On Sustainable Product Development

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1. Introduction

Manufacturing companies stand before a new challenge when it comes to product development. The latest decade the demand for health and environmental concern have been an increasingly important factor beside the technical requirements and economic constraints in product development.

Many tools and concepts in the field of Industrial Ecology are developed in this context, e.g., Life-Cycle Assessment (LCA), streamlined LCA, Design for Environment (DfE), ecological footprint, factor x, environmental space as well as the environmental management systems ISO 14001, EMAS and BS 7750 (Vellinga et al. (1997) give a good overview of different tools). These methods do not necessarily consider the concept of sustainability. Simon & Sweatman (1997) says that Design for Environment therefore should be distinguished from Sustainable Product Design.

The next logical step in the evolution of product development is to broaden the concern from health and environmental aspects to the broad field of sustainability. The challenge of sustainability is to establishing sustainable relationships between the global society and the ecosphere as well as within the global society itself. Thus, "sustainable development" (WCED 1987) is a huge mission which involves a profound transformation of the societal metabolism. Since the global society is not sustainable, different kinds of solid, liquid and gaseous waste are steadily accumulating and resources and ecological functions are steadily diminishing, the resource-potential for health and economy is systematically decreasing. At the same time, the earth's population and the average demand for services are increasing. This can be visualised as entering deeper and deeper into a funnel, in which the space to manoeuvre becomes narrower. (Robèrt et al. 1997). For a firm wanting to skilfully make investments the crucial factor is to direct its investments towards the opening of the funnel, rather than into the wall. The narrow off of the funnel can of course vary for different aspects and in different locations, and can of course be subject for some dispute, but the major trend is unfortunately quite clear: more and more people want more services from a system with decreasing capacity. The wall of the funnel will superimpose itself more and more into daily economic reality in the following ways: environmentally concerned customers, higher insurance costs for risky activities, stricter legislation, higher costs and fees for resources as well as pollution, and tougher competition from competitors who invest themselves skilfully towards the opening of the funnel, i.e. towards sustainability.

The purpose with this paper is to contribute to the discussion about how the perspective in product development can be broaden from environment and health concern to also consider the broader field of sustainability.

We will do that based on a method for strategic planning towards sustainability, developed together with the Natural Step foundation and successfully used be many companies, organisations and municipalities (Robèrt 1992, Robèrt 1994, Holmberg et al. 1996, Holmberg & Robèrt 1997, Robèrt 1997, Robèrt et al. 1997, Nattrass & Altomare 1999). The method is (i) based on a framework of four non-overlapping principles of sustainability (Holmberg et al. 1996, Holmberg & Robèrt 1997), and (ii) it is based on backcasting (Robinson 1990, Dreborg 1996), i.e., instead of trying to predict the future from today's trends (traditional forecasting) one also tries to liberate beliefs about today's situation and tries to understand which requirements and possibilities that sustainability will involve in the future. The method consists of four steps. In the first step the conditions for a future sustainable society is defined. In the next step the firm's present activities and competencies are analysed in relation to the conditions. In the third step future possibilities for the firm are envisioned. In the final step flexible strategies are identified that can link the present situation with the desirable future sustainable situation (Holmberg 1998). The framework helps to describe what parameters will change when the whole society has a metabolism that fits in the requirements set by sustainability. The reason for doing this must not solely be to inspire altruism. It is rather a method to get early warning signals for when long-term investments based on present structure and trends can lead to dead ends. Since the method take the future sustainable situation as its starting point it also helps to liberate beliefs about today's trends. Thereby it is also a tool for supporting creativity, e.g., new product design and new business ideas (Holmberg 1998).

The method has so far mainly been used for strategic planning. In this paper we will describe how principles for sustainability and the backcasting methodology can be used in the product development. In next section we will present the method for strategic planning. The text in that section is based on (Holmberg 1998). In the following section we will discuss how the method can be integrated in the product development process. We will also discuss what further research are needed in order to make this integration more effective.

2. Strategic planning towards sustainability[1]

Figure 1 illustrates different steps in the method for strategic planning towards sustainability. In the first step the criteria for the future sustainable society is defined and discussed. In the next step present activities and competencies are related to the framework. One important result from this step is the identification of non-sustainable activities in the present operation. In the third step the future desirable situation is envisioned and discussed. The main idea with the third step is to get rid of mental restrictions set by the present situation and to open the mind for future options. The inventory of the present situation in the second step and the criteria for a future sustainable situation in the first step often give a fruitful tension for the envisioning in the third step. In the final step strategies are identified that can link the present situation with the future sustainable goal. In this step it is important that the investments (or other kind of measures) lead in the right direction, but it is even more important that the investments are a broad and flexible enough platform for new investments in the right direction (Holmberg & Robèrt 1997). This is also one of the most important characteristics of the whole framework presented in this paper: while many existing tools have the capability to direct new investments in the right directions, few of them consider if the investment is a good platform for further investments or if it may lead into a dead end.

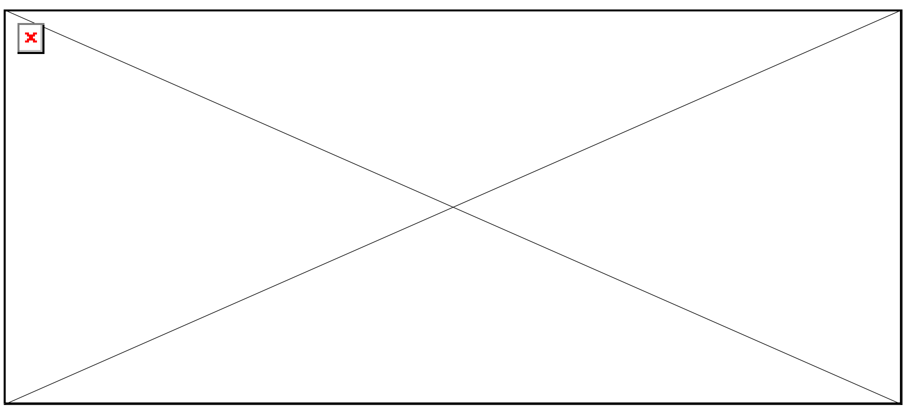

Figure 1. The steps in strategic planning towards sustainability.

2.1. Step 1: Defining criteria for sustainability

In this method the starting point is criteria for a sustainable future. If the planning process does not take a set properly defined criteria for sustainability as its starting point, but just present trends, the course can be dangerously wrong. It can be compared with night-navigation inside the belt of islands by just

[1] The text in this section is based on (Holmberg 1998).

studying the lanterns of other boats. In order to avoid the rocks it is important to try to find relevant lighthouses.

The first version of the criteria for sustainability used in this method was developed by Karl-Henrik Robèrt and John Holmberg around 1990. Several scientific workshops and reviewing processes as well as the experiences from the use of them in education, in scientific consensus processes and by corporations, municipalities and other organisations have lead to a continuously improvement of them, but they still have the same basic meaning (Robèrt 1992, Holmberg et al. 1996, Holmberg & Robèrt 1997, Robèrt et al. 1997).

In order for a society to be sustainable, nature's functions and diversity are not systematically:

I. ... subject to increasing concentrations of substances extracted from the Earth's crust;

II. ... subject to increasing concentrations of substances produced by society;

III. … impoverished by over-harvesting or other forms of ecosystem manipulation

and

IV. ...resources are used fairly and efficiently in order to meet basic human needs world wide.

Clarification of the principles

I. The societal influence on the ecosphere due to accumulation of lithospheric material is covered by the first principle. It implies that the flows of substances from the lithosphere to the ecosphere must not systematically be larger than the flows back into the lithosphere. The balance of flows must be such that *concentrations* of substances from the lithosphere do not systematically increase in the whole ecosphere, or in parts of it. Besides the upstream influence on this balance through the amounts of mining and choices of mined minerals, the balance can be influenced by the quality of final deposits, and the societal competence to technically safeguard the flows through recycling and other measures. What concentration can be accepted in the long run depends on properties such as ecotoxicity, here taken in a broad sense to include effects on the geophysical systems, and bioaccumulation. Due to the complexity and delay mechanisms in the ecosphere, it is often very difficult to foresee what concentration will lead to unacceptable consequences. A general rule is not to allow deviations from the natural state that are large in comparison to natural fluctuations. In particular, deviations should not be allowed to increase systematically. Therefore, what must at *least* be achieved is a stop to systematic increases in concentration. Depending on the characteristics of the substance and the recipient, the critical concentrations differ. In some recipients an increasing concentration of some substances can have a positive effect before a further increase in concentration will be problematic. In other cases the acceptable concentration has already been exceeded.

II. The societal influence on the ecosphere due to accumulation of substances produced in society is covered by the second principle. It implies that the flows of societal produced molecules and nuclides to the ecosphere must not be so large that they can neither be integrated into the natural cycles within the ecosphere nor be deposited into the lithosphere. The balance of flows must be such that concentrations of substances produced in the society do not systematically increase in the whole ecosphere or in parts of it. Besides the upstream influence on this balance through production volumes and characteristics of what is produced, such as degradability of the produced substances, the balance can be influenced by the quality of final deposits, and the societal competence to technically safeguard the flows through measures such as recycling and incineration.

III. The societal influence on the ecosphere due to manipulation and harvesting of funds and flows within the ecosphere is covered by the third principle. It implies that the resource basis for (i) productivity in the ecosphere such as fertile areas, thickness and quality of soils, availability of fresh water, and (ii) biodiversity is not systematically deteriorated by over-harvesting, mismanagement or displacement.

IV. The internal societal metabolism and the production of services to the human sphere is covered by the fourth principle. It implies that if the societal ambition is to meet human needs everywhere today and in the future, while conforming to the restrictions with regard to available resources given by the first three principles, then the use of resources must be efficient in meeting human needs. If we are more efficient, technically, in organisation and socially, more services with the possibility of meeting more human needs can be provided for a given level of impact in nature. Efficiency in that context, if the perspective is large enough, implies not only reduced resource flows per utility, but also improved means of dealing with social issues like equity, fairness and population growth.

In conclusion, in this first step a company that wants to apply this method start with the four principles. Often the process starts with a presentation of the principles, the rationale behind them and this four step backcasting procedure for the management team of a company. The principles are not presented in a prescriptive way, but as guiding instruments for the discussion about sustainability. The result is a better understanding within the company about what the demand for sustainability will involve and how that will influence the company.

2.2. Step 2: Describing the present situation in relation to the criteria for sustainability

In the second step the present activities and competencies are analysed. The result from this inventory are used in the third step. In the third step future sustainable options are envisioned. In order to make the visions realistic it is fruitful to have a good view over the present competence and activities. The inventory in the second step is also used as a starting point for the strategies developed in the fourth step.

For each of the four principles a number of relevant questions can be asked in order to identify if the present delivered products or services, production processes or other activities are in accordance with the principles or not. In this inventory the activities which involve high economic dependence on unsustainable patterns are studied in more detail. Often other more detailed inventory tools can then be used, for instance the LCA-methodology, but they should then be related to the principles in the inventory. The reason is that the societal influence of nature is characterised by high complexity and many delay mechanisms in society as well and within nature. And in order to not miss relevant aspects of sustainability and to make it possible to get early warning signals the inventory should be based on non-overlapping principles which cover all relevant aspects of sustainability. If not there is a great risk that we solve today's problem by creating new problems. Unfortunately, a serious shortcoming of many inventory programs is that they lack such principles (Mitchell 1996).

2.3. Step 3: Envisioning and discussing the future situation.

In this step future possibilities are envisioned based on the principles of a future sustainable society (step 1) and the inventory of the present situation (step 2). Given the restrictions and possibilities set by the principles of sustainability and the information regarding the present situation, e.g., regarding resource turnover, competence within the organisation and the services/utilities that are delivered, there are often a variety of future options.

An essential aspect in this step is to avoid a static view of the present activity or product by focus on the aimed service rather than on the commodity. The product aims at delivering a service or a set of services, which in turn might have the potential to fulfil human needs. The main idea with this step is to rid the mind of restrictions set by the present circumstances and open the mind for future options.

2.4. Step 4: Finding strategies towards sustainability

In the fourth step strategies are identified that can link the present situation with the future sustainable situation. When identifying strategies to move towards sustainability at least the following four points should be considered:

- *Will each measure (e.g., investment or product design) bring us closer to sustainability?* Will it reduce our dependence on dissipative use of scarce elements, dissipative use of persistent compounds foreign to nature, manipulation and over-harvesting causing reduced production capacity and biodiversity and our dependence on wasting of resources in relation to meeting human needs
- *Is each measure a flexible platform for the next step towards sustainability?* Will it be possible to go from the actual investment to another that will bring us even closer to sustainability, or is the investment a dead end? This question is even more important than the previous.
- *Will each measure pay-off soon enough?*
- *Will the measures taken together help society to make change at a sufficient speed and scale to achieve sustainability without too much loss for humans and other species during the transition?*

When searching for strategies towards sustainability it can be helpful to start from the four principles presented above and the following equation, which expresses the impact on nature as a product of four anthropogenic factors, i.e., four factors that humans have the possibility to change.

$$\mathbf{I} = \mathbf{i} * \mathbf{m} * \mathbf{u} * \mathrm{P}$$

where:	**I** =	Impact in Nature;
	i =	**I/M**; Impact / energy & material flow;
	m =	**M/U**; material & energy flow / utility, service;
	u =	**U**/P; utility or service / capita;
	P =	Population

There has been various combinations of factors used in this type of equation, which (at least) goes back to Ehrlich & Holdren (1971, 1972).

The equation can be related to the principles that were presented above. If we look at the left hand side of the equation, principle 1, 2 and 3 put up restrictions for the societal impact of nature. Principle 1 puts up restrictions regarding the assimilation capacity in the ecosphere for substances that society extract from the lithosphere and emit to the ecosphere. Principle 2 puts up restrictions regarding the assimilation capacity in the ecosphere for substances that are produced within society and emitted to the ecosphere. And principle 3 puts up restrictions imposed by societal manipulation and harvesting of the ecosphere.

The right hand side of the equation is related to principle 4, which states that the use of resources should be efficient enough to fulfil human needs everywhere. The factor representing the world population (P) is a difficult one due to the inherent growth momentum in today's population. Even an immediate reduction of the fertility to the reproduction level (around two children per family) will lead to around 8 billion people in the middle of the next century. Around 10 billion people in 2050 is a central projection in United Nations global population estimates (United Nations 1992). Also the factor that represent the utility per capita (u) is a difficult one, since even if it could be argued that we in the developed countries are (materially) wealthy enough, there are strong demands to increase the average global level of service or utility per capita in the future.

The equation illustrates the dilemma facing humankind – the double challenge inherent in the concept of sustainable development: On the one hand to develop and reach an acceptable quality of life from materials/energy flows for a growing population, and in parallel be able to decrease society's harmful physical impact in nature. Many of the solutions to this dilemma can be found in the first two factors in the equation (m & i). Concerning the world-wide societal flows of materials and energy one can identify two main strategies for decreasing the environmental impact of material/energy flows: *dematerialisation*, i.e., more service out a certain exchange of materials with the nature, and *transmaterialisation*, i.e., substitution of less harmful materials flows for more detrimental ones.

3. Sustainability aspects in product development

A systematic approach to product development is based on a structure of the process in different steps (Pahl and Beitz 1996). This approach may increase the efficiency and improve the result of the process. The efficiency can be further increased by the use of integrated product development which implies that the development of different types of activities such as marketing, design and production are carried on parallel to each other (Karlsson 1997, Magrab 1997).

In this section, we describe the structure for the incorporation of sustainability aspects within the process of product development. We base the structure on the method for strategic planning towards sustainability, described in section 2, and on the different steps in the product planning and design process, as denominated and defined by Pahl and Beitz (1996), see figure 2.

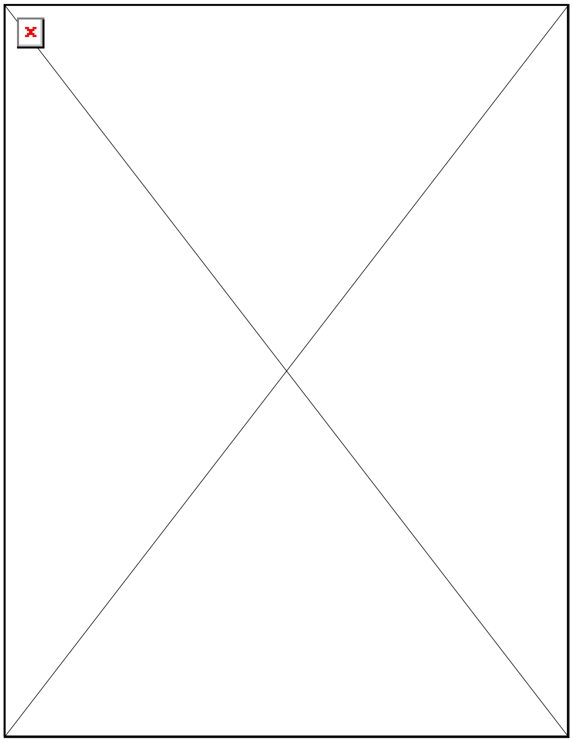

Figure 2. The product planning and design process. Based on Pahl and Beitz (1996).

3.1. Planning and clarifying the task

The step for planning and clarifying the task includes a formulation of a product proposal. This proposal is based on product ideas that are found and selected after an analyse of the market and company situation. The task is then clarified with the elaboration of a requirements list (Pahl and Beitz 1996).

The first three steps in the *backcasting* method, in section 2, can facilitate the incorporation of sustainability aspects when generating product ideas, besides the market and company situation. The fourth step can then, to some extent, be realised with the development of products that are helpful or even critical in the transition towards sustainability.

In the first step of backcasting, the criteria for the future sustainable society is defined and discussed. If the planning process does not take a properly defined criteria for sustainability as its starting point, but just present trends, the course can lead in the wrong direction or even to a dead end. In the second step, the present activities and competencies are analysed. The result from this inventory are used in the third step in which future sustainable options are envisioned. The inventory of the present situation in the second step and the criteria for a future sustainable situation in the first step often give a fruitful tension for the envisioning in the third step.

As a result of the third step, product ideas can be generated that link the present situation with the future sustainable goal. This result can then be used as a starting point for the fourth step of backcasting. It is important that the suggested products can lead in the right direction towards sustainability as being flexible enough platforms for forthcoming products heading towards sustainability. This is also one of the most important characteristics of this approach: while many existing tools for Design for the Environment have the capability to direct new investments in directions to decrease the environmental impact, few of them consider if the investments are good platforms for further investments in the right direction.

The generation of product ideas can result in a description of a service or a set of services that the new products should aim at delivering. The population growth and an increased service level per capita, factors P and u in the "imup equation" in section 2.4, imply that concern has to be taken regarding type and amount of service to deliver. Examples of questions that can be asked when evaluating services are: What human needs are fulfilled by this service? Which restrictions and possibilities can be found if this product was to be incorporated in a sustainable society with 10 billion people?

When a product idea has been generated, this idea has to be clarified. The clarification can result in a list of requirements that have to be fulfilled and a list of desirable qualities. Examples of aspects that can be considered are economic aspects, reliability and safety aspects, and physical surrounding such as geometry and weather. The ambitions concerning sustainability aspects also have to be specified at this stage. If the ambition is to develop a product that works as a bridge towards products that could fit into a sustainable society – how far should this product reach in this direction and in which ways? The four principles for sustainability can be used as a guidance for the requirements list.

The planning and clarifying step result in a product proposal that is based on conditions for a future sustainable society besides additional aspects that are traditionally concidered in product development, and a requirements list that includes sustainability criteria.

3.2. Conceptual design

The conceptual design step imply a development of the principle solution. Essential problems are identified and function structures are established. Working principles and structures are found and combined and firmed up into concept variants. The variants are then evaluated against technical and economic criteria (Pahl and Beitz 1996).

Sustainability criteria can also work as a basis for the evaluation of different concept variants. Principle solutions must be able to fulfil the overall function of the product and the requirements on the specified list from the clarification of the task. Desirable qualities can be weighted according to their importance and the evaluation of concept variants can be based on them. Sustainability aspects can be considered as a part of the requirements list or as desirable qualities.

Sustainability aspects are relevant on a *systems* and on a *sub-systems level*. The services that should be delivered by the product give an overall function of the product. This overall function can be divided into sub-functions. A variety of possible solutions can be found for separate sub-functions as well as for the combination of them. Different concept variants for the overall function could be developed into different products that more or less head in the direction towards sustainability. For example, if we look at some already developed technology – a conventional steam-electric coal power plant can be considered a dead-end technology, while a coal integrated gasifier/combined cycle power plant may be a transitional technology towards sustaianbility. The reason is that much of what has been learned in developing this technology is readily transferable to the biomass integrated gasifier/combined cycle power plant which have better qualifications to fit into a sustainable society. Different possible solutions on a sub-functional level can be, for example, different kinds of systems for the power supply in a car such as electric motors that may substitute for combustion engines for cars in urban traffic. Different options on a sub-system and system level are further elabortated, in more detail, in the embodiment design step.

The conceptual design step results in a principle solution. The choice of principle solution has been made from an evaluation, on a system and sub-system level, partly based on sustainability criteria.

3.3. Embodiment design

The embodiment design includes a development and a definition of the construction structure. The development of the construction structure starts with a preliminary form design and material selection. A refinement and improvement of layouts are done out from a selection of the best preliminary layouts. The layouts are evaluated against technical and economic criteria. The definition of the construction structure includes the elimination of weak points. Errors, disturbing influences and minimum costs are identified. Further, the preliminary parts list and production and assembly documents are prepared (Pahl and Beitz 1996).

The choice of construction structure influences the environmental impact during the consumption and the waste handling phases of the product. Environmental impact in earlier phases of the life cycle of the product and its components and materials such as extraction of resources and various production processes is also influenced by the choices made in this step.

Life cycle assessment (LCA) is a tool that can be used for the evaluation of the environmental impact during the whole life cycle of a product, i.e. from the extraction of resources to the waste handling. Much work and data are usually needed in order to make an LCA relevant and useful. This means that it often does not cover all essential parts of sustainability (Arnold 1995, Owens 1997). Furthermore, most LCAs are based on data from present industrial system as well as present energy and transportation systems. In order to avoid a product design which can lead into a dead end, one must also analyze the product design in relation to the requirements of the future sustainable society. This means that tools like LCA should be complemented with parallel assessments that assume that the product exists in a sustainable society. What parameters will change when the whole society has a metabolism that fits in the framework given by sustainability?

In our approach, the evaluation of the layouts can, besides other criteria, be based on sustainability criteria. The criteria can be based on options for transmaterialization and dematerialization, and such options can be based on the four principles for sustainability. The "imup equation" for environmental impact, see section 2.4., includes two main strategies to decrease the environmental impact per delivered amount of service. *Transmaterialisation*, factor *i*, is a strategy to decrease the environmental impact per amount of materials while *dematerialisation*, factor *m*, can decrease the amount of materials needed to maintain a specific service level.

The *transmaterialisation* strategy is an option when different materials can substitute for other materials without changing the qualities of the product more than is allowed by the set of requirements. The principles can be used as a guidance when evaluating choices of materials. Principles 1, 2 and 3 make it possible to focus upstream and to avoid *potentially* hazardous materials. Information about hazardous materials with known environmental effects can of course also be used in the evaluation. Potentially hazardous materials are, for example, metals that are scarcely occurring in nature, which have a larger potential to increase systematically if emitted to the ecosphere compared to more abundantly occurring metals, and persistent substances, for the same reason. Abundant metals and easily degradable substances could substitute for such substances.

Besides on a material level, substitution is relevant on a raw material and a component level.
The same material may be obtained from different raw-materials, for example, methanol can either be produced from fossil fuels or from biomass. Different types of components can give the same function, for example, the choice of a battery can be made out from a various types. In the product development process, the selection of raw materials, materials and components are further elaborated in the detail design step.

Dematerialisation can be accomplished in two principle ways: reducing the flow, i.e., less material/energy flow to achieve a certain service, or closing the flow, i.e., increased recycling of materials. This strategy is strongly related to the fourth principle of sustainability. *Reducing the flow* implies a more efficient use of a given material for a given function. The material/energy productivity can be increased by decreasing the amount of material/energy needed for a certain service. This can be achieved, for example, by miniaturisation of products or components and by increased quality or reparibility to extend the product life time. The copper wire in power transmission is one example of dematerialisation. By raising the transmission voltage it has been possible to reduce the amount of copper needed to transmit a given amount of electricity.

Closing the flow of materials within society implies that the same material is used again and again. The flow can be closed on different levels: by reusing products, by reusing parts of products or by reusing materials or raw materials. Cycles can be closed within the production process, or in the exchange between producers and consumers. An important condition for successful recycling of materials is that flows are sufficiently pure or separable. Unnecessary *mixing* of different kinds of materials can make separation more difficult, and should therefore be avoided. Design for Disassembly, see for example (Luttropp 1997), has evolved as a strategy for especially facilitating the recycling of products. The effects of the inevitable loss of quality in materials and energy can be minimised through the implementation of *cascading use*, where each step involves a drop in quality requirements. After each recycling step of a certain material, it should be used in such a way that the quality can be kept on the highest possible level. There are mainly three qualities that are interesting: (i) purity, (ii) structure and (iii) exergy. For instance a special steel should not be used as reinforcing iron after only one cycle if one wants to save the *purity*. The bulk *structure* of wood, for instance, can be utilised, if wood is first used as a construction material, before the fibre structure is used in paper of stepwise declining quality and, finally, the chemical structure is utilised in chemical industry or fuel production and combustion. In the energy sector, one can also improve the *exergy efficiency* through cascading use of energy, where each step involves a drop in temperature. In this context, Ayres & Ayres (1996) have discussed *waste mining* as a strategy which utilise waste streams from (currently) unreplaceable resources, for example, recovering elemental sulphur from natural gas and petroleum refineries. This strategy reduces (i) the environmental damage due to the primary waste stream, (ii) the rate of exhaustion of the secondary resource, and (iii) the environmental damage due to mining the secondary resource.

A *dissipative* use of materials, such as chemicals that are emitted to the ecosphere during their consumption, is the opposite to closing the flow strategy. The dematerialisation strategy can be used to decrease the amount of emitted materials and the transmaterialisation strategy can be used to avoid that hazardous (or potentially hazardous) materials are used in a dissipative way.

The embodiment design results in a construction structure which has been chosen after an evaluation of layouts. The evaluation has, besides other criteria, been based on sustainability criteria.

3.4. Detail design

The step of the detail design implies that production and operating documents are prepared. Detail drawings and parts lists are elaborated. Complete production, assembly, transport and operating instructions are concluded and all documents are checked. This final step should result in a product documentation (Pahl and Beitz 1996).

So far we have mainly discussed the design of the product. The design of the product is connected to other activities in the firm such as the development of the production process and the organisation of transports. Sometimes the design of the product can influence other activities in a positive way. Hitachi, for example, designed a division of washing machines made by just six screws. The main purpose was to facilitate the recycling of old washing machines. The design had also the consequence that the production process was facilitated and the manufacturing time was cut by 33 percent (Esty and Porter 1998). Besides that other activities are dependent on the product design they should also be considered from a sustainability perspective by themselves.

Different activities can be connected to different roles of a firm. With some of these roles, the firm has the possibility to also influence other actors in their use of resources. A firm can be divided into four different roles, by which it directly or indirectly influences the ecosphere. By the choice of purchased goods or services, the firm in the role of *purchaser*, influences the suppliers interaction with the ecosphere. In the production and delivery of goods and services the firm acts as a *resource converter* and influences the ecosphere directly. As a *supplier* the firm delivers goods or services, which due to their properties influences the customers interaction with the ecosphere. In the role of *communicator*, the firm takes part in personnel education, advertising and lobbying and it sends product information to customers and requirements to the suppliers, and can thereby influence a whole range of actors.

4. Discussion and conclusions

We have described the structure for the incorporation of sustainability aspects within the process of product development. The main advantage with this approach is that a development towards sustainability is emphasised and facilitated with the use of four principles for sustainability. Based on sustainability criteria, it is easier to avoid the development of products that leads to dead ends. New products should at least be able to work as flexible enough platforms for other products in the development towards sustainability. Further, a structure for sustainability makes it easier to not miss to consider any relevant aspects of sustainability.

The structure we have presented is a first step towards a method for sustainable product development. In our continuing work with this project we will develop this method in more detail and the objective is to achieve a method that can become a useful tool for companies.

Our ambition is to develop a tool that has the form of a set of *hierarchically structured questions*. The questions will be sorted under the steps of the product development process and based on the four principles for sustainability. The questions will be sorted in a hierarchic structure from general to more specific. Most questions will have a qualitative approach while others can result in quantitative measurements when it is found relevant. There are many advantages with using a semi-qualitative approach.

1. The framework and the principles make more sense and will be easier to grasp.
2. It is easier to identify which aspects should be quantitatively analysed.
3. It is easier to identify which aspects are not quantitatively analysed.
4. It is easier to communicate the results, due to the logical structure.
5. It is possible to find solutions with less effort, since it is easier to avoid unnecessary quantitative analysis.
6. It is possible to also cover aspects that are difficult to analyse quantitatively.

Principles 1, 2 and 3 make it possible to focus upstream on fundamentally different mechanisms in the societal impact in the ecosphere: (i) a systematic net increase in concentration of matter that is introduced into the ecosphere from outside the system (the lithosphere); (ii) a systematic net increase in concentration of matter that is produced in society; (iii) a systematic physical deterioration through harvesting and manipulation. This means that the questions can start from these mechanisms.

For instance, the first principle raises the following question to an actor: will the activity or investment cause emissions (directly or indirectly) of substances extracted from the lithosphere? And will they be a part of a flow that leads to systematic increased concentrations in the ecosphere of elements extracted from the lithosphere? (Maybe some of the actual elements are already known to cause harmful effects?) If this is the case, the next question is then to figure out how this can be avoided. For different activities and investments different actors find different solutions: substitute an abundant chemical element for a scarce/toxic element, avoid dissipative uses, increase the recycling, reduce the down-cycling or fulfil the same service with less of the material. The other principles can be used in the same way.

Experience tells us that quantitative measurements of environmental impact, for example LCA, take much effort to perform. The large effort needed can make it expensive to find sufficient data for the measurements. Our qualitative approach to include sustainability aspects in product development can therefore be of special usefulness for small and medium sized enterprises (SMEs) which do not have the same economic possibilities as larger enterprises.

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