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

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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 provide support from a sustainability perspective.

Nine of the 15 tools analyzed included a valuation and were able to provide support in a trade-off situation, but the support was not sufficient. The valuation should include a life cycle 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 lifespan, 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

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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 in 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 in 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 analyzed 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 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 [12–14]).

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'.

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 life cycle perspective, which gives an overall picture of the environmental impact from the product's life cycle 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, 10 Golden Rules, and 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 11 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, 10 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, and 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 are 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.

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 life cycle 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

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

Tool	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 11 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 to 100). But, no quantitative data are needed to perform the grading. *General or concrete prescriptions*: concrete
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
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

(*continued on next page*)

Table 1 (*continued*)

Tool	Presentation
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
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
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: optimize material input, optimize 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
Ten 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

Table 2
Fifteen Ecodesign tools analyzed to ascertain whether they include 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, and White Lists		X

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 analyzed tools. Changes in management routines of forestry, agriculture and fisheries that are necessary from a sustainability perspective cannot be solely described in terms of 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 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 product 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

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*
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 environmental 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
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*

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 violates 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 bioaccumulation. At the time when CFCs 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 suboptimization might occur if the whole life cycle of the product is not covered in the Ecodesign 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 pros in relation to the respective known cons, 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. An 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 the guidelines for the design of strategies towards sustainability should be added to the tool. Such guidelines should be based on backcasting, flexible platforms, good return on investment and the 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, provide 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 life cycle 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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References

[1] van Hemel CG. The IC EcoDesign project: results and lessons from a Dutch initiative to implement ecodesign in small and medium-sized companies. J Sustain Prod Des 1997;7–18.
[2] Lagerstedt J, Sousa I, Luttropp C, Wallace D. Functional and environmental product attributes – an automotive industry case study. In: CIRP–Life Cycle Seminars; 2002.
[3] Ritzén S. Integrating environmental aspects into product development – proactive measures. PhD thesis. Department of Machine Design, KTH, Stockholm; 2000.
[4] Commission for Environmental Cooperation. Supporting green markets, environmental labeling, certification and procurement schemes in Canada, Mexico and the United States. Québec, Canada, 1999.
[5] Ullman DG. The mechanical design process. McGraw-Hill Inc.; 1992.
[6] Jakobsen K. The interrelation between product shape, material and production method. Harrogate: ICED; 1989.
[7] ISO. Environmental management – life cycle assessment – principles and framework. In: International Standard ISO 14040, 1997.
[8] Robèrt K-H, Schmidt-Bleek B, Aloisi de Larderel J, Basile G, Jansen JL, Kuehr R, et al. Strategic sustainable development – selection, design and synergies off applied tools. J Clean Prod 2002;10:197–214.
[9] Robèrt K-H. Tools and concepts for sustainable development, how do they relate to a framework for sustainable development, and to each other? J Clean Prod 2000;8:243–54.
[10] Dreborg K-H. Essence of backcasting. Futures 1996;28(9): 813–28.
[11] Dreborg K-H. Scenarios and structural uncertainty, explorations in the field of sustainable transport. Doctoral thesis. Royal Institute of Technology, Infrastructure; 2004.
[12] Holmberg J, Robèrt K-H, Eriksson K-E. Socio-ecological principles for a sustainable society: scientific background and Swedish experience. In: Costanza R, Segura O, Martinez-Alier J, editors. Getting down to earth – practical applications of ecological economics. Washington, DC: Island Press; 1996. p. 17–48.
[13] Broman G, Holmberg J, Robèrt K-H. Simplicity without reduction: thinking up-stream towards the sustainable society. Int J Inst Manag Sci Oper Res Soc Am 2000.
[14] Ny H, MacDonald JP, Broman G, Yamamoto R, Robèrt K.-H. Sustainability constraints as system boundaries – an approach to make life cycle management strategic. J Ind Ecol, in press.
[15] de Caluwe N. Ecotools manual: a comprehensive review of design for environment tools. Design for the environment research group. Manchester Metropolitan University; 1997.
[16] van Weenen H. Design for sustainable development: guides and manuals. Dublin: European Foundation for the Improvement of Living and Working Conditions; 1997.
[17] Tischner U, Schmincke E, Rubik F, Prösler M. How to do Ecodesign? A guide for environmentally and economically sound design. Berlin: German Federal Environmental Agency; 2000.
[18] Lehmann SE. Umwelt-Controlling in der Möbelindustrie. Ein Leitfaden. Berlin: Institut fur ökologische Wirtschaftsforschung; 1993.
[19] Graedel TE, Allenby BR. Industrial ecology. New Jersey: Prentice Hall; 1995.
[20] Wenzel H, Hauschild M, Alting L. Methodology, tools and case studies in product development. In: Environmental assessment of products, vol. 1. London: Chapman Hall; 1997. p. 543.
[21] Pommer K, Bech P, Wenzel H, Caspersen N, Olsen S. Håndbog i miljøvurdering af produkter-en enkel metode. Miljønyt. Miljø-og Energiministeriet: Miljøstyrelsen; 2001. p. 58.
[22] Brezet H, van Hemel C. Ecodesign. A promising approach to sustainable production and consumption. France: United Nations Environmental Programme (UNEP); 1997.
[23] Meinders H. Point of no return. Philips EcoDesign guidelines. Eindhoven; 1997.
[24] Schmidt-Bleek F. Ökodesign, Vom Produkt zur Dienstleistungserfullungsmaschine. Schriftenreihe. Vienna: Wirtschaftsförderungsinstituts Österreich; 1998.
[25] Karlsson M. Green concurrent engineering: assuring environmental performance in product development. Dissertation, Lund University; 1997.
[26] Luttropp C, Karlsson R. The conflict of contradictory environmental targets. In: Second International Symposium on Environmental Conscious Design and Inverse Manufacturing, Tokyo, Japan; 2001.
[27] Nordkil T. Volvos vita lista. Volvo Corporate Standard; 1998.
[28] Nordkil T. Volvos grå lista. Volvo Corporate Standard; 1998.
[29] Nordkil T. Volvos svarta lista. Volvo Corporate Standard 1998.
[30] Hochschorner E, Finnveden G. Evaluation of two simplified life cycle assessment methods. Int J LCA 2003;8(3):119–28.