentials). The prescribing tools (Strategy List, 10 Golden Rules, Volvo´s White, Grey and Black Lists) all have a qualitative approach.

Nine tools (ABC-Analysis, ERPA, MECO, Philips Fast Five Awareness, Ecodesign Checklist, LiDS-wheel, Strategy List, 10 Golden Rules and Volvo's White, Grey and Black Lists) included concrete (detailed and informative) prescription of environmental aspects. In tools that include general prescriptions on which environmental aspects to consider, the environmental aspects are not given in the tool in any detail but must be decided by the user.

The results from the analysis of valuation in the tools (step I), support in the different trade-off situations (step II) and the support from a sustainability perspective (step III) are presented in the following sections.

3.1 Results from Step I

The results from step I are shown in Table 2.

A valuation is included in nine of the analyzed tools; ABC-Analysis, ERPA, MECO, Philips Fast Five Awareness, Ecodesign Checklist by Econcept, LiDS-Wheel, Strategy List, Ten Golden Rules, Volvo’s Black, Grey and White Lists. However, the valuation is performed in different ways in the tools. For example in the ABC-Analysis it is described in the tool what should be considered in order to perform the valuation, i.e. a product or solution is given the value ‘problematic’, ‘medium’ or ‘harmless’ on the basis of eleven criteria (such as ‘social requirements’, ‘environmental impact’ and ‘risks of accidents’). In another tool, ERPA, different environmental stressors are evaluated by grading considering statements. The checklists (Strategy List, Ten Golden Rules, Volvo´s White, Grey and Black Lists) are another group of tools. These are considered to be evaluating in the sense that they recommend different alternatives or strategies before others.

The valuation in the nine tools differs. These tools were therefore, further analyzed considering the support they provide in three different trade-off situations, as described in section 2. The results are presented in Table 3.

3.2 Results from Step II

The level and area of support differ in the nine tools studied in step II (see Table 3). Four of the nine tools (ABC-Analysis, The MECO Method, LiDS-Wheel, Strategy List), studied in step II, consider three trade-off situations. However, they do not give direct support, only guidance to make a decision. In, for example, the LiDS-Wheel, the criteria are weighted using plus and minus, but no support is given to relate or prioritize the criteria to each other. A weighted result can give a clearer guidance than a non-weighted result. Six of the analyzed tools generate a weighted result. In the ABC-Analysis, Philips Fast Five Awareness, EcoDesign Checklist and the LiDS-Wheel the criteria is weighted qualitatively by grading. In the ERPA, all criteria are weighted quantitatively by grading. Two of the four areas in the MECO method are weighted quantitatively and one is weighted qualitatively.

Table 2. *Fifteen Ecodesign tools analyzed to ascertain whether they include a valuation.*

Tool	No valuation in the tool	Valuation in the tool
Analysis tools		
ABC-Analysis		X
The Environmentally Responsible Product Assessment Matrix (ERPA)		X
MECO Method		X
MET-Matrix	X	
Comparing tools		
Philips Fast Five Awareness		X
Funktionkosten	X	
Dominance Matrix or Paired Comparison	X	
EcoDesign Checklist by Econcept		X
Econcept Spiderweb	X	
Environmental Objectives Deployment (EOD)	X	
LiDS-Wheel		X
The Morphological Box	X	
Prescribing tools		
Strategy List		X
Ten Golden Rules		X
Volvo´s Black, Grey, White Lists		X

Table 3. *Nine Ecodesign tools described and assessed on the basis of the support they provide in three different trade-off situations and whether there is a weighted result from using each tool.*

Tool	*Within one environmental aspect*	*Between different environmental aspects*	*Between environmental aspects and other aspects*
Analysis tools			
ABC-Analysis	*Example of guidance:* A material's toxicity is classified as 'problematic', 'medium' or 'harmless'. Information on a specific material's toxicological properties is not included in the tool. *Weighted result:* yes, qualitatively	*Example of guidance:* toxicity, raw material extraction, pollution are classified. *Weighted result:* yes, qualitatively	*Example of guidance:* Social requirements and environmental costs are classified in the method. *Weighted result:* yes, qualitatively
The Environmentally Responsible Product Assessment Matrix (ERPA)	*Example of guidance:* A scarce or virgin material is given a lower grade than other materials. *Weighted result:* yes, quantitatively	*Example of guidance:* Choice of materials, energy use and residues. *Weighted result:* yes, quantitatively	*No guidance*
The MECO Method	*Example of guidance:* Chemicals are classified as 'very problematic', 'problematic' and 'less problematic'. Materials and energy are calculated as 'consumption of resources'. *Weighted result:* yes, qualitatively and quantitatively	*Example of guidance:* Materials and energy are weighted by calculation as consumption of resources. *Weighted result:* yes, quantitatively	*Example of guidance:* Other aspects can be included. It is up to the user to decide which other aspects to include. *Weighted result: no*

Table 3 (continued)

Tool	*Within one environmental aspect*	*Between different environmental aspects*	*Between environmental aspects and other aspects*
Comparing tools			
Philips Fast Five Awareness	*No guidance*	*Example of guidance:* 'Energy', 'recyclability' and 'hazardous waste content' are evaluated . *Weighted result:* yes, qualitatively	*Example of guidance:* Durability and service are evaluated. *Weighted result:* yes, qualitatively
EcoDesign Checklist	*No guidance*	*Example of guidance:* 'Minimising material input' and 'energy input' are examples of different environ-mental aspects that are evaluated. *Weighted result:* yes, qualitatively	*Example of guidance:* 'Customer benefits' and 'design' are examples of other aspects that can be compared with concrete 'environmental aspects'. *Weighted result:* yes, qualitatively
LiDS-Wheel	*Example of guidance:* Materials that are 'cleaner', 'renewable', 'less embodied energy content', 'recycled' and 'recyclable' are given a higher grade in the method. *Weighted result:* yes, qualitatively	*Example of guidance:* 'Use of materials' and 'reduction of impact' during use. *Weighted result:* yes, qualitatively	*Example of guidance:* Other aspects like 'production techniques' and 'new concept techniques' are considered. *Weighted result:* yes, qualitatively

Table 3 (continued)

Tool	*Within one environmental aspect*	*Between different environmental aspects*	*Between environmental aspects and other aspects*
Prescribing tools			
Strategy List	*Example of guidance:* The tool guides the user e.g. to choose 'nearby raw materials', 'secondary materials' and 'materials that are available in sufficient quantity'. *Weighted result:* no	*Example of guidance:* Different environmental aspects are considered, e.g. 'reduce land use' and 'waste'. *Weighted result:* no	*Example of guidance:* 'Increased service potential' is evaluated together with 'environmental aspects'. *Weighted result:* no
Ten Golden Rules	*Example of guidance:* The tool guides the user e.g. to choose 'less toxic substances' and to use 'suitable' materials for products. *Weighted result:* no	*Example of guidance:* Different environmental aspects are considered, e.g. 'efficiency' and 'materials'. *Weighted result:* no	*No guidance*
Volvo's White, Grey and Black Lists	*Example of guidance:* If the choice is between a chemical that is on the grey and black lists and one that is not, the lists support the user. The white list gives alternatives to different chemicals. *Weighted result:* no	*No guidance*	*No guidance*

3.3 Results from Step III

From the nine tools containing a valuation, there were seven tools (ABC, ERPA, MECO, Philips Fast Five Awareness, Ecodesign Checklist, LiDS-Wheel, and Strategy List) that had a lifecycle perspective. A life cycle perspective can be related to the “System level” in the System Level model described in Section 2.

All the tools contribute to the “Tools level” and the “Action level” of the previously described five-level model for planning, as they are all designed to stimulate actions. However, none of the analyzed tools are informed by the “Success level” and the “Strategy level” as they do not build on any theory for sustainability such as the described four socio-ecological principles. Or in other words, they all lack a framework with defined goals and a methodology for reaching sustainable development with economic/strategic guidance. Examples are LiDS-Wheel, 10 Golden Rules and Strategy List that all highlight dematerialization – indeed an important issue. However, for some substances, dematerialization is not enough to achieve sustainability, e.g. as defined by the four socio-ecological principles [13]. Some practices must be diminished or banned, for example dissipative use of metals and, in particular, scarce elements and certain compounds that are relatively non-degradable and foreign to nature e.g. bromine organic anti-inflammables. Consequently, other types of materials that can be more easily assimilated into natural systems may need to be substituted for the former and thereby be expanded in use.

Degradation of ecosystems by physical means and consideration of social impacts are other aspects that are not considered in the analysed tools. Changes in management routines of forestry, agriculture and fisheries that are necessary from a sustainability perspective cannot be solely described in terms dematerializations. This should be done by active consideration of the land use and how the products affect ecosystems (e.g. type of fishing equipment) (see System Condition 3). Ecological sustainability is in focus but social sustainability should also be considered in order to achieve a sustainable society. This includes a whole array of aspects such as equity, human rights and future generations (see System Condition 4).

Strategic guidelines for sustainable development are not considered in any of the analyzed tools including a valuation. In backcasting, future goals and objectives may be defined and used to develop a future scenario [10]. Each investment, at least if it is large and ties money for relatively long time-periods, ought to serve as a ‘flexible platform’ for future investments, i.e.

provide technical stepping-stones to link to future investments in the same direction. However a flexible platform is not enough, the considered investment also needs to be of economic value for the company, in a short enough time-period, to allow a continuous inflow of resources to maintain the process. The precautionary principle should be applied when there are doubts in regards to the seriousness of ecological consequences of a specific activity [8].

4. Discussion

Trade-off situations often occur in the product development process and the procurement process when alternative solutions emphasize different aspects that have to be balanced against each other. With the support of Ecodesign tools, trade-off situations between different environmental aspects as well as environmental aspects and other aspects can be identified. The studied tools were developed for different purposes; they are intended for ‘analysis’, ‘comparing’ or ‘prescribing’.

All of the tools are useful, as they give a systematic way to structure information, and they generate a result relatively quickly. Many of the tools studied can be used to identify trade-offs. Our opinion is that a valuation has to be included in the tool if the tool is to not only identify trade-offs but to also support a decision in a trade-off situation. Nine of the 15 tools analyzed included a valuation. Ecodesign tools can be useful to structure alternatives even if a valuation is not included in the tools, as in Dominance Matrix, Morphological Box and Econcept Spiderweb. These tools are based on the judgement of the user, the expertise knowledge, responsibility, degree of freedom and consideration. Even when a valuation was included in the tools, the level and type of support in the three studied trade-off situations (one ‘environmental aspect’, ‘different environmental aspects’ and ‘other important aspects’) differed.

The tools have a qualitative or quantitative approach or both. The approaches are all useful and a combination of them can be preferred to facilitate a choice. A potential problem with qualitative results is that, most products may turn out to be rather similar. Many times it is the quantitative aspects that can differentiate between different products [30]. Qualitative approaches are mainly useful to identify critical aspects or problems. One example is when using the tool Philips Fast Five Awareness. If one alternative is better than the reference product on everything but, for example, “recyclability” and another alternative is better than the reference product on everything but, for example, "hazardous waste content" which alternative should be chosen? It is up to the user of the tool to do the weighting and to have enough knowledge to make the right choice. However, because of the difficulties in assigning a fair grade, a fabricated scoring system should be avoided. When a quantitative dimension is needed in order to make a decision, the use of a more comprehensive tool is recommended, for example a quantitative life cycle assessment.

In some of the tools, the criteria can be weighted and thereby give additional support in a trade-off situation. However because a sustainability framework is lacking in those tools it can, at the same time, turn out to actively contribute to a strategically incorrect decision from a sustainability perspective. Robèrt et al. [8] claim that without first defining a sustainable future "landing place" on the systems level, achieving sustainability is an unlikely outcome of any effort.

In all the tools, some criteria have a focus on material aspects, usually in terms of dematerialization or substitution. However, since the criteria are not connected to any theory or principles for sustainability, the tools are probably based on a selection of different negative environmental effects. For example in the ABC-Analysis tool, important aspects can be missed in the process of comparing different product concepts and improvement options as materials. The tool also misses chemical substances that are not yet known to be hazardous but still violate the basic principles for sustainability and might give significant future environmental problems. In the tool, there is a criterion 'Potential Environmental Impacts' that has been divided into: toxicity (hazardous to health), air pollution (destroy atmospheric ozone) and water pollution (toxic to water flora and fauna). If the product contains toxic substances, carcinogenic substances or substances destroying atmospheric ozone it will be evaluated as Problematic (A) in the tool. However other substances that are not covered by this definition, for example new unstudied substances, may prove to have substantial negative effects in the future and will be missed if the term 'problematic' is solely linked to known impacts such as toxicity or bio-accumulation. At the time when CFC's where introduced, this was the perspective and the negative impact on the atmospheric ozone layer only became well known later. Sustainability principles that can be used and that deal with this problem include System Condition 1 (in the sustainable society, nature is not subject to systematically increasing concentrations of substances extracted from the Earth's crust) and System Condition 2 (in the sustainable society, nature is not subject to systematically increasing concentrations of substances produced by society) as presented at the 'Success' level in the System Level model in Section 2.

Important aspects, from a sustainability perspective, are often missing in the tools (for example social and economic aspects together with ecological aspects), which can lead to incremental changes without the long term in mind. This, in turn, leads to concomitant risks of sub-optimized investment paths. However, if the investment path is based on a strategy for sustainability, a step-by-step improvement might be accepted and planned for and in that case it is possible to do the right thing at the right time. But a sustainability aspect is not enough, as unintended sub-optimization might occur if the whole lifecycle of the product is not covered in the Eco-design tool. The entire system might not be considered and therefore, there is a risk that only a small part, even an insignificant part, of the system will be improved.

Improvement measures or material substances that are considered good choices today (for example Volvo's White List) might not be enough in a future sustainable society. Tying large investments to such measures might be the same as taking the organization into an unsustainable blind alley. When future sustainability is the focus, the choice in a trade-off situation should not only be evaluated by currently known pro's in relation to the respective known con's , but also which alternative is the smartest 'stepping stone' on a path towards social and ecological sustainability.

In general we propose that all the analyzed tools can be complemented with other tools and methods based on strategic planning towards sustainability in order to include "success level" and "strategy level" of the previously described five-level model for planning. Example of a strategic planning method for sustainability is described in Broman et al. [13]. However, to be a rational tool for support in trade-off situations, it should also include a valuation, have a life cycle perspective, and provide support in the three different trade-off situations described in Sections 3.1-3.3.

For example, in the above discussed ABC-Analysis tool the criteria could be complemented and based on the theory for sustainability, such as the described socio-ecological principles. To comprise the "strategy level" we suggest that guidelines for the design of strategies towards sustainability is added to the tool. Such guidelines should be based on backcasting, flexible platforms, good return on investment and precautionary principle to avoid costly suboptimizations and blind alleys. [8].

5. Conclusions

Different types of Ecodesign tools designed to be simple, are useful because they give a systematic way to structure information, and they generate a result relatively quickly. Nine of the 15 tools analyzed, support in trade-off situations, but the support was not sufficient. Our suggestion is that an Ecodesign tool should contain a valuation if it is designed to support a user in a trade-off situation. This valuation should include a lifecycle perspective and a framework for sustainability to give a more correct result from a sustainability perspective. This is specifically important in a comparison and a trade-off situation when a product is chosen on the basis of the results from the Ecodesign tool. In order to support different trade-off situations, the tool should include criteria in a sustainability perspective for one environmental aspect, different environmental aspects and other important aspects e.g. cost, social aspects, service.

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Paper III

A method for sustainable product development based on a modular system of guiding questions

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A method for sustainable product development based on a modular system of guiding questions

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Abstract

In this paper, we present a Method for Sustainable Product Development (MSPD) with the aim of integrating social and ecological aspects of sustainability with a strategic business perspective in product development. The method applies backcasting from basic principles for sustainability, which allows a strategic approach, and it includes a modular system of guiding questions that are derived by considering these principles and the product life cycle. Initial testing in Swedish companies indicates that the suggested MSPD promotes a 'bird's eye' perspective and encourage and aid development of products that support society's transformation towards sustainability. Furthermore, it is concluded that the modular system provides flexibility and user-friendliness.

Keywords: *Sustainable Product Development, Modular System of Questions, Method for Sustainable Product Development*

1. Introduction

The main sources of pollution in industrialised countries have for many substances changed from point sources to diffuse emissions from products [1,2]. It is therefore important to include sustainability aspects in decision making at the product development stage [3], especially early in the development process [4]. Once a primary product has been developed and moved to the production line, its sustainability attributes are largely fixed.

Several concepts and tools have been proposed to integrate environmental aspects into product development. Some examples of concepts are 'cleaner production', 'pollution prevention', 'eco-design', 'design for (the) environment', 'design for recycling', and 'sustainable product development' [5]. For a review, see de Caluwe [6], van Weenen [7] and Tischner et al. [8].

In a study of ecodesign tools, Baumann et al. [9] concluded that there is too much tool development and too few studies and evaluations of existing tools. Furthermore, because of slow progress in the actual greening of products, the authors suggest that unsuitable types of tools have been developed. Related, reasons may include limitations in time and economic resources for an effective application of ecodesign tools [10,11], or there may be a lack of incentives other than the expected environmental benefit [12].

We believe there is a lack of tools or methods for sustainable product development (SPD). We suggest that SPD should be distinguished from tools that aim at environmental improvement of products within today’s societal bounds. Today’s 'design for environment' tools can be criticised for not considering how incremental improvements fit into a viable strategy towards sustainability. The difference between SPD and concepts such as 'eco-design' and 'design for environment' has also been emphasised by, e.g., van Weenen [5], Roy [13], Simon & Sweatman [14], and Byggeth et al. [15]. Present ecodesign tools lack a goal defined by principles for ecological and social sustainability and strategic principles for sustainable development [15]. Some of today’s tools and methods for considering environmental aspects have a rather vague connection to the product development process [5] and to the business dimension, which may contribute to making the incentives for Ecodesign or SPD weaker.

A framework including principles for sustainability (PS) and a backcasting planning methodology, and how it can be used for a company's strategic planning towards sustainability has been presented previously [16-19]. We suggest that this framework could be combined with a standard model of a concurrent engineering development process [20] to form a Method for Sustainable Product Development (MSPD). An early version of a MSPD and the experiences from testing this method in ten small and medium-sized enterprises (SMEs) has been presented by Byggeth & Broman [21]. This MSPD attempt was based on a 'sustainability product analysis' (SPA) matrix, in which principles for sustainability and the life cycle of a product constitute rows and columns. However, trying to implement this matrix directly into a product development process turned out to be problematic in practice. Having specific questions concerning sustainability aspects included only in specific product development phases and areas of responsibility was disadvantageous. Technical consultants, e.g., do not always work with the whole development process and relevant aspects could then be missed.

The MSPD presented in this paper has a new structure, but it is based on the same theories, i.e., a model of the product development process extended over the full product life cycle, backcasting and principles for sustainability. In principle, we make use of a SPA-matrix to generate questions but in this case the questions are divided into modules to make it easier and more comprehensible to the user. The work of Hansen [10,11] has been inspiring, as well as the categorisation of sustainability aspects or improvement strategies discussed by, e.g., Fiksel [22], Brezet & van Hemel [23], and Hansen [24]. However, also these approaches lack a clear connection to a framework for strategic sustainable development.

In Section 2, we provide a theoretical description of the suggested MSPD. In the end of each subsection we present issues that we wanted to study by testing the MSPD in companies. In Sections 3 and 4, we present the experiences from initial testing of the MSPD in two companies. Suggestions for further development and improvements are discussed in Section 5.

2. A Method for Sustainable Product Development

The aim of the MSPD is to encourage and aid development of products that support society's transformation towards sustainability. The objectives are: (i) identification of potential problems of present or planned products caused by substances and activities during the product life cycle that are critical with regard to principles for sustainability; (ii) guidance in finding solutions to the potential problems by modifications of present or planned products, and (iii) stimulation of new products and business ideas based on sustainability aspects. The MSPD is designed to promote a 'bird's eye' perspective before more detailed analyses are undertaken. This is to discover essential aspects including those that are difficult to quantify, and to identify the aspects that are essential to quantify more in detail. The overview provided by the above mentioned framework could probably help avoid some detailed quantitative analyses of relatively limited relevance from a strategic sustainable development point of view.

An improvement cycle should employ at the least tools for inventory, impact, improvement and prioritisation assessment [25], all of which are covered in our suggested MSPD. Aspects to be considered are emphasised by guiding questions to the product developers. The MSPD includes one manual and three tools:

- A MSPD manual, with the aim of providing the user with the objectives and the theory of the MSPD, and instructions on how to use its different tools.
- A model of a product development process (PDP), which includes phase-specific questions for various traditional aspects within the phases.
- Sustainability product assessment (SPA) modules, which include strategic guiding questions to identify potentially critical substances and activities during the life cycle of the existing or planned product and questions to generate proposals for improvements.
- A prioritisation matrix, which includes questions to facilitate evaluation and choice among proposals. Sustainability aspects are integrated with traditional economic and technical aspects to improve the applicability of the method from a business perspective.

When a project group has read the manual, they can work with the product development questions for a particular phase. Then the SPA modules should be used. The proposals that are generated from SPA modules will be evaluated in the prioritisation matrix. The most suitable proposal(s) will be chosen before continuing working in the next product development phase.The MSPD is schematically presented in Fig. 1.

Issues that we want to study by testing the MSPD in companies:

- Can the MSPD help identify potential sustainability problems of present or planned products caused by substances and activities during the product life cycle?
- Can the MSPD function as guidance in finding solutions to the potential problems?
- Can the MSPD stimulate new products and business ideas?

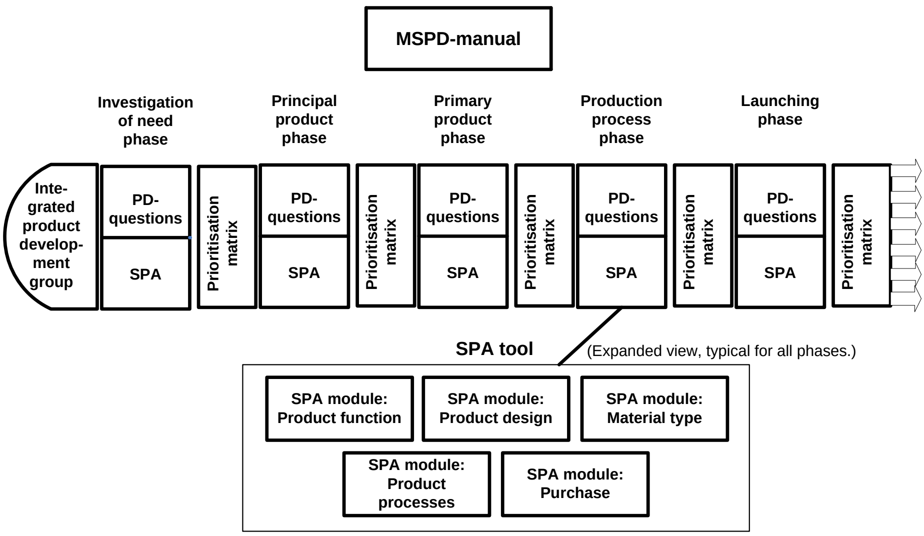

Figure 1. *Schematic illustration of the MSPD. The user will choose the SPA modules that are most relevant for a particular problem. Other suitable tools available at the company can be used to obtain the information needed for answering questions in the SPA modules and in the prioritisation matrix. This way of selecting the modules that are relevant for the respective 'product development' (PD) phase is a way of increasing comprehension and thereby the applicability of the MSPD method. The respective prioritisation matrices should be used before each next phase is entered.*

2.1 A Framework for Strategic Sustainable Development

The framework for strategic sustainable development (FSSD) used in our MSPD is based on backcasting from success of the planning, i.e., from a situation of sustainability defined at the basic principle level. A backcasting perspective facilitates alignment of successive incremental improvements into viable development paths towards a sustainable society, i.e., it helps avoid 'blind alleys'. To temporarily free the mind from the societal bounds of today also brings the potential of stimulating 'quantum leap' innovations in product design. The FSSD has been described in previous publications and its applicability for overall strategic planning of business and policy making has been demonstrated [16-18,26-31][1]. In this paper, the framework is only briefly described in relation to the MSPD. The framework's 'ABCD-analysis' is integrated into our MSPD through the different tools, and the four steps mean:

A. Members of the project group study information and instructions to understand how to work with the MSPD. The FSSD as a whole and its relevance in relation to product development are discussed. This is done the first time the method is used, when new members enter the project group, or whenever necessary for other reasons.

The A-step is represented upfront in the MSPD methodology's manual.

B. An assessment of the current situation is performed as regards the existing product with its accompanying flows and practices. Answers to the overall question: 'In what way does the product or its accompanying flows and practices contribute to society's violation of the principles for sustainability?' are proposed.

C. Possible solutions to the problems listed in B are created in a brainstorming process. This implies the creation of opportunities to fulfil customer's needs in the future when society is sustainable. Answers to the overall question: 'Which product could fulfil the specified needs and could fit into a sustainable society, and which design changes and activities could in principle serve as stepping stones in that direction?' are proposed. Also 'unrealistic' solutions are allowed and noted in this step.

The B- and C-steps are represented in the SPA modules. The SPA modules contain inventory, impact and improvement questions from a sustainability perspective.

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[1] Often referred to as The Natural Step Framework after the NGO promoting it.

D. Actions are prioritised. Smart early steps to take the product design from today's unsustainable solution towards the future vision are searched for. Practical considerations imposed by, e.g., today's societal bounds come in here. The logic of this prioritisation is given by the combination of the following three questions: Is the suggested change: (i) likely in the right direction in relation to the principles for sustainability? (ii) a flexible platform for further development towards sustainability? and (iii) bringing money and other resources into the process, i.e. pay-off, soon enough so that the process can continue.

The D-step is represented in the prioritisation matrix.

We use the principles for sustainability given below. For a background and discussion we refer to [16,18,29-31].
In the sustainable society, nature is not subject to systematically increasing:

1. Concentrations of substances extracted from the Earth's crust.
2. Concentrations of substances produced by society.
3. Degradation by physical means.

And in that society, …

4. People are not subject to conditions that systematically undermine their capacity to meet their needs.

On a product level, the principles imply that materials that are used should either be possible to integrate into natural material cycles within the ecosphere or be possible to integrate into essentially closed materials cycles within the technosphere. Renewable materials, easily degradable chemicals (into naturally occurring substances) and metals that are relatively abundant in the ecosphere can be used with a relatively low risk of contributing to society's violation of the first two principles for sustainability. However, even the use of such substances may violate those principles when emissions are so large that the assimilation and regeneration capacity of the ecosystems are exceeded. Current emissions of NO_x, for instance, are problematic in some regions. The use of rare metals and chemicals that are foreign to nature and relatively persistent is linked to a high risk of contributing to society's violation of the first two principles for sustainability. Such materials require essentially closed cycles. Since it is difficult and costly to achieve close to 100% recycling, such materials are not suitable for large scale societal use. Examples are mercury, cadmium, CFC's and bromine organic anti-flammables.

Furthermore, the principles imply that energy used in production processes, transportation and during the use of a product should not lead to either direct net emissions of, e.g., carbon dioxide from fossil fuels or indirect net emissions during the production of the fuel or electricity. This usually implies that renewable energy sources should be used. For agricultural and forestry products, it is especially relevant to consider the impact on biodiversity, long-term bio-productivity and ecosystem resilience in general.

The point of backcasting from basic principles that, taken together, cover the objective sustainability is to avoid sub-optimisations (blind alleys). It is therefore important to consider all the principles, taken together, when laying out the investment paths.

2.2. The Product Development Process

A method for sustainable product development should be integrated with the product development process (PDP) to be successful in a company [21,32]. Many tools and methods lack this integration [7]. Several theoretical models of the product development process exist; see, e.g., models presented by Olsson [33], Andreasen & Hein [34], Ulrich & Eppinger [35] and Ullman [36]. In addition, several company-specific variants of these theoretical models or in-house developed procedures are used in practice [21]. In our MSPD, we suggest a PDP model that is flexible and compatible with various needs of companies. We use a concurrent engineering PDP model but do not predefine (require) specific parallel areas of expertise such as design, production and market. Instead, the company is free to define its own group of expertise for each project, since different expertises can be relevant for different companies and projects.

The PDP model comprises five phases: (I) investigation of need, (II) principal product, (III) primary product, (IV) production process and (V) launch and use. Examples of specific questions and guidelines for the different phases are presented in Table 1. They are based on checklists and handbooks of different origins, for example, so-called milestone questions suggested by Hansen [24]. Like our phase-specific questions, these are general and not adjusted for a specific product.

The phase-specific questions and guidelines may imply the use of other tools, such as computer aided design (CAD), the finite element method (FEM), failure mode and effects analysis (FMEA) and virtual reality (VR). This can also provide information necessary for answering questions in the SPA modules, in which the sustainability aspects are treated.

The PDP model with its phase-specific questions and guidelines is intended for companies that do not have a specific PDP model defined. For companies with an already defined PDP model, this can be integrated with the MSPD. The project leader can also select other phase-specific questions and guidelines for the PDP phases defined for the project.

Issues that we want to study by testing the MSPD in companies:

- Is the PDP model flexible and compatible with various needs of companies?
- Do the phase-specific questions and guidelines raise important aspects that should be considered?

Table 1. *Examples of phase-specific questions and guidelines for the different product development phases in the MSPD.*

	Investigation of need phase	*Principal product phase*	*Primary product phase*	*Produc-tion process phase*	*Launch-ing phase*
Inte-grated product develop-ment group answer these questions together	Define the customer need. What is this need from a global pers-pective, and what further conclusions and oppor-tunities can be drawn from such a global human perspective?	Make a general description of the product type.	Are nec-essary calcula-tions and simula-tions and/or prototype features for the product reported?	Make necess-ary calcula-tions and tests for the produc-tion.	What aspects related to the use of the product can be foreseen already upfront in the product develop-ment process, so that these aspects are thought of at the time of launch of the new product?

Table 1 (continued)

	Investigation of need phase	*Principal product phase*	*Primary product phase*	*Production process phase*	*Launching phase*
Integrated product development group answer these questions together	Describe the product function.	Describe principal products and note where these are described in detail.	Will the product fulfil the product requirement list and the company policies and goals?	Does the production system fulfil the requirements for the working environment?	Prepare a marketing plan and a plan for customer support.
	Is it a redesign of a product or a new product idea?	Which criteria will be used to evaluate the different principal product solutions?	Carry out a detailed product design for all the product parts and specify the costs.	Carry out a detailed description of the production system.	Prepare necessary documentation and information for the end-of life handling.

2.3. The Sustainability Product Assessment Modules

Questions concerning sustainability aspects are organised into a system of sustainability product assessment (SPA) modules. The idea of the system of SPA modules originates from field investigations among a group of SMEs [21] and the main reason is to facilitate the use of the MSPD and give the user the possibility to decide which sustainability aspect should be used and when. We suggest the modules *product function, product design, material type, production processes, and purchase*. Together the questions in these modules cover the product life cycle, from extraction of raw materials to recycling or disposal of the used product. In each module the SPA questions are divided into inventory-impact questions, representing the B-step in the ABCD-analysis, and improvement questions, representing the C-step in the ABCD-analysis. Each question is also connected to one or several of the principles for sustainability, discussed in Section 2.1. Examples of SPA questions for each module are presented in Table 2.

Some SPA questions in the modules also include information or links to information; e.g., definitions of scarce and abundant metals, respectively, and the fact that a relatively scarce metal, for example, copper, has a higher risk of giving increases of concentration in the ecosphere than an abundant metal, for example, aluminium [37].

The purpose of answering the SPA questions is to generate proposals for a solution to a potential problem from a sustainability perspective and it is beneficial if several proposals are generated. Quite different proposals can be good solutions. For example, for the material content there are two main alternatives (as discussed above): either (1) the material is possible to integrate into natural material cycles within the ecosphere or (2) the material is possible to integrate into essentially closed materials cycles. The first alternative puts a demand more on the material type while the second alternative puts a demand more on the product type (function), product design and societal systems.

Issues that we want to study by testing the MSPD in companies:

- Is it possible to specify a generally valid order in which the modules should be used?
- Is a specific module strictly assigned to a specific product development phase or area of responsibility?
- Is any module relevant in any phase?

Table 2. *Examples of questions for each of the SPA modules.*

SPA module	*B-or C- step and principles for sustainability (PS: 1-4)*	*Example of questions*
Product function	B/PS: 1, 2, 3, 4	Is there a dissipative use of the product and does the product consist of; metals; chemicals; resources from ecosystems; resources put in global human need perspective?
	C/PS: 1, 2, 3, 4	Are there any product types with no dissipative use of the materials, that can be incorporated into societal cycling of materials (low material losses) or even into tight technical loops with no or very small losses to the environment and that fulfil the customer needs?
Product design	B/PS: 1	Are fossil fuels currently needed for the usage of the product?
	C/PS: 1	How can the product be designed to use renewable energy sources (directly or via electricity) during the usage phase?
Material type	B/PS: 1, 2	What materials are used that cannot be incorporated into the ecosphere, e.g. scarce metals or chemicals non-degradable and bio-accumulating?
	C/PS: 1, 2	What alternative materials can be used that can be more easily incorporated into the ecosphere, e.g. relatively abundant metals, chemicals that are relatively easily degradable and renewable materials?
Production processes	B/PS: 1, 2, 3, 4	What measures are taken in the production processes to reduce the material and energy use?
	C.1/PS: 1, 2, 3, 4	How is the material and energy usage reduced for the production processes through more efficient production processes?
	C.1.1/ PS: 1, 2, 3, 4	How are waste and residual products reduced through more efficient production processes and recycling systems?

Table 2 (continued)

SPA module	*B-or C- step and principles for sustainability (PS: 1-4)*	*Example of questions*
Purchase	B/PS: 4	What materials, resources, etc. are purchased that lead to unfairly used resources from a sustainability perspective in earlier product life cycle phases, i.e. in supply chains.
	C/PS: 4	From which suppliers can you purchase materials, resources etc. that: - firstly, do not result in unfairly used resources from a sustainability perspective in earlier product life cycle phases, i.e. in supply chains - secondly, have a lower impact on unfairly used resources from sustainability perspective in earlier product life cycle phases, i.e. in supply chains. Or alternatively, which suppliers would be interested to enter a path of systematic progress towards compliance with principles for sustainability.

The questions are marked with B or C and principles for sustainability (PS) 1-4, which represent the B-step and the C-step in the ABCD-analysis and the basic principles for sustainability 1, 2, 3 or 4 on which the questions are based.

2.4. The Prioritisation Matrix

The prioritisation matrix is used for evaluation and choice of the proposals that have been generated by using the SPA modules and the PDP model. The prioritisation matrix is used after each PDP phase before continuing to the next phase. The proposals are listed in the matrix and the evaluation is based on answers to following five questions:

i. *Is the proposal technically feasible?* This includes expected development costs and required technical expertise.
ii. *Could the proposal be developed in a realistic time for the specific project?* This means that the proposal can be developed within the

time frame for the project or bring in such important advantages that a delay is acceptable.

iii. *Can the proposal result in a good return on investment?* This includes expected production costs and market demand, both in the short -and long term.

iv. *Is the proposal environmentally adapted?* This means minimized environmental impact throughout the product's life cycle but within the societal bounds of today. See Appendix A for a proposal of a more elaborated definition of the term 'environmentally adapted', as presented in the MSPD.

v. *Is the proposal a deliberate step towards sustainability?* This means maximized probability that the proposal could be further developed towards a sustainable product, evaluated from a backcasting perspective with the principles for sustainability described in Section 2.1 as the future constraints. See Appendix B for a proposal of a more elaborated definition of the term 'deliberate step towards sustainability', as presented in the MSPD.

These five questions are based on the three questions of the D-step of the ABCD-analysis (described in Section 2.1), and on traditional aspects used in evaluation tools for product development; e.g., functionality, durability, manufacturability, cost [35].

We suggest a four level grading, and colours to facilitate illustration and communication within the project group. The meanings of the colours are: green, good/yes; yellow, rather good/possible; orange, rather bad/difficult; and red, bad/no.

We cannot recommend any general order in which to consider these five questions. In practice, it can be relevant to start with questions that are likely to demand less investigation since there is a possibility that proposals can be rejected before all questions have been considered, which could then reduce the work load. For example, if a product is not technically feasible, further investigations concerning the other questions are not necessary within the current project.

'Environmentally adapted' products are usually the main goal when using ecodesign tools, which indeed may be an important result. However, it is good enough only if it is also a step on a viable path towards sustainability. The choice from using the prioritisation matrix should aim at product proposals that are either highly likely to fit in a sustainable society directly, or can act as bridging solutions that function as deliberate steps towards such products. If a proposal is not likely to fit directly in a sustainable society it is important that a clear strategy can be seen of how it can be a part of further development. That it can act as a ´deliberate step towards sustainability` should, if necessary, be prioritised ahead of ‘environmentally adapted’ in relation to today’s societal bounds.

Issues that we want to study by testing the MSPD in companies:

- Can the prioritisation matrix be used for evaluation and choice of the proposals that have been generated from questions in the PDP model and the SPA modules?
- Can the colours (green, yellow, orange, red) facilitate illustration of the evaluation?
- Does the prioritisation matrix improve communication within the project group?

3. Test Set-Up

The restructured second version of the MSPD was tested during a one-year period in two different types of companies in Sweden. A consulting firm specialising in product development tested the MSPD for a previously developed halter of composite material that will be used by an industrial robot moving sheet metals for trucks. A project leader, a product developer and a prediction engineer worked in a project group. A manufacturing company that specialises in exhaust systems for cars tested the MSPD for a previously developed exhaust manifold for a diesel engine. A project leader (environmental manager), a product developer, a prediction engineer and a production process developer worked in a project group. These two companies were used as a test panel because they are two of the ten companies that were involved in the first project of developing the MSPD [21], and then contributed with many helpful comments. They were interested in using the MSPD in the future and the managers were supporting their participation.

The main purpose of this survey was to find out whether any potential sustainability problems of the present products could be identified and to evaluate whether MSPD could, in principle, work as guidance in finding alternative solutions to the present or planned products. Furthermore, we wanted indications of the user friendliness of the new structure of the MSPD, its flexibility, and its need for further research and development.

The survey, was designed according to guidelines from [38,39]. There was no intention to collect quantitative data and processing it statistically. After one year of project work a questionnaire (open questions) were sent to the project groups and then a follow-up in-depth interview (the same questions as in the questionnaire) took place between the researcher and parts of the project group. (In the consulting firm the project leader answered the questions and in the manufacturing company the project leader and the product developer answered the questions.) The data from the interview was written down immediately afterwards and also compared with the answers in the questionnaire in order not to miss any details and avoid any misunderstanding. Also the working materials from the companies, collected in the MSPD database, were reviewed in parallel to the analysis of the interview questions.

The questionnaire/interview questions were designed to answer the research questions, "issues", presented in Table 3. Some questions had control questions to make sure the answers were not misunderstood. The questions were divided into six parts:

1. General questions about MSPD. For example:
    - Have the MSPD worked as guidance in finding solutions to the potential problems by modifications of present or planned products?
    - Have new products and business ideas been discussed due to the use of MSPD?
2. Questions about the MSPD-manual. For example:
    - Has the MSPD-manual supported the user with enough instructions for how to use the different tools as well as information about the underlying theory, objectives and structure of the questions?
    - Is expert knowledge (guidance) needed to understand how to use MSPD and the underlying theory?
3. Questions about the product development process (PDP) model. For example:
    - Is the PDP model flexible and compatible with various needs of companies?
    - Do the phase specific questions bring up important aspects that should be considered?
4. Questions about the SPA-modules. For example:
    - Based on the experience from using the MSPD, do you think it is possible to specify a generally valid order in which the modules should be used?

- Based on the experience from using the MSPD, do you think a specific module is strictly assigned to a specific product development phase or responsibility area, or can all modules be relevant to use in any phase?

5. Questions about the prioritisation matrix. For example:
   - Did the columns; technically feasible, realistic time, good return on investment, environmentally adapted, deliberate step towards sustainability, aid evaluation of proposals?
   - Do the colours used (green, yellow, orange, red,) facilitate illustration of the evaluation?
6. Other questions. For example:
   - Which are the requirements for successful implementation of the MSPD in your company?
   - What are the barriers and obstacles to implement the MSPD at your company?

Table 3. *The results from testing the MSPD, indicating which issues could be verified or dismissed.*

Issues	*Verified/dismissed by the test*
Can the MSPD help identify potential sustainability problems of present or planned products caused by substances and activities during the product life cycle?	Yes- Verified.
Can the MSPD function as guidance in finding solutions to the potential problems?	Yes- Verified
Can the MSPD stimulate new products and business ideas?	Yes- Verified
Is the PDP model flexible and compatible with various needs of companies?	Yes- Verified
Do the phase-specific questions and guidelines raise important aspects that should be considered?	Yes- Verified
Is it possible to specify a generally valid order in which the modules should be used?	No - Dismissed
Is a specific module strictly assigned to a specific product development phase or area of responsibility?	No - Dismissed
Is any module relevant in any phase?	Yes - Verified
Can the prioritisation matrix be used for evaluation and choice of the proposals that have been generated from questions in the PDP model and the SPA modules?	Yes- Verified
Can the colours (green, yellow, orange, red) facilitate illustration of the evaluation?	Yes- Verified
Does the prioritisation matrix improve communication within the project group?	Yes- Verified

4. Results

In Table 3, the results from testing the MSPD are summarised. This initial testing is used to give an indication of whether the MSPD development goes in the right direction as regards the ability of the method to identify potential sustainability problems, provide guidance for alternative solutions and its user friendliness. Furthermore, it should be pointed out that although we believe that the MSPD has a potential of stimulating also ‘quantum leap’ innovations, the test cases performed so far can only be used to point out the ability of the method to guide incremental improvements into viable paths towards sustainability.

Experiences from the two companies testing the MSPD in the different product development projects are described in the subsections below.

4.1 Experience from using the PDP model

The project groups experienced the PDP model as an important part of the MSPD. Together with its phase-specific questions, it was considered as general, relevant, flexible and compatible with various needs of the companies. The users recognised the working procedure for product development and the phase-specific questions. They considered the PDP model important as a guide for the overall development process.

4.2 Experience from using SPA modules and SPA questions

For each of the product development phases, one particular SPA module was used in the manufacturing company. They felt it logical to use the SPA module ‘*product function*’ in the ‘investigation of need’ phase, the SPA module ‘*product design*’ in the ‘principal product’ phase, the SPA module ‘*material type*’ in the ‘primary product’ phase, the SPA module ‘*production processes*’ in the ‘production process’ phase, and the SPA module ‘*purchase*’ in ‘launch and use’ phase. On the other hand, the consulting company used all the SPA modules in all the product development phases. It was seen that the need for using different SPA modules is different for different products and for different projects. To specify an order in which the modules should always be used was not recommended by the test groups but was considered to decrease the usefulness and flexibility of the method.

The SPA questions were considered general and appropriate. For the consulting firm they were adequate as they work with different types of products. For the manufacturing company, more product-specific hands-on guidance for their product category would have facilitated the use of the MSPD. However, they stated that the general SPA modules are still important and should be possible to use in parallel with more product-specific questions and guidelines in order not to limit the creativity and the degree of freedom.

The project groups believed that also potential sustainability problems can be discovered when answering the SPA questions. Furthermore, alternative solutions and proposals were generated and the MSPD increased the awareness of how different solutions have an impact on sustainability, even if the principle product solution and the product structure had already been defined for these projects. For example, the consultant company were considering substituting the material for their product from composite material to aluminium. The manufacturing company stated that when using the MSPD they became aware of different alternative solutions and evaluated more thoroughly the necessary amounts and the types of materials used for the product.

4.3 Experience from using the Prioritisation Matrix

The prioritisation matrix was used after each product development phase for evaluation and for a choice of the proposals that had been generated from questions in the SPA modules. The questions used in the prioritisation matrix were considered relevant and to facilitate weighing between the proposals. The project groups recognised the potential of the matrix for improving the communication within the project group and for decision-making. The project groups also felt the colours helped visualise the evaluation of the different proposals. Finally, the groups believed that the method as a whole helped aligning proposals with a viable path towards sustainability.

4.4 Improvement Proposals and Prerequisites for Implementation

To complement the MSPD with product-specific SPA questions and guidelines and with questions and guidelines for working environment were the main improvement proposals from the project groups. It may be worth mentioning here that parallel to our MSPD development, we have started to develop so called templates for sustainable development (TSPD). Those will be more product category specific but build on the same underlying structure and theory as the MSPD. For a further discussion, see [40].

Provided that the MSPD is integrated into the management systems at the companies, recognised in the company policy and supported by the management, the project groups identified no barriers to implementing the MSPD at the companies. A person responsible for the implementation at the company (e.g., the person responsible for the management systems at the company) and an introduction to the MSPD for the first projects were considered as other prerequisites for implementing the MSPD successfully.

5. Discussion and Conclusion

Using principles for sustainability, and backcasting from a future sustainable reference situation bears the potential that product development is not only influenced by descriptions of observed negative social and ecological impacts and our present understanding of those. Investment paths towards compliance with basic principles for sustainability can also help us *avoid* impacts, even impacts that are not yet described. We emphasise that improvement proposals should not only deal with current problems, but while doing so *also* be fruitful steps in a path towards sustainability. In previous studies we have concluded that companies that are systematically guiding their development towards sustainability in this way should stand a fair chance of being affected relatively less severely by unexpected costs and other risks [18,26]. We therefore believe that a method like MSPD could better support the development of sustainable products in comparison to ecodesign tools that lack a framework for sustainability. This is specifically important in a comparison and a trade-off situation when a product is chosen on the basis of the results from the Ecodesign tool [15].

Initial testing in Swedish companies indicates that the MSPD described in this paper promotes a ‘bird’s eye’ perspective and encourage and aid development of products that support society’s transformation towards sustainability, i.e., that the MSPD can help align improvements with viable paths towards sustainability. It increases the awareness of the choices in trade-off situations and it was considered instructive by the test groups. MSPD has its strength in finding the sustainability related hot-spots from a ‘bird’s eye’ perspective. This is to discover essential aspects including those that are difficult to quantify, and to identify the aspects that are essential to quantify more in detail. However, when detailed analysis and comparisons are necessary, MSPD will probably not be enough. In those cases, a quantitative ecodesign tool, for example life cycle assessments (LCA), could compliment MSPD.

The tests indicate that there are reasons for having questions concerning sustainability aspects in a separate system of SPA modules, rather than stating such questions in the phases of the PDP model itself (which was the case in the previous version of MSPD [21]). The main reasons are:

- Sustainability aspects can be integrated into different PDP models. This flexibility is important as many companies have company-specific variants of the established theoretical models of the PDP or in-house developed procedures with company-specific checklist questions. A smaller resistance can be anticipated against the MSPD if the whole tradition of product development within the company does not need to be replaced.
- One or several specific modules can be used in several of the PDP phases and areas of responsibility. For example, the material type module can be used early in the first product development phase to roughly scan material alternatives and can then be used again later in the product development process to make a more detailed investigation for a final choice.

The tests also indicate that it is not possible to specify a generally valid order in which the modules should always be used, and a specific module cannot always be strictly assigned to a specific product development phase or area of responsibility. The order 'product function', 'product design', 'material type', 'production process' and 'purchase' is common, but not compulsory. For example, it is usually wise to ask questions about the product function before asking questions about product design. However, for some projects any module may be relevant in any phase and a non-serial interaction between the modules is possible. For some projects all modules may not be relevant. When to use a certain module will become more and more clear to the product developer with increased experience of working with the MSPD.

For the questions within the respective SPA modules, no generally valid order can be specified either. According to the ABCD-analysis, however, inventory-impact questions (B-step) are usually considered before improvement questions (C-step). For example, the inventory-impact question: Is the product running on fossil fuels? has a follow-up improvement question: How could the product be designed to run on renewable energy sources? That is, potential problems of existing products are identified first and then improvement proposals are generated from these potential problems and improvement strategies. However a strict hierarchical tree structure, in the meaning that questions must always be considered in a specific order and that a specific question always leads to the same follow-up question depending on the answer, would lead to a far too complicated and non-flexible methodology.

Whether a higher extent of such stricter hierarchical structures is meaningful for a specific product type needs further investigation.

The tests have pointed at some areas, and have given some ideas, for potential improvement. Primarily these concern more hands-on guidance for various product categories and the interaction of the MSPD with other questions and guidelines such as for the working environment. The MSPD could also be further adapted for implementation at the companies, which require further research and testing of MSPD.

MSPD is based on principles for ecological and social sustainability and strategic principles for sustainable development. It also includes a valuation and has a lifecycle perspective. Therefore it should be able to give support in a trade-off situation and to give a more correct result from a sustainability perspective, which is one of the main advantages with MSPD, in comparison to some existing ecodesign tools [15].

For future work, more in depth studies should be made particularly on the prioritisation matrix. The ability of the MSPD to promote more radical innovations should also be studied.

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Appendix A

Definition of ‘environmentally adapted’:

i. The product design is such that:
    - minimum amount of material is used to reach desired functionality
    - heavy materials are exchanged for lighter materials (especially important for products that are transported)
    - materials with known negative environmental impact are exchanged for materials with less environmental impact

ii. The transport is such that emissions are minimised through:
    - use of local suppliers in preference to regional/global suppliers
    - use of transport based on renewable resources

iii. The production system is such that :
    - wastage is avoided in the production processes
    - the processes have optimised usage of energy and other resources
    - the production flow is even, i.e. efficient logistics
    - emissions contributing to known environmental effects are limited by different cleaning technologies, e.g., air cleaning systems, water treatment plants and catalysts
    - materials with known negative environmental impact are exchanged for materials with less negative environmental impact

Appendix B

Definition of ‘step towards sustainability’: a temporary solution as regards technical, economic and market aspects that makes the development of a fully sustainable solution possible and likely.

A sustainable solution does not contribute to society’s violation of basic principles for sustainability (as described in the main text).

Examples of measures that should be considered are:

i. The materials used in the product, the materials needed for the usage of the product and the materials used in the production processes are:
   - metals abundant in the ecosphere and/or
   - easily degradable chemicals and/or
   - renewable materials

If not to 100%, there should be no deliberate dissipative use of the materials and the design is adapted for a high degree of reuse or recycling, made possible by, e.g.:

-economically viable collection systems
-modular system product design
-long life length of product parts
-few product parts
-easy disassembly

ii. The energy resources that are used during the usage phase, the production phase and the transportation of the product are preferably based on renewable sources.

iii. For the use of biologically productive areas during the usage phase, the production phase and the transportation of the product, impoverishment of biodiversity and long-term production capacity must not occur.

iv. In purchase of materials, product part and other resources, fair trade and demand for justice should be prioritised.

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Paper IV

Introducing templates for sustainable product development through an evaluation case study of televisions at the Matsushita Electric Group

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Introducing templates for sustainable product development through an evaluation case study of televisions at the Matsushita Electric Group

Henrik Ny, Sophie Hallstedt, Karl-Henrik Robèrt and Göran Broman

Abstract

We have previously developed a method for sustainable product development (MSPD) based on backcasting from basic sustainability principles. The MSPD informs investigations of product related social and ecological sustainability aspects in all parts of a concurrent engineering product development process. We here introduce an idea of “templates” for sustainable product development (TSPDs) as a complement to the MSPD. The idea is to help the company integrated product development team to arrive faster and easier at an overview of the major sustainability challenges and opportunities of a given product category in the early development phases. The idea is also to inform creative communication between top management, stakeholders and product developers. We present this approach through an evaluation case study, in which the TSPDs were used for an overview sustainability assessment of TVs at the Matsushita Electric Group.

We are particularly interested in studying whether the TSPD approach has the ability to: (i) help shifting focus from gradual improvements of a selection of aspects in relation to past environmental performance of a certain product category, to a focus on the remaining gap to a sustainable situation (ii) facilitate a common understanding among different organizational levels of major sustainability challenges and potential solutions for a certain product category and (iii) facilitate a continued dialogue with external sustainability

experts, identifying improvements that are relevant for strategic sustainable development.

Our findings indicate that the TSPD approach captures overall sustainability aspects of the life-cycle of product categories and that it has the above abilities.

Keywords: *backcasting, strategic sustainable development, sustainable product development template, The Natural Step (TNS)*

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. 2007b). This method is designed to put product development in the context of a stepwise approach for society to comply with basic socio-ecological sustainability principles (SPs), and to focus also on strategic competitive elements of such transitions. 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 like environmental management systems (EMS), life-cycle assessment (LCA) and computer aided design (CAD) (Byggeth 2001; Byggeth et al. 2007b).

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

[1] Physical artefact, software, processes, services, or combinations of these in systems.

products to close these gaps. They therefore decided to get advice from external sustainability experts. As a result, an advisor from the nongovernmental organisation (NGO) The Natural Step International (TNSI)[2] was engaged to lead a sustainability assessment of Matsushita's TVs. At the time, Matsushita was more interested in an external opinion of the overall sustainability performance of their TVs, than to engage upfront in a more extensive MSPD exercise to arrive at new and more sustainable lines of TVs. Drawing from the MSPD experience, the sustainability expert suggested a new and more straight-forward approach aimed at providing what Matsushita asked for. The expert first applied the same approach as in the MSPD to arrive at an overall sustainability assessment of TVs in general, a 'template' for sustainable product development (TSPD) of TV's. Thereafter the Matsushita integrated product development team could relate the specifics of their TVs to the template. This group includes product developers and representatives from top management and the term "the client" will hereafter be used when referring to them as a group. The idea was to rapidly increase the ability of company in-house product developers to see and apply the overall long term sustainability picture as an aid for identifying a suitable mix of dematerialization and substitution investments. The idea was also to give them a means for communication to top management to receive support for actions.

Article Purpose

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

The following research questions are addressed:
Are there indications, if so which, that the client in line with the aim of the template approach

i. Has moved from a traditional focus on gradual improvements of a selection of aspects in relation to past environmental performance, to a focus on the remaining gap to a future sustainable situation?
ii. Has reached a common understanding among different organizational levels of major sustainability challenges and potential solutions?

[2] TNSI 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.

iii. Has facilitated a continued dialogue with external sustainability experts, identifying improvements that are relevant for strategic sustainable development?

Overarching Research Method

The research was conducted in several steps that are described in further detail in the coming sections:

- Describing the background theory
- Describing and clarifying the template approach
- Evaluating the effect of the template approach in the Matsushita TV case
  a. What was the sustainability performance of the Matsushita TVs before the approach was introduced?
  b. Was the template approach applied as intended?
  c. What indications of resulting product-related sustainability improvements could be found?

Background Theory

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. This framework also suggests how organizations can plan and act to support society’s transformation towards such a society while avoiding financial risks associated with unsustainable practices and foreseeing new business opportunities. This planning challenge is dealt with at five different interacting levels (Robèrt 2000; Robèrt et al. 2002):

Level 1. The system (in this case, the organization within society within the biosphere).
Level 2. Success in the system (in this case, products supporting society’s compliance with principles for sustainability).
Level 3. Strategic guidelines to arrive at success in the system (in this case mainly “Flexible”, “Direction” and “Pay-back” as described below).
Level 4. Actions aligned with the strategic guidelines to arrive at success in the system (in this case, mainly product life-cycle improvements).
Level 5. Methods, tools and indicators designed to help prioritize and monitor actions that are strategic to arrive at success in the system.

This framework has been developed in a scientific consensus process into a concrete planning method called backcasting from sustainability principles (BSP) (Robèrt 1994; Holmberg 1995; Robèrt et al. 1997; Holmberg et al. 1999; Robèrt 2000; Broman et al. 2000; Robèrt et al. 2000; Robèrt et al. 2002; Ny et al. 2006). The current wording of the sustainability principles (SPs) (level 2) is:

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.

Backcasting from sustainability principles is in practice often run by an external facilitator that takes an inter-disciplinary group of company representatives through the following ABCD working procedure:

A. Discuss the framework as such, to reach acceptance for it as a shared mental model for the work to come.
B. Start an iterative process of brainstorming, describing current practices in relation to the SPs.
C. Identify alternative future solutions or visions that are likely to comply with these principles.
D. Evaluate and prioritize between early strategic actions (investments) to close the gap between B and C. The main three strategic guidelines for this prioritization are:
    1. choose "flexible platforms" or investments that are likely possible to develop further towards success as defined by the SPs and other goals set up by the organisation (this guideline is called "Flexible" in step D of figure 1),
    2. seek to reduce the contribution to society's violation of the SPs ("Direction" in figure 1),
    3. strive for sufficient return on investment soon enough to continuously reinforce the process ("Pay-back" in figure 1).

In the decision regarding an individual investment, though, the three guidelines need to be assessed in a dynamic interplay between each other (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).

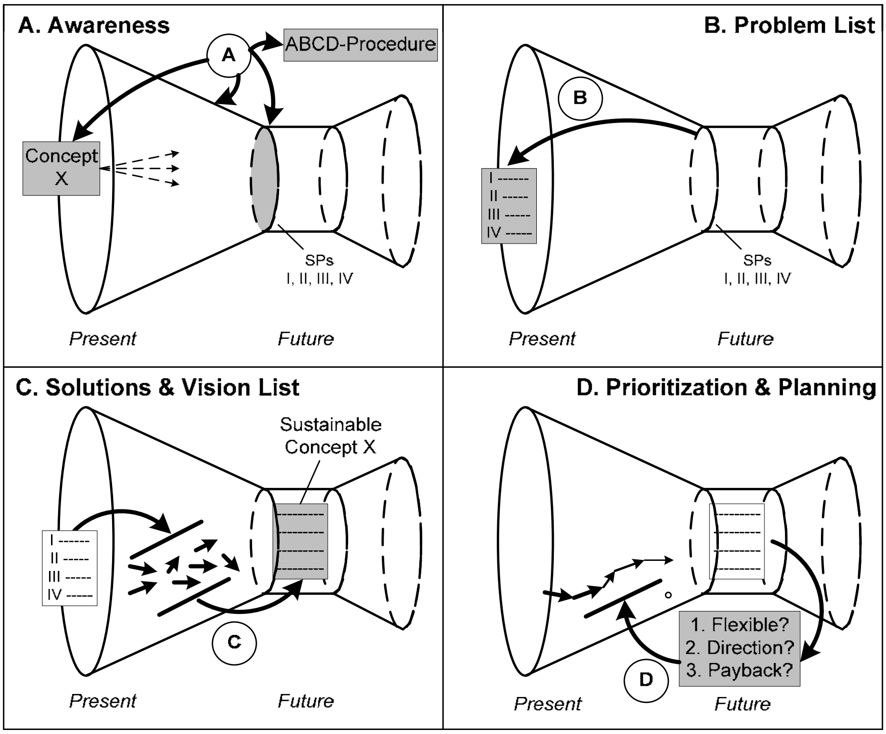

Figure 1. *The ABCD Procedure of backcasting from Sustainability Principles (Adapted from Ny et al. (2006)). Start by agreeing on a mental model of the concept of study (Concept X), the sustainability challenge (a decreasing window of opportunity, the funnel), the SPs (I-IV) and the ABCD procedure as 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).*

Sustainable Product Development

The difference between Sustainable Product Development (SPD) and concepts such as 'eco-design' and 'design for environment' (DfE) has previously been emphasized by several authors (van Weenen 1997; Roy 1997; Simon and Sweatman 1997). Roy, for example, claims that SPD goes beyond the environmental optimization of products and processes, aiming to create product designs that are ecologically sustainable while providing functions that meet basic human needs. Simon and Sweatman agree, defining DfE as incremental improvements of existing products without challenging the status quo of current unsustainable consumer society. Another study has scrutinized some methods and tools for eco-design/DfE in relation to the above mentioned framework for strategic sustainable development, identifying several gaps that need to be dealt with before they can be used for SPD (Byggeth and Hochschorner 2006). None of the studied methods/tools was based on a framework with defined socio-ecological sustainability goals and none of them had a methodology for strategically moving towards such goals. Moreover, degradation of ecosystems by physical means (SP3 of the BSP) and degradation of the social system (SP4 of the BSP) were not both covered by any of the scrutinized tools. Byggeth and Hochschorner also suggest that product development should not only aim at improvement of products regarding an arbitrary 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 if principled reasoning in relation to the SPs would have been used. Already at the time when CFCs were first introduced, they were known to be foreign to nature and designed for low degradability. These known properties made CFCs especially prone to increase in concentration in nature once they are emitted (as an analysis in relation to SP II would have shown). This means that large scale use of such substances in society should not have been allowed without rigorous control.

To support prevention and proactivity, a method for sustainable product development (MSPD) has been proposed (Byggeth et al. 2007b) in which the above mentioned framework is integrated with a concurrent engineering development process (Olsson 1976; Roozenburg and Eekels 1995; Ulrich and Eppinger 2003).

The overall purpose of the MSPD is to:

- Provide basic knowledge about sustainability from a full systems and life cycle perspective.
- Provide strategic approach to sustainable product development.
- Provide basic knowledge about product development methodology.
- Raise awareness of product-related sustainability issues and point to sources of more detailed sustainability- and environmental information needed to address these issues.
- Initiate relevant investigations and link traditional design considerations with sustainability considerations to stimulate creativity.
- Aid identification and clarification of trade-offs and prioritization of short and medium term actions.
- Aid documentation in line with the above structure.

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 throughout 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 such as Factor analyses, Footprinting or LCA, but a way of making better use of such (Robèrt 2000; Robèrt et al. 2002; Ny et al. 2006).

The Expert-Guided Template Approach

Why is it needed?

Sometimes top management, as well as product development teams, may need an early and quick overview of the sustainability performance of a given product category. The most essential sustainability aspects should be highlighted in a format that is easily accessible without a prior need to learn in depth how the MSPD works. Templates for sustainable product development (TSPDs) were therefore developed. 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. 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.

The MSPD and TSPD approaches can also be used in combination (figure 2). 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 ABCD procedure described in figure 1). Thereafter, the MSPD can be applied throughout the product development process to go deeper into B and C as well as exploring more in depth prioritizations between the options (D of the ABCD procedure).

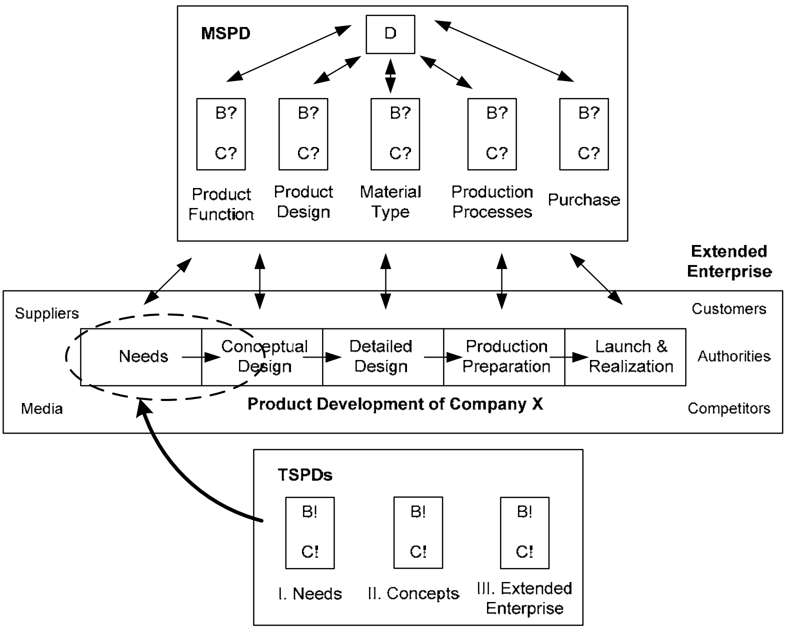

Figure 2. *The application of MSPD and TSPDs in a product development process. The MSPD consists of several modules of probing questions on sustainability challenges (symbolized by "B?") and potential solutions (symbolized by "C?") that could be used as creative input to the product development team throughout the product development process. The MSPD also supports the prioritization between potential solutions (D). The templates include expert statements on expected sustainability challenges (symbolized by "B!") and potential solutions (symbolized by "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.*

How is it done?

The overall intent of the TSPD approach is to creatively identify short- and long-term options for developing product categories towards sustainability. The specificity of such a product category will have to be decided from case to case but generally it will cover products aimed for the same function. Economic and other constraints are evaluated in later stages, and the TSPDs are then part of the input for the prioritization of actions. There are TSPD procedures both for evaluating an existing product and to provide planning support for a new product concept. Both procedures require the facilitation by an internal or external expert ("the sustainability expert") in strategic sustainable development and the template approach. "The client", as defined above, refers to the integrated product development team of a company that uses the template approach.

Evaluating an existing product

1. The sustainability expert leads a preparatory dialogue with the client.
2. Triggered by generic key questions (table 1), the sustainability expert identifies and makes statements about overall current sustainability problems of the product category, (Step B of the ABCD procedure). This is followed by identification and overall statements about potential solutions and visions for a future sustainable situation (Step C of the ABCD procedure).
3. The client responds to these statements, by providing aspects from competence fields like product development and management. 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 the client.
5. Items 3 and 4 are repeated until consensus is reached for this overview assessment.
6. A final presentation is given in a common session and a consensus report, including the templates, is produced.

Providing planning support for new products

1. The sustainability expert leads a preparatory dialogue with the client.
2. Together they identify the desired function and an existing product that can fulfill this function.
3. They use the identified product as a reference when walking through steps 2-6 of the above procedure for evaluating an existing product.

What is it?

There are three templates, each containing the current situation (B), and possible future solutions and visions (C) (figure 2):

- Template I: “Market Desires/Needs” (focusing on market desires and their relation to basic human needs and on identifying the desired product function),
- Template II: “Concepts” (focusing on life-cycle sustainability consequences of meeting the market desires with a certain product concept)
- Template III: “Extended Enterprize”(focusing on societal stakeholder consequences from the product concept and on how they can be influenced).

The issues covered by the three templates are considered to be particularly relevant for the creation of a generic overview. The two first templates (“needs” and “concepts”, respectively) are chosen stages of the concurrent engineering process and template III (“extended enterprise”) takes a societal stakeholder outlook. More detailed stages of the concurrent engineering process like 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 of the backcasting procedure (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 templates I, II and III are described briefly below.

Table 1. *Master Template Matrix.*

Time	I. Market Desires /Needs	II. Concepts	III. Extended Enterprise
	Templates		
B (current situation)	**Current market desires addressed:** What *current* market desires is the product/service intended to meet? What are some *current* overall sustainability problems related to these market desires? How do these market desires relate to basic human needs?	**Conceptual design of today's product:** What *current* flows and management routines from the life cycle of the chosen product/service concept are critical from a full sustainability perspective? In other words, what *critical violations* of the sustainability principles could be identified for the following general lifecycle phases?: • resource extraction, supply chain & manufacturing • distribution and use • final disposal or reuse/recycling/ land filling	**Current stakeholder communication/ cooperation:** What *current* preferences and conditions of *societal stakeholders* are opposing the introduction of more sustainable product/service concepts? Is the company trying, through external communication and actions, to change these preferences and conditions? If so, how? What *current product/service value-chain* cooperation is agreed upon and what gaps can be identified that prevents responsible handling of sustainability problems throughout the lifecycle?

Table 1 (continued)

Time	I. Market Desires /Needs	II. Concepts	III. Extended Enterprise
C (future solutions/visions)	**Likely future market desires to address:** What *new* market desires are likely to evolve in the future as responses to the sustain-ability challenges? What *new* market desires, related to your core business, could improve the chances of fulfilling basic human needs? Are there any market trends that point in this direction?	**Likely conceptual design of future product:** Could the physical flows, management routines, etc, related to the *current* life-cycle of the product concept be developed to reduce the risk of societal violation of the basic sustainability principles? In other words, what *solutions* to product-related sustainability problems could be identified for the following general lifecycle phases?: • resource extraction, supply chain & manu-facturing • distribution and use • final disposal or reuse/recycling/ land filling Could *new* product/service concepts be developed that meet the current and/or future market desires while reducing the risk of societal violation of the basic sustainability principles?	**Likely future stakeholder communication/ cooperation:** What *future societal stakeholder* preferences and conditions would be particularly favourable for the development of more sustainable product/ service concepts, and how could the company interact with external stakeholders to facilitate such change? What *future strategic product/service value-chain cooperation* would be particularly favourable for responsible handling of sustainability problems throughout the lifecycle? How could the company develop such cooperation?

Template I – Covering ”Market Desires/Needs”

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. Among other things, this means 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 products 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.

The global sustainability challenge may pose critical questions as to the true human service/utility of any product idea. When it comes to human needs, we draw especially from (Max-Neef 1992) who claims that nine universal basic human needs should be satisfied (subsistence, understanding, protection, affection, idleness/leisure, creation, identity, participation and freedom). Max Neef states that these needs are constitutional, that is, what differs between cultural contexts is *how* such basic needs are satisfied, not the needs as such. Furthermore, people should have the capacity to meet all their needs over time to avoid “starvation” symptoms and destructive compensation activities. Poor people, for example, are likely to make sure that their children are fed, even though it may mean that they cut down the irreplaceable rainforest or steal from others. A sustainable society will have to maintain itself over time and therefore have interpersonal relations robust enough to sustain not only the social system, but the global ecosystem as well. In this context products could be seen as satisfiers of human needs.

What could then a socially aware company that strives to contribute in a transition to a sustainable society do? It should not only do some randomly selected good things for its stakeholders but could also identify for each stakeholder how each of the above nine human needs might be violated throughout the product lifecycle. Then the company could systematically address all those violations.

Template II – Covering "Concept"

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 conceptual 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 involved components. One should also establish broad ideas of the shape and the kinds of materials of the product and its parts (French 1985). It should also be possible to roughly assess aspects like 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 design constraints and evaluation criteria. Sustainability aspects should play a major role in the concept phase, for example, to stimulate creativity in concept generation and to guide evaluation. Template II thereby gives early indications of negative impacts on ecological and social systems that product concepts might cause throughout their life-cycle.

Template III - Covering "Extended Enterprize"

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. The intent of Template III is to complement this marketing planning by stimulating creativity around possibilities for the company to influence customers' and other stakeholders' preferences, as well as market conditions such as legislation, taxes, subsidies, and other politically decided incentives. This wider business opportunity perspective (extended enterprise) overlaps with the product life-cycle focus normally covered by "extended producer responsibility" (Lindhqvist 1992, 2000). Since it is rarely possible for a single company to fully control the full life-cycle of its products, the TSPD approach promotes cross sector dialogues and business agreements with other companies and stakeholders. Judging the potential for, and timing of, such market influences is important in deciding what product concepts to prioritize.

Case study: Evaluating the Template Approach for TVs at Matsushita

In this section we evaluate 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.

About Matsushita

In 2002 the Matsushita Group consisted of over 300 companies globally, with 290,000 employees, and annual global sales of USD $67 billion.[3] The Matsushita Group operated mainly in four business domains, 60 percent of which was represented by TVs, camcorders, audio equipment, and mobile phones under the Panasonic, Technics, and Quasar brands.

Before the Sustainability Assessment

Around the year 2000 a new legislation trend started in some Northern European countries including Norway (Regulation Regarding Electrical and Electronic Products 1998) and Sweden (Producer Responsibility for Electrical and Electronic Products Ordinance 2000). Japan joined in by passing several basic laws for establishing a recycling based society (Specified Home Appliance Recycling (SHAR) Law 2001). The SHAR law assigns part of the responsibility for end-of-life management of TV sets, refrigerators, air conditioners, and washing machines to producers. Some main driving forces behind this law were the scarcity of final disposal sites and the increase of Electrical and Electronic Equipment (EEE) in the waste stream (Tojo 2004). These legislative developments emphasized Matsushita's need to continue their already successful work with environmental issues. 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 Matsushita was then whether they had

[3] For further detail, see: http://www.matsushita.com

missed any critical sustainability aspects that should be considered for future planning and that could trigger innovation. Matsushita therefore, in year 2000, went to Northern Europe and asked external sustainability experts from the non-governmental organization The Natural Step International (TNSI) for advice (Matsushita 2002).[4] A first step, an overview assessment of Matsushita and its operations, was completed in 2001 (Lindman and Nyström 2001). In the same year, the Japanese law for recycling of specified home appliances was passed and Matsushita established a major recycling plant for electric and electronic waste (METEC). This move made Matsushita a crucial part of the national recycling schemes mandated by this law (Matsushita 2006). As a next step, the sustainability expert then 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. Matushita did not at that time prioritize to get involved with a new detailed method like the MSPD. Instead, they wanted the expert to first identify their main sustainability gaps. This led to the development of the template approach described above.

The sustainability Assessment

According to a leading Japanese TNSI 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.

[4] The lead advisor was Karl-Henrik Robèrt, founder of TNSI and adjunct professor at Blekinge Institute of Technology.
[5] Sukeichi Miki, CTO, Senior Managing Director, Member of the Board in charge of technology, quality and environment at Matsushita Electric Industrial Co. Ltd.

Template I

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

Table 2. *Excerpts from the Matsushita template sustainability assessment (Robèrt 2002) – Template I.*

Time	Triggering questions	Sustainability expert's statements	Matsushita's responses	Sustainability expert's feedback
B (current situation)	Which services does TV currently provide to people? …and what are the overall sustain-ability problems linked to these services?	*"TV is a medium of communicating information and knowledge as a component of a larger human-machine interactive system."* *"…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."*	[Expert's statements applicable, and, in addition]: *"There are some minorities who can send and receive information with multilingual and sign services"* *"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%]."*	[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."* [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 sustain-ability, 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.* *"…producing TV in new ways, through means of dematerializations and substitutions for each SP, seems to be a good idea..."*	[Expert's statements applicable and Matsushita is]: *"Aiming for TV set production in which Reduction and Recycle is pursued thoroughly"* [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…]: *"No comments at all about the business potentials of TV in the developing world are presented."* [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 Dialogue in Template I:

This is based on table 2 and the complete Template I from the original template assessment (Robèrt 2002).

- 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.
- Matsushita opens up to see TVs in a widened perspective beyond current market desires. The potential of TV to function as a transition agent towards a sustainable society and a resource saver is discussed.
- The recycling achievements brought up by Matsushita in their B responses actually rather belongs to Template II (see table 3), as do dematerialization and substitution regarding the product itself brought up by the sustainability expert. The desire to avoid such misunderstandings was one reason behind the new formulation of the triggering questions (see table 1).
- The sustainability expert points out that Matsushita had not convincingly addressed rebound effects from increased efficiencies. In this case, more efficiently manufactured (and therefore also cheaper) TVs may lead to larger material flows from higher sales, as well as to lower incentives for consumers to reuse and recycle. Again, such aspects belong better to Template II where life-cycle implications are discussed.
- Both the sustainability expert and Matsushita failed to include some obvious aspects of the social impact of TVs. Examples are some well known negative health effects due to obesity, passivity, lack of social interactions in person, etc. 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, 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 (Robèrt 2002) – Template II.*

Time	**Triggering Questions**	**Sustainability expert's statements**	**Matsushita's responses**	**Sustainability expert's feedback**
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]: *"…wasteful methods of resource extraction, for example, in mining industry, using unnecessary large amounts of materials in the production of the heavy TVs."* [On substitution aspects]: *"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."* *"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]: *"…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…"* [On substitution aspects]: *"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."* *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]: *"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]: *"…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."* [On substitution aspects]: *"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."* *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]: *"Lightening weight: Substitute PDP (plasma display panel) or LCD (liquid crystal display) and so on for conventional display."* [On substitution aspects]: *"SP I. We are aiming to replace all plastics with metal such as Mg."* *"SP II. We are aiming to abolish the usage of anti-flammable materials containing bromine or chlorine by march 2006."* *"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 Dialogue in Template II

This is based on table 3 and the complete Template II from the original template assessment (Robèrt 2002).

- 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. This is shown for example in the Sustainability expert's feedback:

  > *"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."*

- 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. This is why the reformulated triggering questions in table 1 pinpoint three life-cycle phases that should be covered by the assessment: (i) Resource extraction, supply chain and manufacturing, (ii) Distribution and use, and, (iii) Final disposal or reuse/recycling/land filling.
- The focus in the sustainability expert's statements, Matsushita's responses and the sustainability expert's feedback is, as intended, mainly on product concept details. 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, the Matsushita responses here revolved around the socio-ecological life-cycle impacts of the product concept that Template II was meant to deal with.

Template III

In table 4, 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 (Robèrt 2002) – 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]: *"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]: *"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]: *"A very good example of outreach from Matsushita is the offered possibility to repair TVs."* [Further outreach is also encouraged: *"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…]: *"…merge forces with other companies to either implement new possibilities on private ground or reduce the costs for utilizing already existing infrastructures."* [Influence authorities to promote a sustainability and life-cycle perspective, by developing]: *"…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]: *"…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."* [Lists current efficiency-related problems]: *"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]: *"…getting prices high enough on the depositing of scrap and on extraction of virgin materials and fossil fuels"*

Analysis of Dialogue in Template III

This is based on table 4 and the complete Template III from the original template assessment (Robèrt 2002).

- 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. In step B, for example, the expert encouraged Matsushita to focus on stakeholders to promote less resource consuming societal support systems:

  > *"…merge forces with other companies to either implement new possibilities on private ground or reduce the costs for utilizing already existing infrastructures."*

- 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 still mainly focus on the product itself and its environmental problems and solutions.
- 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:

  > *"… 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."*

Dissemination of Results from 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 main sustainability challenges for Matsushita's TVs. Several actions suitable to deal with those challenges were also identified (Matsushita 2002):

Template I - Market Desires/Needs

- Plans for wider TV service concept.

> *"… develop active plans to […] offer products or services in ways that are not confined to sell TV sets conventionally …"*

- TVs fulfilling basic human needs (e.g., in developing countries).

> *"… consideration should be given to the developing countries, regarding TVs as an asset for achieving sustainable development, also taking into account the need to curb rebound effects from IT, and to develop active plans for its sustainability ..."*

Template II - Concepts

- Increased dematerialization and recycling rates.

> *[Matsushita needs to] " achieve a much higher recycling rate of TVs than is presently occurring. To improve rates, it is also necessary to eliminate impurities from materials used in TVs …"*

- Substituting substances that are persistent and foreign to nature.

> *[Matsushita needs to] "conduct critical investigation of the current activities in relation to Magnesium, before a substitution is made to this metal. An investigation from energy used for mining and processing to recycling, from the standpoint of sustainability […] [In addition to this] "all compounds that are persistent in and*

foreign to nature need to be phased out, and to that end a more rigorous analysis of chemicals needs to be done."

- Long term vision within sustainability constraints and supply chain management guidelines.

"For the supply chain, guidelines are necessary for sustainable use of forest resources, strip-mining processes, and restoration of natural systems after resource extraction" [and, to] "define and declare Matsushita's long-term vision that complies with The System Conditions of a sustainable society..."

Template III - Extended Enterprise

- Promoting sustainability through stakeholders.

"… promote wider communication and influence the society at large […] [by] forming partnerships with other businesses, universities, and governmental institutions, as well as approaching customers …"

Some Related Events after the Sustainability Assessment

Improvements in Reporting

Matsushita Electric Group 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 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 TNSI (Takami 2006) that the idea of a wider societal outreach that was suggested in the Extended Enterprise template was really

[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

helpful and, in the years to come, Matsushita did much to educate consumers about products with improved sustainability performance. Matsushita has also re-invited TNSI 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.

Improvements "on the Ground"

Inspired by the promising results from the TSPDs on TVs and refrigerators, Matsushita in 2003 went on to make a TSPD for their recycling plant (METEC) (Robèrt 2003). In the same year, Matsushita launched a Green Procurement initiative with ranking of chemical substances for information in product design, aiming to reduce environmental loads (Matsushita 2003). This measure was consistent with the recommendation from template II to substitute substances that are persistent and foreign to nature. In line with recommendations from Template III (to promote sustainability through their stakeholders), Matsushita continued to encourage customers to minimize environmental impact by awareness–raising on the correct usage of products. They also continued to offer repair services and improved their customer services. Also in line with Template III, Matsushita in 2003 established a personnel system to "approve diversity in values and work together to ensure safety" (Matsushita 2003).

Corporate Social Responsibility (CSR) emphasizes the need for organizations to consider the interests of society by taking responsibility for the impact of their activities on stakeholders and the environment. In the early 2000's the international CSR movement had a breakthrough in Japan, bringing social sustainability to the attention of top management (Takami 2006; Tojo 2007). Many Japanese corporations, including Matsushita, started new CSR departments to deal with these issues. Matsushita also developed something called the Clean Procurement Declaration, which meant to ensure compliance with new supplier selection standards which included social and ecological concerns (Matsushita 2006). This was in line with the recommendations from Template II to include sustainability issues in supply chain management guidelines. In their updated overarching sustainability assessment that was performed in 2004, TNSI recommended Matsushita to promote green procurement tools and to expand their CSR efforts. Furthermore, Matsushita was encouraged to not only make their TVs and other products more effective but also to deal with the potentially increased cumulative negative effects from larger sales volumes of the more effective and cheaper TVs (rebound effect). Finally, TNSI suggested that Matsushita should improve their sustainability vision and update their strategy accordingly.

In 2005 the Swedish policy on extended producer responsibility for electrical and electronic equipment went into effect. In the same year, Matsushita launched a design project for disassembly called “3R Eco Project” and phased out several of the substances that were targeted for substitution one year later by the EU RoHS directive. This included Lead, Mercury, Cadmium, Hexavalent Chromium, and two brominated flame retardants (PBB and PBDE) (Matsushita 2006). These measures were in line with recommendations from Template II (to increase dematerialization and recycling rates and to substitute substances that are foreign to nature). In the same year TNSI made an analysis of Matsushita’s climate change initiatives (Oldmark and Wännerström 2005).

In 2006, the final versions of several influential sustainability related EU directives were taking shape. These included the “Restrictions of Hazardous Substances in Electrical and Electronic Equipment (RoHS)”, the “Waste Electrical and Electronic Equipment (WEEE)” and the “Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)”. This meant that companies, like Matsushita, that intended to continue to do business on the EU market had less than a year left to adapt their activities to comply with these directives. In 2006, Matsushita made several product related improvements that were in line with recommendations from the template assessment (Matsushita 2006):

- The “New Lifestyle Household” concept with resource efficient home appliances was presented (Template I: Widen the TV-service concept!).
- The recycling rate of used TVs had reached about 70% (Template II: Increase dematerialization and recycling!).
- The company continued to focus on substituting substances targeted by the RoHS directive (Template II: Phase out substances that are foreign to nature!).
- For the first time Matsushita talked about the need to move beyond improving the efficiency of their products to also look at measures that may deal with the increased energy needed for all appliances sold in China and Asia (Template I: Deal with rebound effects of improved TV efficiencies!).
- Matsushita introduced an Early Quality Monitoring system to incorporate customer feedback in daily operations (Template II: Promote sustainability also through work with stakeholders!).

In the same year, TNSI updated the overarching sustainability assessment of Matsushita's operations and also facilitated a dialogue on the new Matsushita Green Plan for 2010 (Matsushita 2006).

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 captures overall sustainability aspects of the life-cycle of a certain product category. The TSPD approach has in the Matsushita case demonstrated to be a functional basis for dialogue about sustainability related issues within the company and thereby facilitating sustainability related decision making later on. Based on the case study we therefore argue that the TSPD approach has the qualities we looked for in our three research questions:

(i) Shifting focus from gradual improvements of a selection of aspects in relation to past environmental performance, to a focus on the remaining gap to a sustainable situation.

The study indicates that, at least in the Matsushita case, the TSPD approach did shift the focus of the client organization towards its sustainability gap. The mechanisms for this were 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 Matsushita to widen their perspective beyond environmental performance to also 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 a common understanding among different organizational levels of major sustainability challenges and potential solutions.
The top management commitment to support sustainability efforts in product development indicates that the TSPD approach indeed facilitated a sustainability communication between top management and product development levels. One concrete 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."*

It is mainly Templates I and III that facilitate communication between organizational levels. 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 organizational levels need to work with societal outreach and value-chain cooperation. The dematerialization and substitution considerations in Template II are at first mainly of interest to product developers but could also link to top management levels, for example when large investments are needed for certain dematerialization and substitution measures. The initial Matsushita responses in Template III, though, were not in line with this template's visionary perspective but rather examples of some isolated actions that had been successful recently. Therefore, in the feedback, the sustainability expert challenged the top management to bring in such perspectives. Bringing the most essential sustainability aspects to the attention of the top management would probably also increase their willingness to allocate resources to the product development level when there is a need for more in-depth sustainability assessments with methods and tools like the MSPD and/or LCA.

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.

(iii) Facilitation of a continued dialogue with external sustainability experts, identifying improvements that are relevant for strategic sustainable development.

It appears from the study that the TSPD approach influenced the organization’s ability to identify product improvements relevant for strategic sustainable development. Matsushita gained more sustainability knowledge and a better overview of the sustainability implications of the studied product category (TVs). They later studied other products (their refrigerators and their recycling plant) in the same way, and developed more comprehensive cooperation with societal stakeholders (mainly customers but also employees, authorities and suppliers). Over the years to come, Matsushita gradually deepened their dialogue with external experts and showed progress in relation to the sustainability requirements identified in the initial sustainability assessments. This progress was also likely influenced by the increasing pressure from customers and from Japanese and EU product policy legislation (e.g. WEEE, RoHS and REACH). Subsequent award-winning sustainability reports and top management statements showed that Matsushita’s sustainability reporting improved during the same time period. 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 focus on the wider dimensions of sustainability, and new yearly assessments have followed (Matsushita 2003, 2004, 2005). Even though the template approach was successful in this context, some of the observed 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. This could reduce the total time for this type of assessment due to a smaller need for corrective feedback. We also believe that the new formulation of the triggering questions in table 1 will help avoid misunderstandings.

After the first use of the template approach at Matsushita several new templates and related approaches have been developed. Several technical and sustainability-related assessment tools (including the template approach) have been integrated in a new suggested iterative design optimization procedure (Byggeth et al. 2007a). This procedure was tested for water jet cutting machines and led to the identification of concrete design changes that could reduce electricity consumption and improve cutting accuracy at maintained cutting speed. Another application of the template approach is an assessment approach aimed at identifying strategic capabilities of company decision systems (Hallstedt 2008). A number of master theses have also used the template approach for a range of topics, including sustainable biofuels development (Franca et al. 2006), SSD for clean development mechanisms under the Kyoto Protocol (Dyer et al. 2006) and strategic sustainable development (SSD) for business incubators (Blankenship et al. 2007).

In future research, in order to improve the usefulness of the template approach, we plan to further our ability to track how template suggestions are transformed into concrete design changes and to what degree those changes help products to progress towards sustainability. We also 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 modeling and simulation 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 V

Introductory procedure for sustainability-driven design optimization

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Introductory procedure for sustainability-driven design optimization

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and Karl-Henrik Robèrt

Abstract

In response to the increasingly competitive global market, there is a growing interest in design optimization. Being able to include aspects of socio-ecological sustainability in product design should aid companies to both improve current competitiveness and to identify viable long-term investment paths and new business opportunities in the evolving sustainability-driven market.

A case study of a water jet cutting machine is used to illustrate a new iterative optimization procedure that combines a technical assessment with a sustainability assessment. Sustainability assessment methods/tools are first used to identify prominent sustainability problems from present-day flows and practices ("societal indicators") and to generate ideas of long-term solutions and visions. Based on this, preliminary ideas about likely desirable changes in machine properties are obtained. Technical investigations are then performed to assess if/how these particularly desirable changes in machine properties could in principle be realized through changes in design variables. After that, obtainable changes are fed back to a new and more refined sustainability assessment to find out the societal implications of these changes. This may in turn result in other desirable design changes, which may call for a new and more refined technical assessment, etcetera.

The experience from the case study indicates that the suggested integrated and iterative working procedure should be able to add information about socio-ecological impacts of product properties and influence design criteria used in prioritisation situations during product development.

***Keywords**: product development, optimization, sustainability assessment, simulation, water jet cutting*

1. Introduction

Product innovation is a particularly critical intervention point for the transformation of society towards sustainability. Overuse of resources and socio-ecological impacts of production, distribution, use and disposal are evidence that current methods of decision making during product innovation are insufficient. In many cases, the majority of a product's socio-ecological impacts are already committed at the design phase. Being able to include aspects of socio-ecological sustainability in product design should therefore aid companies to improve current competitiveness as well as to identify viable long-term investment paths and new business opportunities in the evolving sustainability-driven market.

Several methods/tools have been proposed to integrate environmental aspects into product development. Some examples are 'cleaner production', 'pollution prevention', 'eco-design', 'design for (the) environment', 'design for recycling', and 'sustainable product development' [1-3]. There is however, a slow progress in the actual "greening" of products. Reasons may include limitations in time and economic resources for an effective application of eco-design methods/tools [4, 5], or there may be a lack of incentives other than the expected environmental benefit [6]. In addition to that, some of today's eco-design tools have a rather vague connection to the social and/or business dimension of sustainable development [7]. Some methods/tools have been developed with the specific aim to bridge this gap. This includes a Method for Sustainable Product Development [8], Strategic Life-Cycle Management [9], Templates for Sustainable Product Development [10], and Systems Modeling within Sustainability Constraints [11, 12].

Assessment of the technical functionality of a design proposal is another important part of product development. This could be done through physical testing or computer simulation. A major advantage of computer simulation is that the number of design proposals that could be tested within a limited frame of time and money can be significantly increased compared to physical testing [13]. Simulations of some technical aspects of a product are often used to aid product design optimization. A virtual machine, for example, has been used to investigate how particularly desirable changes in machine tool properties could be realized through changes in design variables [14, 15]. Such optimizations have, however, often a relatively narrow focus on technical and to some degree business economic aspects. To avoid sub-optimization, the economic perspective should be better integrated in prioritization decisions. They should also take into account the use phase of the product [16]. And foremost, to our knowledge, there is no commonly used optimization procedure that combines life-cycle parameters from a sustainability assessment with parameters from a technical assessment. Such a combined optimization procedure might provide valuable support for sustainable product development.

This paper provides basic ideas for an iterative optimization procedure that combines a technical assessment with a sustainability assessment. In this way, it might be possible to find win-win-win situations for the company, the customer and society as a whole and thus to avoid some trade-off situations early on. The procedure is introduced through a case study.

2. Case Study - Water Jet Cutting

2.1 Case Relevance

Water jet cutting is used as a first case study, mainly due to its good basic potential to be an effective and sustainable manufacturing technology. Some advantages are high accuracy and flexibility, low work piece material losses and inert and abundant main processing substances (water and sand). It is also possible to cut in different types of material and material thicknesses. Compared to most other cutting techniques, there is also often a lesser need for post-operations, due to low thermal and mechanical influence on the work piece.

2.2 Water Jet Cutting Technique

Water jet cutting is a manufacturing technique that uses the erosion power of water and sand to shape the work piece. The basic principle is to channel highly pressurised water through a narrow nozzle in the cutting head, concentrating a high amount of energy in a small area and thereby creating the cutting power. Others have described this in more detail [17]. A typical water jet cutting machine design is shown in Figure 1.

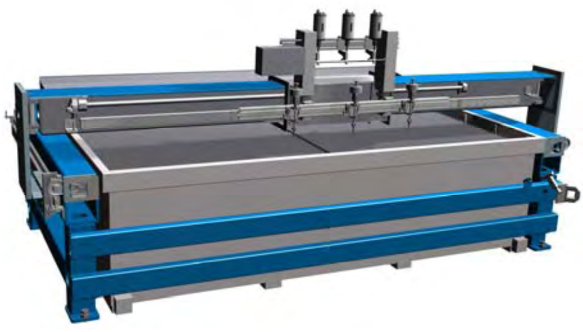

Figure 1. *Example of a water jet cutting machine.*

2.3 Case Working Procedure

The first step of an integrated assessment is to gain an initial understanding of what conceptual designs to assess and in relation to what product design criteria. Here, the focus is already set on water jet cutting machines – both today and in a sustainable future. The product design was initially focused around technical performance like cutting accuracy and speed but other relevant objectives should be clarified through the iterative integrated assessment.

Successively more and more refined sustainability assessments were carried out using methods/tools like:

- Strategic Life Cycle Management (SLCM) [9] based on the ABCD-procedure for Backcasting from Sustainability Principles [18, 19].
- Templates for Sustainable Product Development (TSPDs) [10].
- Causal Loop Diagrams (CLDs) and resulting Reference Behaviour Patterns (RBPs) [11, 12, 20-22].

In parallel, more and more refined technical assessments were carried out using methods/tools like:

- Intuitive thinking, supported by highly simplified models for which an analytical solution could be found through hand calculations.
- Simulation using more detailed models that call for numerical solutions, for example, the finite element method.
- Multi-disciplinary simulation of the complete system using a "virtual machine" [14, 15].

The two simulation domains mutually influence each other, so there is need for iterations between them (see Figure 3 and 4). Since the main purpose of this paper is to suggest a working procedure, only some illustrative results from the assessment of water jet cutting are presented below.

2.4 Sustainability Assessments of the Water Jet Case

2.4.1 Strategic Life-Cycle Management

SLCM and ABCD are methods/tools for overarching sustainability assessments. An ABCD identifies the main potential sustainability-related problems and principle solutions for a certain company, product or activity. Such an assessment could be upgraded to an SLCM by more systematically integrating a life-cycle overview, including supply-chain, manufacturing, use and reuse, recycling or disposal. Both methods also give suggestions for how to prioritize between potential solutions to the problems. In this study SLCM was used to make an initial overarching strategic action plan of the water jet cutting company and its life-cycle activities. This also gave input to a template for sustainable product development, and other related assessment and communication tools that are described below.

Among other things the SLCM showed that electricity use could be a concern relative to other properties (see B-step in Table 1). This is due to the current generation of the electricity in unsustainable energy systems. This led to recommendations like buying electricity from renewable energy sources, mapping out and reducing energy and material use, etc (see steps C and D in Tables 1 and 2).

2.4.2 Templates for Sustainable Product Development

This is an approach to compile and communicate narrative statements from a sustainability expert on potential sustainability problems/benefits of a studied product concept and related principle solutions [10]. This is to trigger creativity in product development teams, and starting their sustainability assessment from an informed position. The template approach is particularly intended for the early stages of the product innovation process when the design freedom is still large. In this study the template approach was used to clarify product development consequences of the overarching sustainability problems/benefits and principle solutions from the SLCM assessment of the water jet cutting company. The results of the TSPD and SLCM were also later used as input to a Causal Loop Diagram (CLD), giving a systems description of water jet cutting in a sustainability context.

The TSPD added to the sustainability assessment, among other things, a concrete recommendation to focus on reducing the weight of the moving parts in the water jet cutting machine (see template IIC in Table 3) but without reducing its manufacturing accuracy and speed. This would reduce the energy use for water jet cutting activities throughout the machine life-span, which would in turn reduce the impacts of unsustainable energy systems such as climate change. Other ways to reduce energy use were also identified such as improved jet efficiency.

Table 1. *Steps B and C of an SLCM assessment. Examples of sustainability problems/benefits in relation to Sustainability Principle 1 (B-step) and action ideas (C-step).*

ABCD Assessment Step		**Life-Cycle Phases**	
	Assembly	**Use**	**Waste management**
B (Current problems/bene-fits)			
SP 1	- Use of virgin scarce metals in electronics	- Electricity use for moving parts and water pump	- Use of fossil fuels in waste transportation
SP 2	- …		
SP 3	- …	- …	- …
SP 4	- …	- …	- …
		- …	- …
C (Action Ideas)	- Design for disassembly and recycling - … - … - … - … - …	- Reduce material and energy consumption through improved design - Improve jet efficiency - Map out life-cycle material and energy use -… - …	- More compact machine design would reduce waste generation and trucks could be substituted by railroad transportation … - … -… - …

Table 2. *Step D of an SLCM assessment. Examples of how action ideas from the C-step are prioritized and planned.*

Actions	**Priority (time frame)**		
	Very High (yr 1)	**High (yr 2-5)**	**Medium to Low (yr 6+)**
- Map out life-cycle material and energy use	>>>>>>		
- Reduce material and energy use through improved design		>>>>>>>>>>>>	
- Design for disassembly and recycling		>>>>>>>>>>>>	
- Improve jet efficiency		>>>>>>>>>>>>	>>>>>>>

Table 3. *Examples of sustainability problems/benefits and action ideas resulting from TSPDs.*

TSPDs for Water Jet Cutting			
I. Market Desires /Needs	**II. Concepts**	**III. Extended Enterprise**	
Current market desires addressed: … ”Water jet is used to cut different materials in high accuracy applications like the automobile and aircraft industries” … … “Waterjet is a resource efficient and relatively safe cutting technology that helps creating a good factory working environment.” …	**Conceptual design of today's product:** ...”water jet cutting uses fossil fuel based electricity and thereby contributes to increasing atmospheric CO_2-concentrations” - **…** - **…**	**Current stakeholder communication /cooperation:** … “there is a lack of cooperation ,e.g., for material recycling “… - **…** - **…**	**B (current problems/benefits)**
Likely future market desires to address … “Cutting speed and accuracy will need to be improved” … - **…**	**Likely conceptual design of future product:** …”Focus on reduced moving weight” … … “Focus on a self sufficient system with internal recycling of sand and water” … - **…**	**Likely future stakeholder communication /cooperation:** …”start strategic cooperation with material recycling companies to improve purity of recycled fractions”… - **…**	**C (future action ideas)**

2.4.3 Causal Loop Diagrams and Reference Behavior Patterns

A Causal Loop Diagram (CLD) is a method/tool that aims to clarify the causal structure between variables of a given problem. The variables are connected with positive and negative arrows, which denote that the target variable is either increased or decreased by an increase in the source variable. A Reference Behavior Pattern (RBP) intends to map out potential behavior over time for key variables of the CLD. The system boundaries of a CLD are largely set by the specific question that it should try to answer. This study used an initial CLD that after some iterations was focused on investigating the following question: What are some relations between the water jet cutting life-cycle (and machine performance), its sustainability impacts and customer demand for water jet cutting?

The CLD assessment resulted in a widened perspective on the driving forces behind the sustainability impacts of water jet cutting (Figure 2). It was shown that improved technical performance (e.g. reduced moving weight, increased cutting accuracy and/or increased speed) could have an important role in reducing the energy and material use of the water jet cutting life-cycle. Related sustainability impacts and costs could also be reduced. The CLD assessment also opened up for a later assessment of the socio-ecological consequences of the design changes that were suggested by the technical assessment. More sophisticated technical reasoning was also initiated. For example, it was found that a decreased moving weight might reduce other aspects of machine performance like cutting accuracy and speed. Reduced accuracy could lead to an increased need for post-operations that, in turn, could increase the energy demand of the whole manufacturing process and also add other negative side-effects from a larger sustainability perspective. Moreover, if a high cutting speed is not maintained the water consumption might increase, which is negative from a sustainability perspective. Because of these possible relationships between lightness, accuracy and speed, a minimum requirement for accuracy and speed was set before the optimization study (see below).

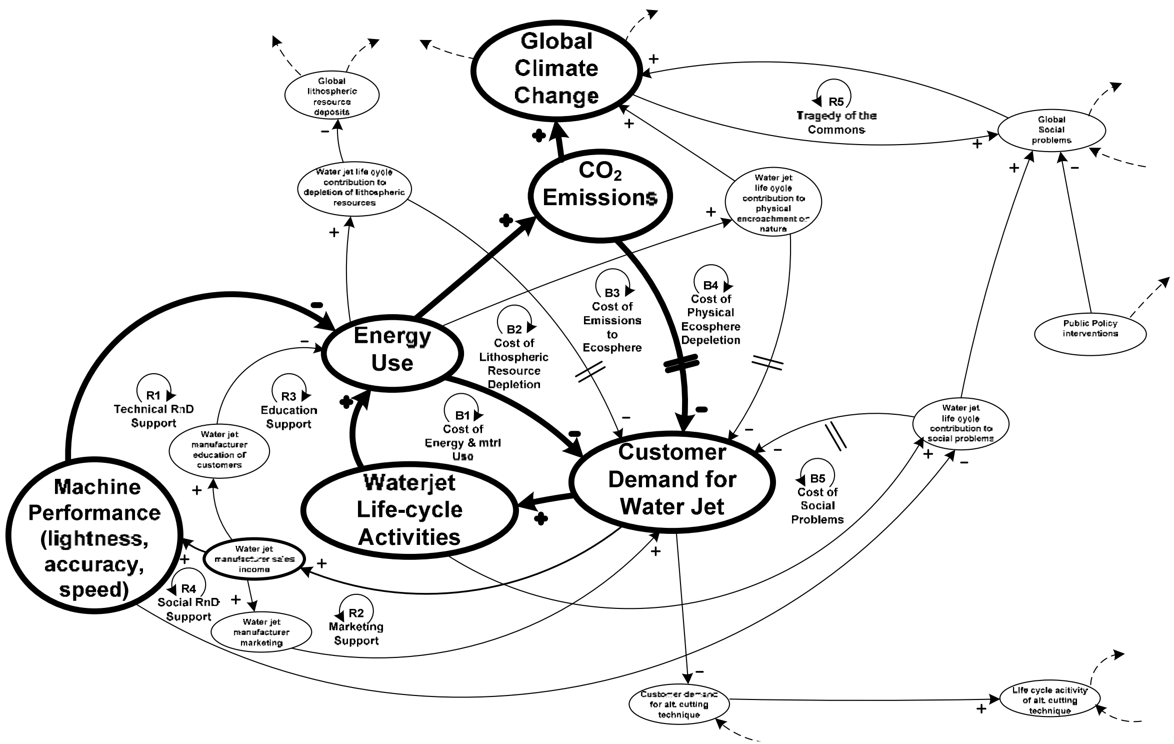

Figure 2. *Causal Loop Diagram with emphasis on how improved machine performance (e.g. reduced moving weight) could reduce energy use and thereby indirectly both (i) increasing customer demand for water jet cutting and (ii) decreasing CO_2 emissions and its related contribution to climate change.*

2.5 Technical Assessments of the Water Jet case

2.5.1 Estimations and Hand Calculations

The first step in an assessment of the technical aspects of a conceptual design might be to derive a highly simplified mathematical model for which an analytical solution could be found through hand calculations. This study includes, in the present case, an estimation of stresses in the structure due to bending loads arising from normal operation of the machine. Preliminary results indicate that a lighter and less stiff design could in principle be used without risking structural failure.

2.5.2 Finite Element Calculations

A more detailed model takes the hand calculations further to include more product components, more realistic representation of included components and their interactions and boundary conditions. In the general case it then often becomes difficult to describe a product simply enough to find an analytical solution. Therefore, numerical methods, for example, the finite element method, are frequently used. Parameter studies might also be conducted to increase the knowledge about the studied system. In the present case a finite element model of the machine was used in a parameter study to sort out, for the specific design criteria, influential design parameters.

2.5.3 Virtual Machine Modeling and Simulation

Machine tools are mechatronic systems, i.e. multi-disciplinary products including mechanical as well as electronic components and intelligent computerized control systems. Design of such systems demands an overall understanding of the behaviour of the complete system. More advanced simulation tools are therefore needed, incorporating all relevant aspects of the multi-disciplinary design problem. A previously developed virtual machine concept could be used in this context [14]. This virtual machine includes a real control system, a hardware-in-the-loop simulator of the machine and a virtual reality model for visualisation. It is used within a parallel multidisciplinary design approach, simultaneously analysing the mechanics and the control, and thereby utilising interaction effects. This approach has been shown to be superior to the traditional sequential design approach [15].

The virtual machine used in this study contained several sub-models; a finite element model simulating the flexibility of the moving mechanical parts, a motor model, and a multi-body model of the transmission. The simulation model was parameterized and automated. This means that the optimization algorithm was able to influence the model by varying certain aspects of it, like its geometric quantities and/or material properties. Given the input from the sustainability assessment, all major moving machine components were identified and parameterized in the virtual machine.

2.5.4 Virtual Machine Optimization Study

A design optimization study needs to clarify both what the objective is and how design parameters can be varied to achieve this objective. Then there needs to be some algorithm that identifies which design parameter combination that best fits the objective. The primary objective of this optimization study, to reduce the weight of the main moving components, came from the TSPD sustainability assessment. Two other essential machine performance objectives, high cutting accuracy and speed (i.e. the time it takes to cut the work piece), also need to be considered. Also these objectives have sustainability implications, which were clarified from the CLD and the related above discussion. Both for this reason and for ensuring traditional competitiveness of the new alternative machine designs that were scrutinized by this optimization study, cutting accuracy and speed where not allowed to decrease in relation to current levels. Some key design parameters of the mechanics and the control were then chosen as variables in the optimization study. The design problem therefore consisted of a mixture of continuous and discrete variables. A genetic algorithm was chosen since such have the ability to solve problems of this type. By including both mechanical and control system parameters simultaneously in the optimization study, the potential trade-off between lightness and accuracy and/or speed could actually be avoided in this case. The optimization study revealed a significant potential for design improvements. The weight of the main moving components can be reduced by more than 30 percent, at the same time as the cutting accuracy can be improved by more than 60 percent at maintained cutting speed (small increase by 2 percent).

2.6 Societal Sustainability Consequences

The above described CLD (Figure 2) could also be used to estimate societal consequences of design changes suggested by the technical assessment. In this case, the effect of reduced moving weight was in focus and in particular how this would lead to lower energy use and, indirectly, lower CO_2 emissions and, in turn, less contribution to global climate change. In general, energy savings often make both the organization's and society's transformation towards sustainable energy systems easier for several reasons. Energy savings could, for example, reduce costs and thereby enable investments in substitution to new renewable energy sources. Since not the whole previous amount needs to be replaced by new energy sources (due to energy savings), the transformation could proceed faster towards renewable and more sustainable energy sources.

If electricity use is proportional to the moving weight then it would be possible to reduce electricity use by up to 30 percent. The power use for electric motors driving the moving parts of an average water jet cutting machine in normal operation is about 3 kW and it normally runs 1500 hours per year. Furthermore, if it is assumed that the improved water jet cutting machine replaces cutting equipment that is at least as polluting, the 1 kW of power savings could be assumed to be a minimum net reduction. Saving 1 kW for a machine that runs for one operating year (1500h) would translate into 1500 kWh per year. Assume that the machines are used in the United States. The above energy savings would then (based on the mix of energy sources in US electricity [23] and the CO_2 emissions per kWh of those energy sources [24]) translate into a CO_2 emissions reduction of 315 kg per machine and year. This quantification of energy savings (dematerialization) could then be used in various scenarios.

3. Result

The water jet case shows the potentials for an integrated sustainability and technical assessment. The working procedure is interactive and iterative in order to finally suggest what design variables that have the most significant socio-ecological impacts (Figure 3).

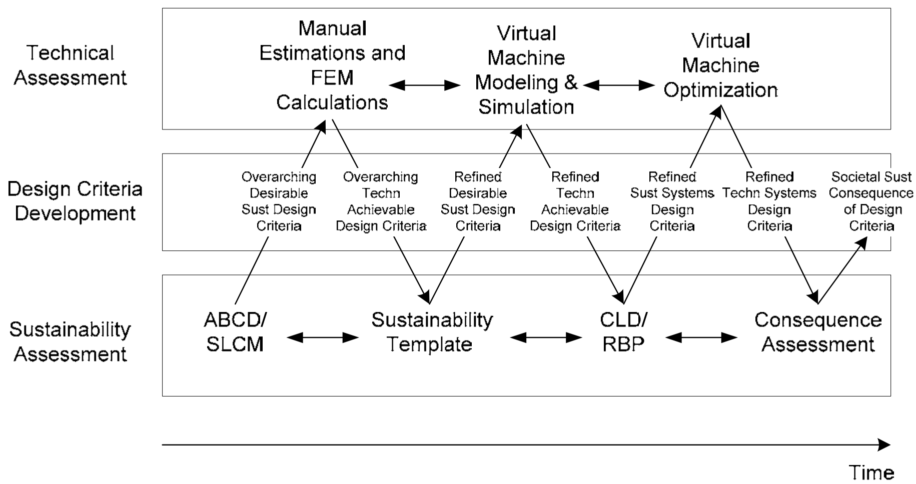

Figure 3. *Gradual refinement of product design criteria through an integrated and iterative assessment.*

The new integrated assessment procedure could be expressed in general terms (Figure 4). Overarching sustainability assessment methods/tools, should first scrutinize water jet cutting (and to some extent competing techniques such as laser- plasma- and gas cutting) to identify prominent sustainability problems from present-day flows and practices ("societal indicators"). Ideas of long-term principle solutions and visions are also generated, and then based on this a first rough idea about likely desirable changes in machine properties is obtained. Introductory technical investigations are then performed to assess if/how these particularly desirable changes in machine properties could in principle be realized through changes in design variables. Obtainable changes are then fed back to a new and more refined sustainability assessment to find out the societal implications of these changes. This may in turn result in other desirable design changes, which may call for a new and more refined technical assessment, and so on.

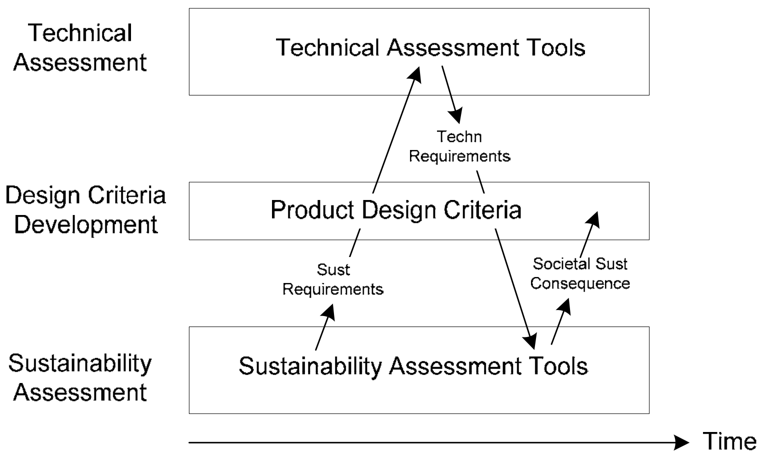

Figure 4. *A suggested generic working procedure for an integrated and iterative sustainability and technical assessment.*

4. Discussion & Conclusions

This paper suggests a working procedure for a combined sustainability and technical assessment in order to facilitate design optimization informed by a societal perspective. Preliminary ideas are presented through a case study of water jet cutting. Both overarching and more detailed sustainability-related and technical methods/tools are used iteratively to arrive at design changes that are likely to support sustainable development of society.

The initial sustainability assessment resulted in a list of desired changes, in particularly sustainability related product properties for water jet cutting machines. This included the weight of the moving parts, the life-span of the product components, the recycling system of the abrasive material and a cleaning system for the process water. Out of these, a reduced weight of the moving parts was introduced as an added goal in the technical optimization study. The main reasons for focusing on this single property were that (i) moving weight is connected to energy consumption during use and this is currently a major contributor to sustainability problems like climate change, (ii) the moving weight is relatively easy to change through material choices and geometry optimization, (iii) the moving parts could also be modeled separately from other complicated subsystems like the water jet and its penetration of the material that is cut, and (iv) the main purpose of this paper is to introduce some preliminary ideas for - and not to perform a full - combined sustainability and technical assessment.

The technical study resulted in a *theoretical potential* for reducing the weight of the main moving parts by more than 30 percent, while simultaneously improving cutting accuracy by more than 60 percent and increasing the manufacturing speed by two percent. Reduced weight also indirectly reduces the need for steel and other materials that the water jet machine consists of. This means that negative sustainability effects from those material life-cycles could be reduced as well. Other authors have suggested a computer model for optimizing *the practical use* of a water jet cutting machine [16]. That study suggests that it could be possible to increase the cutting speed and thereby reduce the operating and maintenance costs by changing operational parameters like abrasive flow rate, water pressure and number of used cutting heads. As found in the current study, an increased cutting speed could be beneficial also from a sustainability point of view.

Product development considers several criteria like costs, quality, ease of maintenance, etc. It is here suggested that a necessary addition to this picture is the consideration of socio-ecological implications of product properties. An integrated and iterative procedure should also be used to reach a satisfactory solution from technical, business-economic and socio-ecological perspectives. Furthermore, it is suggested that such sustainability-informed optimization should be included particularly in the early phases of the product development process. This would aid the ability to make well-informed decisions early on and thus potentially identifying innovative solutions for the evolving sustainability-driven market. It would also potentially avoid costly and difficult changes later in the product development project. The experience from the case study indicates that the suggested working procedure should be able to add information about socio-ecological impacts of product properties and influence design criteria used in prioritisation situations during product development.

Future research will address how to further clarify how technical and sustainability-related assessments could be effectively coordinated to support prioritization in product development. Another upcoming research focus is the prioritisation process itself. Future studies will also include other products and methods/tools like quantified sustainability-related systems modeling and simulation and life cycle assessments.

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Paper VI

An approach to assessing sustainability integration in strategic decision systems

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An approach to assessing sustainability integration in strategic decision systems

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Abstract

Once a company has decided to integrate sustainability into its business strategies, the question of what decision support that could be applied becomes essential, and specifically at what organizational level what type of support should be used. This article aims at an approach to assess sustainability integration in a company's strategic decision system and some generic guidelines for how to improve it.

A new assessment approach based on guiding questions was developed and tested in two small and medium sized companies and two large companies. Strategic capabilities of their decision systems were identified – both in general and in relation to sustainability. The results were validated against experiences made with a large number of clients by two management consultancies.

We suggest that systematic integration of sustainability in company decision processes and the development of more sustainable products should be facilitated by:

(i) creating an overarching supporting organizational context, including senior management awareness and commitment to a widely adopted definition of sustainability, sustainability integration in business goals and policies, and, to that end, adequate resource allocation,

(ii) institutionalizing internal company capacity building and communication on sustainability,

(iii) introducing integrated methods, tools and indicators for both senior management and product development teams that focus on how to close the gap between the present situation and long-term socio-ecological sustainability.

Our study indicates that the assessment approach, as intended, could be used as a generic template to assess the current state of sustainability integration in company decision systems.

Keywords: *strategy, decision systems, decision support system, sustainability, sustainable development, product development, organizational communication*

Introduction

The Global Sustainability Challenge and Emerging Decision Support

There is a growing consensus among scientists of various fields that society is currently on a long-term unsustainable course (Meadows et al. 1972; Steffen et al. 2004; Millennium-Ecosystem-Assessment-(MA) 2005; Gore 2006; Stern 2006; Intergovernmental-Panel-on-Climate-Change 2007). The main upcoming human challenge will be to collectively make the transition to a sustainable society. Companies that acknowledge this sustainability challenge will probably also see the business case in systematically diminishing their contribution to society's unsustainability (Holmberg and Robèrt 2000). Such companies will increase their chances to improve their brand value, avoid costs and see new market opportunities (e.g. Willard 2005). In the near future companies will need to formulate their business goals within global socio-ecological sustainability constraints and learn how to strategically plan and invest accordingly.

In response, a vast range of methods, tools and concepts have been developed, each focusing on certain aspects of this challenge. These include Environmental Management Systems (EMSs), Life Cycle Assessments (LCAs), cleaner production and eco-design (de Caluwe 1997; van Weenen 1997; Tischner et al. 2000; Robèrt et al. 2002; Byggeth and Hochschorner 2006) and various kinds of ecological indicators like ecological footprint (Rees and Wackernagel 1994) and Factor 10 (Schmidt-Bleek 1997). The recent emergence of Corporate Social Responsibility (CSR) and triple bottom line reporting indicates that companies now also have started to emphasize the social sustainability dimension (Global-Reporting-Initiative 2006).

The growing number of sustainability-related methods, tools and concepts has led to a new challenge – to explain how they relate to each other and when each should be used when planning for sustainability. A unifying "Framework for Strategic Sustainable Development (FSSD)" has been developed to systematically deal with sustainability, and to select and inform applicable decision support (Robèrt 1994; Holmberg 1998; Holmberg and Robèrt 2000; Broman et al. 2000; Robèrt 2000). This framework is also called "The Natural Step (TNS) Framework" from the NGO that has facilitated its development and application. Several sustainability pioneers have already used this framework to assess how their respective methods, tools and concepts relate to sustainability and to each other (Robèrt et al. 1997; Holmberg et al. 1999; Rowland and Sheldon 1999; Robèrt et al. 2000; Robèrt et al. 2002; Korhonen 2004; MacDonald 2005; Ny et al. 2006; Byggeth and Hochschorner 2006; Byggeth et al. 2007). The FSSD has also been used and implemented by both policy makers (Rowland and Sheldon 1999; Cook 2004; Robèrt et al. 2004; James and Lahti 2004; Gordon 2004) and business leaders (e.g. Electrolux 1994; Robèrt 1997; Anderson 1998; Nattrass 1999; Broman et al. 2000; Leadbitter 2002; Matsushita 2002; Nattrass and Altomare 2002; Robèrt 2002; TNSI 2002).

Sustainability still not sufficiently implemented

In spite of the increasing awareness of the business case for sustainability and the growing knowledge of how to integrate sustainability into business, the majority of companies has not yet moved on to implementation (e.g. Strandberg 2002; Forum-for-the-Future 2003; van Marrewijk 2003). Bob Willard (2005) has a similar standpoint and, based on several case studies in pioneering companies, he talks about five stages of sustainability integration:

- ***Pre-Compliance:*** ignoring sustainability and opposing related regulations
- ***Compliance:*** obeying laws and regulations on labor, environment, health and safety.
- ***Beyond Compliance:*** recognizing the opportunity to cut costs mainly through higher resource efficiencies and reduction of waste, leading to both financial and ecological gains. Sustainability is still separated from core business development.
- ***Integrated Strategy:*** Sustainability is integrated in the company's vision and informs key business strategies to be more successful than competitors through innovation, design, and improved financial risk

assessments. According to Willard, very few companies in the world have yet arrived at this stage.

- ***Purpose and Passion:*** This is actually not a next stage of development for most companies but rather a special type of companies, being originally designed to 'help saving the world'.

How then, can decision support be developed and applied to facilitate companies moving towards the fourth integrated stage above and make decisions that effectively bring them closer to sustainability?

Purpose

The purpose of this article is to develop an approach to assess sustainability integration in a company's decision system and to find some generic guidelines for how to improve it. The following question is then central: *what decision support could be applied, and specifically at what organizational level should what type of support be used, to facilitate decisions that effectively takes the company towards sustainability?*

Terminology and Background Methodology

Decision Support Systems and Organizational Levels

Research on decision-processes and decision support systems is inter-disciplinary, including fields like computer science, cognitive psychology, business management and product development theory. The term decision support system normally refers to a computer-based software or, more specifically:

> "interactive computer-based systems that help decision-makers utilize data and models to solve unstructured problems" (Sprague and Carlson 1982, p. 4)

Decision support systems have been described and classified in several different ways. Alter (1980) divide them according to what types of generic operations they can support (e.g. data analysis and optimization) and Power (2004) focuses on their dominant technology component or driver (e.g. communications-driven and data-driven). This study takes an overarching perspective on decision systems including not only methods, tools and concepts used in decision support systems, but also information processed and actors involved at different organizational levels. Decisions about sustainability and other long-term strategic challenges are naturally taken mainly at the senior management level, whereas other organizational levels, such as product development teams, hopefully are aligning their work with the strategic direction. Senior management and product development levels, and their interaction on sustainability related decisions will therefore be studied in more detail (figure 1).

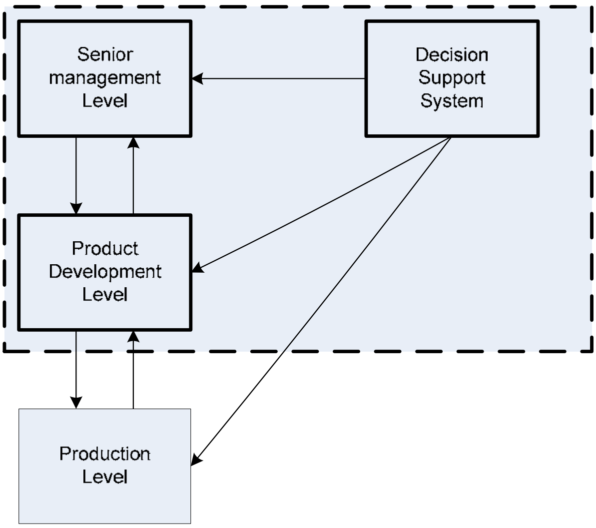

Figure 1. *Decision system in a company with focus on interactions between decision support system, and senior management and product development levels.*

A Framework for Strategic Sustainable Development (FSSD)

A generic framework for planning in complex systems constitutes a background methodology of this study. Five interdependent but distinct levels are explored to establish their respective contents and relationships (Robert 2000). The framework is encouraging a thorough enough definition of the system (i), to be able to arrive at a robust definition of the goals of the planning exercise (ii), which is a prerequisite to be able to be strategic (iii) when actions (iv) and support for monitoring, coordination and decision-making (v) are selected and informed. The framework is logical and intuitive, and when applied for organizational sustainability planning it is called 'a framework for strategic sustainable development' (FSSD) (Robèrt 2000; Robèrt et al. 2002). In table 1 the logics behind this framework is explained by applying it both to individual chess planning and SSD planning of an organization. The general applicability of this framework can also be demonstrated by applying it to other team-related planning exercises like football.

Table 1. *Framework for strategic planning in complex systems – for chess and for strategic sustainable development (SSD).*

Levels of generic planning framework	**Chess as example** **- for individual success in chess**	**SSD as example** **- 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.	Organisation X, within society with stakeholders, laws, etc., within nature with its natural laws, basic resources, etc.
2. Success	Compliance with principles for checkmate.	Organization X in compliance with its vision within constraints set by principles for global socio-ecological 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. In doing so, strike a reasonable balance between (ii) progressing towards checkmate and (iii) being economic with the pieces.	With each investment decision, (i) strive to strengthen the organisation's platform for coming investments that are likely to take it towards compliance with success as defined above. In doing so, strike a reasonable balance between (ii) advancement speed and direction and (iii) return on investment.
4. Actions	Performing individual chess moves in line with the strategic guidelines.	Implementation of individual investment decisions in line with the strategic guidelines.
5. 'Tools'	Chronometer, standardized play patterns, statistics, etc.	Environmental management systems, eco-design tools, indicators, life-cycle assessments, investment calculus, etc.

Practical application of the FSSD in an organization most often involves an A-B-C-D-procedure (e.g. Holmberg and Robèrt 2000; Ny et al. 2006):

A. Sharing and discussing the suggested FSSD in relation to the organization with all participants of the planning exercise.
B. Identifying strengths and weaknesses of current organizational business ideas, activities, material and energy flows in relation to an organizational vision, informed by the sustainability principles (SPs) of the FSSD. The SPs state that in the sustainable society, nature is not subject to systematically increasing:

    1. Concentrations of substances extracted from the Earth's crust (e.g. fossil carbon or metals).
    2. Concentrations of substances produced by society (e.g. nitrogen compounds, CFC's, and endocrine disrupters).
    3. Degradation by physical means (e.g. large scale clear-cutting of forests and over-fishing).
    4. And, in that society …
    5. people are not subject to conditions that systematically undermine their capacity to meet their needs (e.g. from the abuse of political and economic power).

C. Brainstorming actions/investments (level 4 of the FSSD) and tools (level 5) that may help the organization to comply with its success definition (level 2).
D. Prioritizing early actions from C that not only takes care of the short-term challenges but also prepares for coming actions to eventually comply with the success definition.

Development and Application of a New Assessment Approach

Assessment Approach Overview

The assessment approach we suggest is based on the above described FSSD and has two stages:

1. Inventory of current general and sustainability orientated strategic decision systems.
2. Assessment of the *strategic capability* of these decision systems – both in general and in relation to sustainability.

The approach is based on guiding questions and was developed and tested in two large companies and two small and medium sized companies (SMEs). The results were also validated against client-relationship experiences of two management consultancies.

Selection of Case Study Companies

Two large companies, portraying themselves as beyond compliance according to the classification described in the introduction, were selected. One of them might even belong to the small group of companies that have integrated sustainability in the strategic business planning (they have used the above described FSSD). The two selected SMEs both appeared to be at the compliance stage. This seems to be in line with another study, stating that it is less common that SMEs work actively with environmental issues than medium-sized and large enterprises (NUTEK 2003). In this context it is important to point out that the studied companies were not compared to their competitors. Rather, we were looking for the remaining gap to sustainability for each of them. This means that the studied companies may be leaders on their respective markets but still get suggestions on how to improve in relation to sustainability. The apparent differences between the selected companies were expected to make the study more interesting - in terms of what types of problems and solutions that could be identified. The two management consulting companies were added to the study as reference companies, sharing their experience from advising a large number of companies on strategic planning processes. One of these reference companies was focused on sustainability and the other on facilitating organizational learning.

About Case Study Companies

Aura Light International AB is a medium sized (about 120 employees) long-life lamp manufacturer with their main office and manufacturing unit located in Karlskrona, Sweden. Their competitive edge is to design long-life variants of standard lamps and thereby reducing the customer's need for new lamps and costly replacement procedures. Aura-light only produce a few of their major lamp types in Karlskrona. They often outsource production of smaller volume lamp types. Auralight has been successful in reducing the mercury content while prolonging the life of their lamps. They see this as an advantage as they expect that the market will put an increasing focus on sustainability requirements. The R&D manager therefore sees the importance of identifying suitable support tools for integrating sustainability requirements in business decisions.

Evolator AB was at the time of the study a small (about 20 employees) technology development company located in Karlskrona, Sweden. They strived to adapt closely to individual customer requirements and their specialty is compact hemming units for the manufacturing industry (mainly for “folding” car door metal edges). Their competitive edge in relation to traditional hemming services was that they require only half the work area and half the cost to deliver the same hemming service. Evolator faced competition from large tool manufacturers and given the recent publicity around climate change the CEO realized that the future market will be sustainability-driven. He therefore wanted to learn more about sustainability and Evolator’s potential to use sustainability arguments for gaining competitive advantage.

Tetra Pak Carton Ambient AB was at the time of the study a sub-division (about 700 employees) of Tetra Pak - a large multinational packaging solution provider with a focus on aseptic white milk. Their main site is located in Lund, Sweden but they have operations throughout the world. Tetra Pak has a tradition of caring for the environment and they make efforts to reduce environmental impacts both in their internal operations and along those life cycle value chains they depend upon. This includes the packaging design process, its life-cycle (forestry, paper industry, transportation, recycling and energy recovery) and the packaging content lifecycle (agriculture, food processing, transportation, and waste management). Under the current increasing global awareness about climate change and other sustainability issues, Tetra Pak Carton Ambient entered this project to share sustainability knowledge with the other companies and to get a benchmark in relation to the research front.

Hydro Polymers Ltd was at the time of the study a (about 400 employees) multinational plastics manufacturer with a focus on Poly Vinyl Chloride (PVC). Their head office is located in Oslo, Norway. They have a tradition of close cooperation with suppliers and sometimes they co-develop products. In recent decades Non Governmental Organizations (NGOs) and legislators have increased their focus on the environmental impacts of PVC. This led to a significant market pressure on the PVC industry. Hydro Polymers therefore decided to take the initiative and launched a series of proactive measures to regain the market’s trust. They applied the above described FSSD both to their own business operations and recently to their whole value chain of suppliers and clients. Hydro Polymers decided to join this project to increase their knowledge about recent methods, tools and concepts for the integration of sustainability aspects in strategic management and product development and to share their sustainability knowledge and get a benchmark in relation to the other companies.

Indigo Management AB is a small (about 10 employees) management consultant firm in Karlskrona, Sweden. They focus on organization development and education for increased competitiveness and profitability, combining tools from the field of organizational learning with concrete strategic planning tools. They draw a lot from the excellence model of the European Foundation for Quality Management (EFQM). Indigo Management joined this project to share their experiences from many client companies and to learn more about sustainability issues that have come into focus recently. They also wanted to learn more about the FSSD as a complementing strategic management methodology.

The Natural Step International (TNSI) is a Swedish multinational NGO focused on facilitating knowledge and experience transfer between industry and academia in the field of strategic sustainable development. They use the FSSD as a strategic planning methodology. The FSSD is continuously developed in a consensus process between researchers and consulting professionals. TNSI was interested in taking part in this project to both share their experiences from many client companies and to learn more about current barriers that prevent companies from implementing changes in a sustainable direction.

Inventory Stage

Introductory questions

We tried to ensure that we had a common language before going into the detailed parts of the interviews. This was done to avoid later miscommunications and misunderstandings and to ensure that the interview subjects would understand the interview questions. This meant asking the interview subjects to define and give examples of how they understand some terms that were important for the interview (questions 1 to 7 in Appendix A). The most important of these terms was *strategic decision*.

From overarching questions to main interview questions

At first, four overarching questions that cover the information and decision pathways in a company with focus on senior management and product development were formulated (figure 2). A fifth ‘improvement question’ was also included in this set of overarching questions:

1. What methods, tools and concepts are used today **at senior management level** to identify and make decisions about long-term sustainability related challenges?
2. How do senior management level decisions influence product- and process levels?
3. What methods, tools and concepts are used today **at product- and process levels** to identify and make decisions about long-term sustainability related challenges?
4. How do product- and process level decisions influence the senior management level?
5. How can decision processes be improved to manage long-term sustainability challenges?

From this set of overarching questions, more detailed interview questions, covering a decision system’s ability to support both general and sustainability related strategic decisions, were derived (questions 8 to 17 in Appendix A).

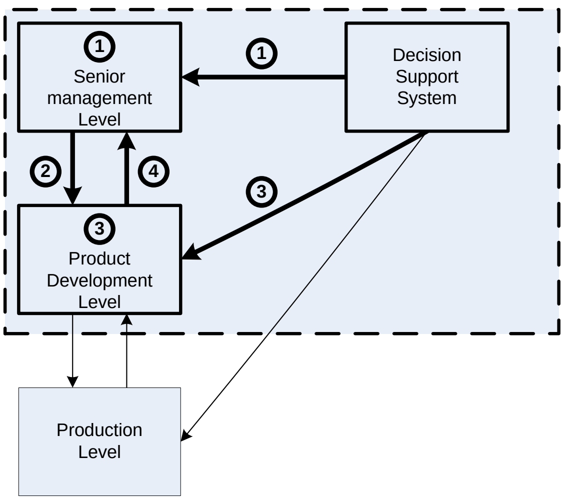

Figure 2. *How the four first overarching questions relate to organizational levels and a company decision support system.*

Control questions

The interviews were ended with three control questions that should indicate whether the company's strategic decision system is able to deal with their sustainability challenges (questions 18 to 20 in Appendix A).

Process for interviews and observations

To decrease the risk of subjective interpretation of the interview results the same two researchers were always present at the interviews, data assessment and result reporting. Furthermore, all interviews included the following basic steps:

- Pre-interview with a key-person that was involved in the decision processes and had inside knowledge in the company's organization and structure.
- Interview(s) with other representatives at the company. The same set of questions was used at all companies.
- Summary of the results from the interviews.
- Corrections of the results based on feedback from the persons involved at the company.

In addition to the interviews at all studied companies, decision meetings were observed by researchers in the two SMEs. Some suppliers to one of the larger companies were also interviewed.

Strategic Capability Assessment Stage

The FSSD has previously been used to map out how various methods, tools and concepts can contribute to SSD (e.g. Robèrt et al. 2002; Byggeth and Hochschorner 2006). We have previously also suggested a Method for Sustainable Product Development (MSPD) (Byggeth et al. 2007) and Templates for Sustainable Product Development (TSPD) (Ny et al. 2008) that use guiding questions based on the SPs and strategic guidelines of the FSSD (level 2 and 3) to guide the user towards relevant sustainability issues and solutions. The idea has been to avoid prescriptive guidelines but rather opening up to creative dialogue and innovation within sustainability constraints. In this study we merge these approaches and create question templates based on all five levels of the FSSD (table 2). The idea is that these questions should facilitate diagnosis of the strategic capability of a company's whole decision system – both in general and for sustainable development.

Table 2. *Templates for assessing strategic capability of company decision systems – in general and for sustainability.*

Levels of generic assessment framework	Template 1 Assessing company decision system - for general strategic capability	Template 2 Assessing company decision system - for strategic sustainable development capability
1. System	How does the company describe its business idea, operations and relations to key stakeholders? *Advisor response: …* *Company response: …*	How does the company describe its business idea, operations and relations to the environment and societal stakeholders globally? *Advisor response: …* *Company response: …*
2. Success	How, if at all, does the company define its long-term success? *Advisor response: …* *Company response: …*	How, if at all, is global sustainability integrated in the company's long-term success definition? *Advisor response: …* *Company response: …*
3.Strategic Guidelines	How, if at all, does the company use overarching strategic guidelines for planning towards success in general? *Advisor response: …* *Company response: …*	How, if at all, does the company integrate sustainability in overarching strategic guidelines? *Advisor response: …* *Company response: …*
4. Actions	How, if at all, are decisions in practice made in line with strategic guidelines towards the company's long-term definition of success? *Advisor response: …* *Company response: …*	How, if at all, are decisions in practice made in line with strategic guidelines towards the company´s long-term definition of success? *Advisor response: …* *Company response: …*
5. 'Tools'	How, if at all, are decisions justified and monitored by suitable methods, tools and concepts? *Advisor response: …* *Company response: …*	How, if at all, are decisions justified and monitored by suitable methods, tools and concepts? *Advisor response: …* *Company response: …*

Results from the Inventory Stage

The result from about 20 case company interviews and decision meeting observations (appendix B) is presented below. The data is the responses to the detailed interview questions (appendix A), but it is here summarized and organized along the previously mentioned five overarching questions.

1: Sustainability decisions at senior management level

Common:

- For all case companies the decision support system, at the senior management level, included business plan, budget and review tools for competitor strengths and customer requirements.

Uncommon:

- With the exception of Hydro Polymers none of the studied companies had formalized procedures for how to find the company´s sustainability challenges and for how to let them inform senior management decisions.

The large companies vs. the SMEs:

- The two larger companies had come further than the SMEs in standardizing and implementing support for strategic decision making throughout their organizations.

2: The influence of decisions from senior management level on product development level

Common:

- The study showed that various formal information channels (e.g. meetings and intranet) were common ways to influence product- and process levels from management level.
- In some cases the senior management's strategic intent was also indirectly revealed through the launch of a sequence of related concrete activities. For example, at Evolator, a decision was taken to move the company's traditional focus from adapting to the specific requirements of the clients in each project to also create a standardized product portfolio. After that, numerous supporting decisions and actions were taken like changing name, selling the company to a new owner to finance the continued production process, moving to a new building, etc.

Uncommon:

- Hydro Polymers differed again as they included sustainability related long-term decisions in their business plan and had an action plan with targets that influenced the activities in the company at different levels.

Success factors:

- The reference companies had experienced that the senior management level influence on the product- and production levels are facilitated by:
    - *Commitment.* This could be demonstrated by the setting of clear overarching goals. For example, at Hydro Polymers senior management had clearly defined compliance with the SPs of the FSSD as part of their vision. Based on this, they were convinced enough to undertake certain investments already before these could be economically justified in the short term. One example is the phase out lead before competitors, even though this decision caused practical problems at the production level since established routines and equipment had to be changed.
    - *Participation.* Indigo Management says that in their experience decisions are more likely implemented if companies invite the staff to take part in defining the desired outcome.
    - *Communication.* Both Indigo Management and TNSI emphasized that exchange of information and a common understanding of the same goal facilitates effective team work and community building.

3: Sustainability decisions at product development level

Common:

- All studied companies used various product development methods and tools (e.g. Computer Aided Design (CAD), calculation tools, risk assessments and simulation tools) to get data input for decision-making.
- Customer requirements and prioritizations from the senior management were also used.

Uncommon:

- It was uncommon that senior management required that sustainability was taken into consideration in the product development process. This might be one reason why Ecodesign tools, according to the experience of the reference companies, are not commonly used in industry.

Large enterprises vs. SMEs

- In the two larger companies, evaluation tools and multi-criteria decision support tools were used. The environmental departments at Tetra Pak, for example, uses traditional quantitative Life Cycle Assessments (LCAs) to take ecological aspects into consideration in the decisions and evaluation processes of product projects.

4: The influence of decisions from product development level on senior management level:

Common:

- In all studied companies informal personal discussions with the senior management together with project meetings were the common ways to distribute information and thereby influence the senior management level.
- Normally the senior management delegates detailed decisions to the product development level. Decisions can, however, be moved back to the senior management level based on certain criteria (such as when overall cost frames are at risk to be exceeded).

Large companies vs. SMEs

- In the large companies, ideas from the product development level are also spread by the intranet and sorted by cross-functional teams.
- Tetra Pak had through their Design for Environment (DfE) approach a systematic way of informing the senior management level about ecological life-cycle consequences of potential projects.

5: Companies' own suggested improvements of their decision system to manage long-term sustainability challenges:

Large companies vs. SMEs

- The SMEs did not suggest any concrete sustainability related improvements of their decision processes. Maybe this was due to their relatively limited experience with the sustainability context of their business.
- The interviewed representatives from the larger companies and the reference companies suggested several general improvements, including to:

- learn how to concretize the word sustainability and if possible make it measurable.
- prioritize sustainability issues at the senior management level in order to integrate sustainability in the daily activities throughout the company.
- spend more time and involve more people to discuss how to prioritize between potential investment paths before decisions are made.
- get a systematic way to balance between what is the most simple way forward today commercially (tactics) and what is needed in the long-term (10 years or more) (strategy).

Results from the Strategic Capability Assessment Stage

This is the aggregated summary of the advisors' (i.e. the authors) responses to the template questions (table 2) when looking at all case study companies.

1 The Systems Level

How does the company describe its business idea and operations in relation to:

a) its key stakeholders?

- All studied companies had a clear business idea and processes and tools for mapping out their role in relation to their closest stakeholders (customers, suppliers, employees, authorities).

b) the environment and societal stakeholders globally?

- The large enterprises had a systematic understanding of their indirect impacts on other stakeholders (e.g. third world citizens) and the environment. This was lacking in the studied SMEs and the reference companies had similar experiences with their clients.
- Both Hydro Polymers and Tetra Pak had also close sustainability focused cooperation with key-suppliers.

2 The Success Level

How, if at all,

a) does the company define long-term success?

- All studied companies had defined business goals. Tetra Pak had, for example, defined its aim and role by identifying their vision and mission. Their vision (what they want to achieve) is to "make food safe and available everywhere". Their mission (what they want to do to achieve their vision) includes for example to "work for and with their customers to provide preferred processing and packaging solutions for food".

b) is global sustainability integrated in the company's definition of long-term success?

- A shared success definition for planning toward sustainability did only exist at Hydro Polymers. This definition is based on the SPs of the FSSD. Hydro Polymers had also defined and acted upon five key challenges that followed as a consequence to their success definition (Everard et al. 2000).
- Tetra Pak had included environmental sustainability and good corporate citizenship in their mission but not defined those terms.

3 The Strategic Guidelines Level

How, if at all, does the company use overarching strategic guidelines for planning towards

a) success in general?

- All studied companies regularly ran a planning process with focus on traditional short term tactical business success. This included comparisons with competitors on brand strength, costs, product portfolio, market share, stock value, etc.
- Tetra Pak also used a strategy map with the dimensions "Financial", "Customer", "Business Processes" and "Organizational Learning" to guide daily work towards the vision and mission. Larger organizational objectives were then broken down to individual objectives through balanced scorecards (i.e. a tool for measuring whether the activities of a

company are meeting its financial and other objectives in terms of vision and strategy (e.g. Kaplan and Norton 1996)).

b) sustainability?

- Hydro Polymers was unique since it used a sustainability plan as a strategic guideline. This plan, covered five years of past progress and another five years of future commitments, had been developed through backcasting from a future where the key sustainability-related challenges are successfully dealt with.

4 The Actions Level

How, if at all, are decisions and activities, whether sustainability focused or not, in practice made in line with strategic guidelines?

- All companies could give examples of activities that were influenced by strategic guidelines. We have already mentioned such an example from Evolator.
- Only Hydro Polymers, where sustainability was defined at the success level, allowed sustainability issues to inform decisions and activities. And they have allowed this perspective to inform also their relationship with the value chain. They have, for example, made a strategic decision to educate the suppliers in strategic planning towards sustainability. As a result they planned, allocated responsibility and resources for a series of sustainability dialogue meetings with key suppliers. They explained to the supply chain that sustainability performance will be a criteria for making business with Hydro Polymers in the future. Some of these suppliers also took part in a tailor-made university distance course ("Leading Change for a Sustainable Chemical Industry") with the objective of teaching change agents to influence their respective companies to enter a more systematic transition towards sustainability in line with Hydro Polymers' experiences. Some of the suppliers (e.g. Rohm & Haas) have already moved on to bring the integration of sustainability efforts into their own business visions, and to include their own supply chains in the same type of dialogue as Hydro Polymers.

5 The 'Tools' Level

How, if at all, are decisions and activities, whether sustainability focused or not, justified and monitored by suitable methods, tools and concepts?

- All studied companies used methods, tools and concepts to justify and follow up decisions. Still, sustainability issues were, in particular for the SMEs, not systematically covered by such support. In particular, social sustainability aspects seemed to be less understood and dealt with. Using the FSSD perspective, social sustainability aspects can be summarized as activities that systematically violate the fourth SP and thereby degrade the social system. This includes abuse of authority (e.g. enforced labor, undermining labor unions, etc) and abuse of economic power (e.g. non-livable wages, exploiting investments, etc).
- Senior management, as exemplified by a senior manager at Tetra Pak, wanted the environmental department to concretize the term sustainability and translate it into quantifiable units that more easily could be processed in existing long-term prioritization support.
- It was unusual among the SMEs with supporting internal policy measures to motivate individuals to work in the desired direction. The larger companies were again different. Both Hydro Polymers and Tetra Pak had, for example, extensive requirements on what decisions support to use at different levels in the company. Hydro Polymers had also initiated internal education programs on sustainability and Tetra Pak used the above mentioned balanced scorecard, a strategic planning and management system, to break down the company-wide business goals to individual goals and to track progress in relation to the goals.
- Hydro Polymers also had some support tools for dealing with social sustainability. This includes the fourth SP of the FSSD and Corporate Social Responsibility indicators.

Concluding Discussion

The aim of this study was to develop an approach to assess sustainability integration in a company's strategic decision system and, based on the results from using this approach, to lay out some generic guidelines for how to improve such decision systems. We believe that our approach demonstrated an ability to identify how a company could integrate sustainability in its strategic decision system. It could effectively differentiate companies from each other from a sustainability perspective and identify important challenges and opportunities as regards visions and strategic processes. Using our approach, we found indications that, on the Bob Willard scale of sustainability integration (Willard 2005), the two SMEs were at the "Compliance" stage, Tetra Pak at the "Beyond Compliance" stage and Hydro Polymers at the "Integrated Strategy" stage. We also found indications, through the reference companies and literature studies, that very few companies in the world have reached this "Integrated Strategy" stage (e.g. Strandberg 2002; Forum-for-the-Future 2003; van Marrewijk 2003). We found several potential reasons for this lack of sustainability integration:

Senior management fails to relate long-term strategic sustainability challenges to short term tactical business challenges

Modern industry exists in a competitive environment where investment "horizons" are shrinking. This means that short term profit is prioritized at the expense of long-term considerations. Though impacts related to unsustainability already cost money and other resources (Balmford et al. 2002; Stern 2006), some strategic actions for sustainable development are not likely to pay off for decades. Willard (2005) suggests that lack of senior management support is a major barrier to implementing sustainability efforts in companies. Still, some of the studied companies were looking for practical ways to include long-term sustainability issues in their senior management decisions without hindering competitiveness in the short term. Hydro Polymers stood out as one of those companies that had to a high degree succeeded in this respect. The potential of their approach is also strengthened by examples from other businesses like the multinational modular carpet manufacturer Interface (Anderson 1998), IKEA and Scandic Hotels (e.g. Nattrass 1999) and many others (e.g. Robèrt 2002). Our study showed that Hydro Polymer's senior management had a systematic way of identifying key business challenges and strategic goals in relation to a global sustainability definition. Concrete daily decisions throughout the company are made in line with the key challenges and strategic goals. This demonstrates a shift in focus from incremental improvements of current practices (tactics) to closing the remaining gap to future sustainability (strategy). In concrete terms this systematic approach has lead to, for example, a phase out of lead-based PVC stabilizers years before required by legislation (Leadbitter 2002), new products based on recycled post consumer PVC and active promotion of sustainability and sustainable development to suppliers, partners and customers (e.g. Leadbitter 2002; Hydro-Polymers 2006). Hydro Polymers is therefore years before its competitors in this regard.

Senior management lack a systematic incentive/disincentive and monitoring system to facilitate implementation of sustainability measures

Our study indicates that a public statement of senior management sustainability commitment is a good starting point. Nevertheless, implementation is not likely to follow if senior management commitment is not followed by integration of the defined sustainability into concrete business goals, general sustainability awareness education and incentive/disincentive systems (e.g. allocation of time, money and staff). Without allocated resources the employees would have to work with sustainability issues in their spare time or let their prioritized jobs suffer. Despite such unspoken incentives to maintain status quo in many companies, some innovations and organizational transformations seem to be initiated by visionary and committed internal change agents. An example from our study was a key supplier that got involved with Hydro Polymers' supply chain initiative, partly as a result of the personal commitment of one manager within the supplier organization.

Companies, at all organizational levels, lack a standardized "toolbox" for sustainability-related information in decision processes

We argue that a systematic approach to sustainability integration in decision processes requires at least the capacity to: (i) understand the sustainability problem, (ii) generate possible solutions/innovations, (iii) communicate between organizational levels through a common 'language/terminology', (iv) evaluate and prioritize among alternative solutions and (v) implement prioritized solutions and follow up on their effects. A growing number of methods, tools and concepts are evolving to address these requirements (de

Caluwe 1997; van Weenen 1997; Tischner et al. 2000; Robèrt et al. 2002; Byggeth and Hochschorner 2006). Our study indicated deficiencies especially regarding the ability to understand sustainability, in particular regarding the social dimension, and to communicate it between organizational levels.

The studied companies normally used similar product development tools covering areas like modeling and simulation of design and manufacturing, competition benchmarking, risk assessment, and quality and/or environmental management systems. The larger companies, but not the SMEs, used standardized support tools throughout their organizations, including, eco-design and CSR tools. Hydro Polymers also had convincing sustainability integration at the senior management level. Still, we could not identify a systematic use of product development methods and tools that included a socio-ecological sustainability perspective. In line with Lindahl (2005) we argue that complementation of existing product development methods and tools should be guided by senior management and not be left to the preference of designers. This means that it is crucial for the senior management to adopt a pro-active attitude in this matter and it is their responsibility to ensure that appropriate training is given and that appropriate methods and tools are actually used.

Recommendations

Based on the results and the concluding discussion we suggest that the systematic integration of sustainability in a company's decision system and, indirectly, the development of more sustainable products, should be facilitated by:

1. An overarching supporting organizational context.

This includes at least:

(i) explicit senior management commitment,
(ii) an adopted sustainability definition,
(iii) main business challenges identified in relation to the sustainability definition,
(iv) company-specific sustainability challenges integrated in business goals and sufficient allocation of resources to deal with them. This means to combine strategic backcasting planning and tactical forecasting planning.

2. Institutionalized internal company capacity building and communication on sustainability.

This includes at least:

(i) implementing supporting internal policy measures like general sustainability awareness education,

(ii) economic incentives and disincentives for development towards sustainability.

3. Integrated company ”toolboxes”.

An integrated “toolbox” should be introduced that focuses on how to close the gap between the present situation and long-term socio-ecological sustainability. This means to at least covering capabilities like:

(i) identification of sustainability challenges relevant to the organization,

(ii) generation of possible solutions and innovations,

(iii) communication between organizational levels through a common ‘language/terminology’,

(iv) evaluation and prioritization among solutions according to certain criteria, indicators and/or simulation scenarios. Methods and tools for investment calculus and risk assessment that integrates sustainability aspects seem to be especially desired, and will also be part of (iii),

(v) concrete action planning for implementation of prioritized alternatives,

(vi) continuous progress monitoring, through indicators and feedback systems, to deal with deviations in relation to the long-term goals.

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Appendix A: Interview questions at the inventory stage

Introductory questions to ensure relevant use of terms in the interviews

Q1. What is your interpretation of the word ‘strategic decision’?
Q2. Could you give us an example of a strategic decision?
(How was the decision taken? Give some background to the decision, the decision process, any support tools used, and some concrete result of the decision implementation?)
Q3. Was this decision strategically important?
Q4. What persons/functions were involved in the decision?
Q5. When was it made obvious for all that the decision was made?
Q6. How was the decision made obvious to all?
Q7. Was this a typical decision in your company?

Main interview questions

Overview question

Q8. What are your **overarching** formal decision processes (including activities like regular meetings, workshops, forums, reporting etc.) for product related investments, and how do you involve different:

a. organizational levels (top management, middle management and/or operational level)
b. time perspectives (short and long-term)
c. cost and investment magnitudes

Please illustrate your answer.

Detailed questions

Q9. What decision support for strategic top management decisions exist today in the company?
Q10. How are the above-mentioned decision support used to deal with sustainability problems?
Q11. How are strategic top management decisions transferred to product and production levels?
Q12. What decision support for strategic product and production decisions exist today in the companies?
Q13. How are the above-mentioned decision support used to deal with sustainability problems?
Q14. How are the product and production level decisions transferred to top management level?

Q15. Who is responsible for strategic decisions at different organizational levels (i.e. top management, product and production levels)?
Q16. Who is responsible for sustainability related decisions at different organizational levels (i.e. top management, product and production levels)?
Q17. How can the decision processes be improved?

Control questions with focus on the company strategy for sustainable development

With the previous questions in mind, taking a more long-term perspective:
Q18. What is your company's definition of a sustainable society?
Q19. What are your main company challenges in relation to that definition?
Q20. What is your company doing at a strategic level to handle these challenges?

Appendix B: Inventory stage activities in the companies from the autumn 2006 to summer 2007

Time	Company	Activity	Persons involved
November 2006	Evolator AB	Pre-interview and meeting	Bo Claesson: CEO
November 2006	Evolator AB	Observations of decision meeting	One Salesman; Two Eng. Techn. Design, One Project leader, One Project Owner
November 2006	Auralight International AB	Pre-interview and meeting	Mats Ericson; R & D Manager
November 2006	Auralight International AB	Observations of decision meeting	Project Manager International, Marketing Assistance, CEO/Sales Managers, Purchasing Manager International, Nordic Purchasing Manager, Project leader, R & D Manager
December 2006	Hydro Polymers Ltd.	Pre-interview and meeting	Jason Leadbitter; Sector Sustainability Director
Februari 2007	Indigo Management AB	Pre-interview and meeting	Jan Flink; CEO
Februari 2007	Tetra Pak Carton Ambient AB	Pre-interview and meeting	Lars Binder; Manager Development & Engineering, Johan Persson; Development & Engineering, Helena Tillborg, Inger Hellborg, Ilaria Gentile, Catrin Besch; Commercial Operations Environment

Mars 2007	Auralight International AB	Interview and feedback meeting	Mats Ericson; R & D Manager
Mars 2007	Indigo Management AB	Interview and feedback meeting	Jan Flink; CEO
Mars 2007	Evolator AB	Interview and feedback meeting	Bo Claesson: CEO
April 2007	The Natural Step International	Interview and feedback meeting	Jonas Oldmark; Secretary-General
April 2007	Tetra Pak Carton Ambient AB	Interview and feedback meeting	Inger Hellborg; Commercial Operations Environment, Lars Binder; Manager Development & Engineering, Lars Henriksson; Manager Development Strategy and Planning
June 2007	Hydro Polymers Ltd.	Interview and feedback meeting	Paul Wheatley; Director Sector Logistics & Gel Compounding, Ross Law; Development Manager, Dave Barnfather; Purchasing & Planning Manager,
June 2007	Chemson; Supplier to Hydro Polymers Ltd.	Interview	Michael Schiller; Head of Group R & D
June 2007	Unger; Supplier to Hydro Polymers Ltd.	Interview	Jan Ivar Ruud; Managing Director

ABSTRACT

Product development is a particularly critical intervention point for the transformation of society towards sustainability. Current socio-ecological impacts over product life-cycles are evidence that current practices are insufficient. The aim of this thesis is to form a foundation for sustainable product development through the integration of a sustainability perspective into product development procedures and processes.

Literature reviews and theoretical considerations as well as interviews, questionnaires, observations, testing and action research through case studies in various companies have indicated gaps in current methodology and have guided the development of a new general Method for Sustainable Product Development (MSPD). This method combines a framework for strategic sustainable development based on backcasting from basic sustainability principles with a standard concurrent engineering development model. A modular system of guiding questions, derived by considering the sustainability principles and the product life-cycle, is the key feature. Initial testing indicates that this MSPD works well for identification of sustainability problems as well as for generation of possible solutions. However, these tests also indicate that there is sometimes a desire for a quick overview of the sustainability performance of a specific product category. This is to guide early strategic decisions before the more comprehensive and detailed work with the MSPD is undertaken, or, alternatively, when an overview is sufficient to make decisions. In response, a Template for Sustainable Product Development (TSPD) approach is presented as a supplement to the MSPD.

To generate products that support sustainable development of society it is necessary to combine sustainability assessments with improvements of technical product properties. An introductory procedure for such sustainability-driven design optimization is suggested based on a case study. For maximum efficiency of a company in finding viable pathways towards sustainability, it is also necessary to coordinate different methods and tools that are useful for sustainable product development and integrate them into the overall decision-making processes at different levels in companies. To find gaps in the sustainability integration in a company's decision system, an assessment approach is suggested based on case studies.

A general conclusion from this research is that the support needed for making sustainability-related decisions are not systematically integrated in companies today. However, this thesis also indicates that it is possible to create generic methods and tools that aid the integration of sustainability aspects in companies' strategic decision-making and product development. These methods and tools can be used to guide the prioritization of investments and technical optimization on the increasingly sustainability-driven market, thus providing a foundation for competitive sustainable product development.

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