PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Environmental assessment in product development

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Environmental assessment in product development

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In the last few years the environmental focus in the product producing industry has shifted from the manufacturing processes to the products themselves, as these are accountable for all the environmental impacts in all life-cycle phases. The environmental properties of a product are determined in the product development stage; it is necessary to supply the product development function with methods/tools to assess the environmental consequences in product life-cycle and to support selection of environmentally friendly solutions.

In this paper a set of tools to support environmental assessment of products and product development is presented. The tools have been tested in five Danish companies and have proven their practical applicability.

1. Introduction

In the last few years it has become clear that our present industrial production and consumption culture is facing dramatic changes in the future due to the following: pollution and waste problems; non-renewable resource consumption; and rapid growth in the world population (with increased production/consumption demands).

The developing countries are fighting poverty and health problems and we have no choice but to support their struggle for economic growth, which is a prerequisite for a more stable world.

Our best contribution is to develop a new sustainable industrial culture, which can be scaled up by a factor of 5–6 compared to the present level without creating unacceptable environmental and resource problems.

The term sustainability appears more and more often in literature, but is used in many different meanings. Broadly, the content of the term is determined by the different value criteria of the various interest groups around a company (share holders, customers, suppliers, employees, local community, national and international community, political interest groups, etc.). A closer study of these criteria will give the result that the following responsibilities for a company are mandatory in the future: economic; social/societal (including ethical); and environmental.

In this paper, mainly the environmental responsibility will be discussed. A broader discussion of the social/societal responsibilities can be found in Alting (1995) and Saemann (1995).

If we look at the environmental responsibility, an acceptable performance can only be achieved if it results from a strategy involving all business functions and

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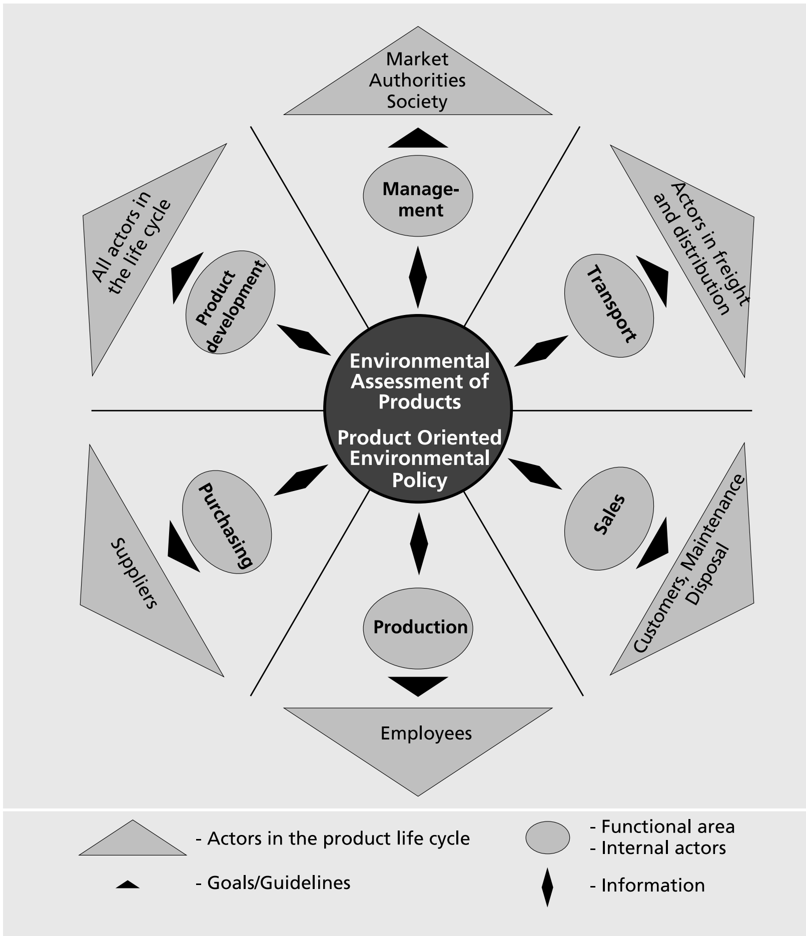

Figure 1. Product oriented environmental company policy (Alting *et al.* 1996).

employees (see figure 1). For each functional area a more detailed description of policies, guidelines, actions, etc., must be developed.

In this paper, only the product development function will be discussed in the following. The environmental focus is shifting from manufacturing processes to products, as illustrated in figure 2. If we look at a product life-cycle, the main environmental emphasis so far has been on the manufacturing phase and, to some degree, on the disposal phase. This emphasis has given very good results, but at the same time the number of products per household, energy consumption and waste have increased more and have caused a larger environmental impact. Therefore, the only alternative is to shift the focus to products and to minimize the environmental impact in the whole life-cycle. The result hereof is that future environmental control is mainly in the hands of the customer in interaction with the company.

To be able to cope with these issues the company must develop its products in a life-cycle perspective and must be able to document the environmental impacts in all life-cycle phases.

At the Institute of Product Development, Technical University of Denmark, a research and development programme was initialized in 1991 with the following aim:

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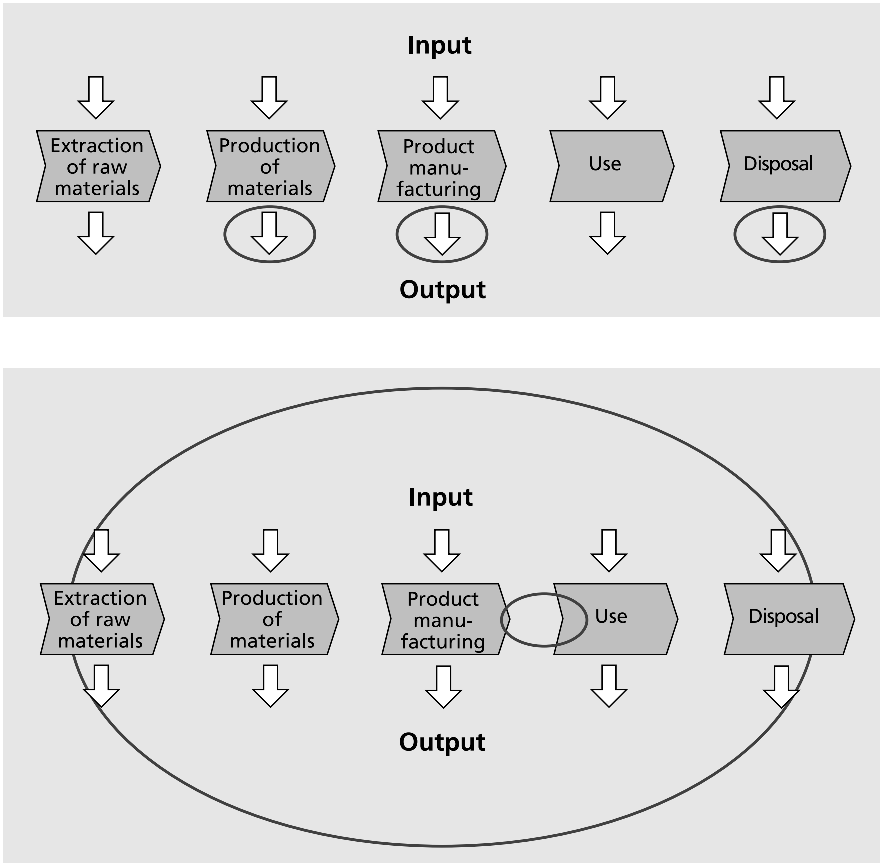

Figure 2. Shifting focus from the manufacturing phase to the complete life-cycle, i.e. to products (Alting *et al.* 1996).

to develop methods for environmental assessments of complex industrial products; to develop guidelines for design of more environmentally friendly products; to develop a database and a PC-tool for supporting environmental assessment; and to implement the methods and tools in participating companies.

The programme was a collaboration between the Institute of Product Development, Technical University of Denmark, The Federation of Danish Industries, The Environmental Protection Agency and the five companies Bang & Olufsen A/S, Danfoss A/S, Gram A/S, Grundfos A/S and KEW Industri A/S.

2. The resulting tools

The result of the programme is a set of tools focusing on the product development function in the company with the purpose of building the environmental properties into the product alongside with other necessary properties. There are two target groups in the companies for the tools, as shown in figure 3. One is the product developer, responsible for decisions in developing new products from specifications over conceptual selections to detailed solutions. The other target group is the environmental specialist, responsible for the assessment of the environmental impacts of the products. The reason for focusing on two target groups is the recognition of the fact

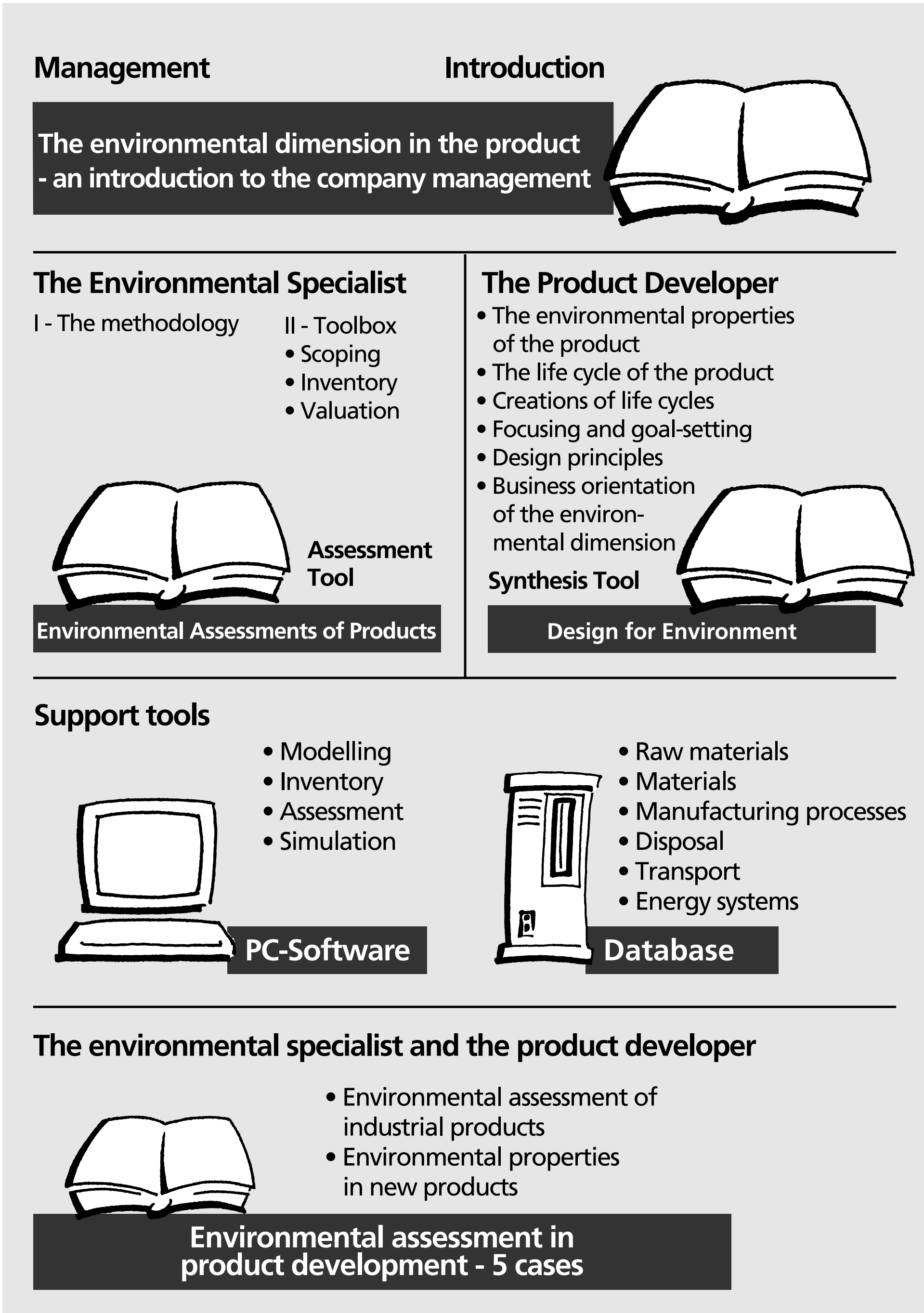

Figure 3. Deliverables from the Danish development programme EDIP (Environmental Design of Industrial Products) (Wenzel *et al.* 1997).

that neither the product developer nor the environmental specialist can handle the problems alone. The environmental specialist assesses the environmental properties of the products and the product developer builds the properties into the products.

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Before further presentation of these two sets of tools, a discussion of what we mean by an environmentally friendly product will be given.

3. Environmentally friendly products—what are they?

A definition of a product is something that provides a useful output (service, benefit, yield, etc.) for the user. This output/yield, or the satisfaction of the user's need, is the cause of the product's existence. Therefore, it is this output, which can be defined as the functional unit of the product, that must be accountable for all the environmental impacts from the product in all its life-cycle phases.

A functional unit can be delivered in different ways. The advantage of looking at the products themselves and not the manufacturing processes is that this opens up for the possibility of comparing the environmental consequences of different ways of providing the desired functional unit. Thus, it becomes possible to develop and choose products based on environmental considerations. Figure 4 shows examples of different functional units and ways of delivering these. The coffee can be kept in different cups, the hairdressing can be performed in different ways and the lawn can be kept by different means.

To ensure that the different ways of providing the functional unit are comparable, the functional unit must be defined and quantified precisely. The functional unit is the fundamental basis for the environmental assessment. When alternative solutions are compared, everything else can vary but the functional unit. Figure 4 describes the functional unit for three user needs and the different solutions are all specified to deliver the selected functional unit. Due to different lifetimes of the different types of solution products, more products may be included to deliver the same functional unit.

The examples in figure 4 have deliberately been made very different, but, independent of the frames for solution space, the considerations are the same.

The environmentally friendly product does not exist and the most environmentally friendly product is the one that is not produced. Therefore, environmentally friendly is a relative term, i.e. one product may be more environmentally friendly than another. This is exactly the case if it delivers the same functional unit with a smaller total environmental impact in the whole life-cycle. This is the fundamental principle of the developed methods/tools.

4. The assessment method

Environmental assessment of products is a new principle, but it is built on the knowledge and experience gained within environmental sciences through the last decades. The valuation method in the environmental assessment of products is primarily tied to the principles developed within environmental assessment of chemicals and chemical substances, as they are found in, for example, emissions of waste water and gases from industry. The effect of a substance on the environment depends on the following three factors: the amount of emission; how dangerous it is; and the amount and concentration of it when reaching the environment where the effect may appear.

This is true for emission to air, water and soil and it can be expressed as

$$\text{effect} = \text{amount of substance} \times \text{hazardous potential} \times \text{exposure}.$$

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Figure 4. Different ways of obtaining the same functional units (Wenzel *et al.* 1997).

The hazardous potential describes the ability of a substance to release a certain effect. The exposure expresses the degree in which the substances arrive to the areas in the environment where the effect may appear (see Hauschild & Wenzel 1997). The question now is: what does it mean to assess a product environmentally? How does this differ from the above emission discussion?

Figure 5 shows a product—an electric mixer. As shown, it has no environmental impact. It only has an environmental impact through its history and its future. This is due to the fact that the environmental impact from a product results from the processes in which it interacts. It is the processes that exchange substances/materials or energy with the surroundings and an environmental impact can only take place when there is an exchange. Fundamentally, therefore, there is only one way to perform environmental assessment of a product and that is to assess all the processes in which

Figure 5. A product.

the product is involved. The problem is thus similar to the above discussion about assessment of emissions. For one product only, many emissions will have to be assessed and added. The new challenge is to assess many types of effects concurrently, both different types of resource consumption, environmental effects and health effects. It makes the problem different in the way that it is the wholeness and the comprehensive view that are important and details about the individual emissions may be left out. The number of processes, in which the product takes part through its life-cycle, often prevents all locations and site-specific considerations around the emissions in the life-cycle to be known. This means that variations in time and spreading conditions in the recipient after emission are often unknown. The consequence is that environmental assessment of products mostly cannot encounter valuation of the exposure as described above for chemical substances. A valuation of the exposure of the organisms in the environment is necessary to predict the actual effects of the emission. When this is not possible for products, the environmental assessment here is limited to dealing with potential effects or effect potentials.

Therefore, the principle in environmental assessment of products can in brief be formulated as

$$\sum \text{effect potentials} = \sum \text{amount of substance} \times \sum \text{effect potential of substance},$$

where the summation is taken over all substances and impacts through a product life-cycle. Depending on where and when an emission or an impact actually takes place, the effect potential may release real effects to a larger or smaller degree.

This characteristic of environmental assessment of products is the most significant feature. It is the consequence of the difficulty of acquiring data specific for the product in time and space—and this is true for all other methods. This feature must be kept in mind and results must not be overinterpreted when conclusions are not clear. This lack of accuracy in assessments is not a negative drawback. On the contrary, the accuracy of the assessment is in most cases appropriate for the purpose

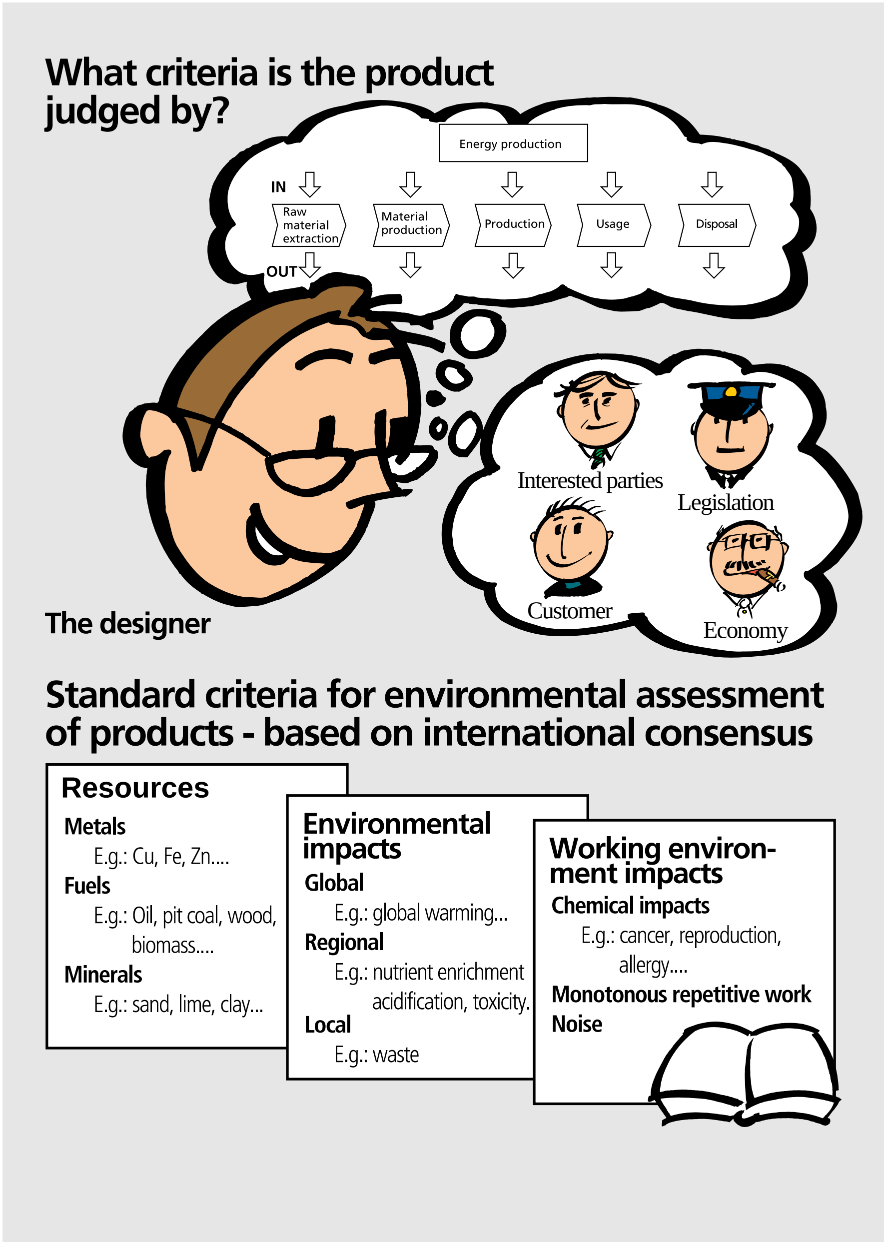

Figure 6. Parameters in assessing the environmental properties of a product (Alting *et al.* 1996).

of the assessment, i.e. to establish an overview and support prioritization between environmentally different solutions in a product.

5. The tool: environmental assessment of products

The environmental assessment tool is the central part of the results of the research. The developed method is the basis for quantifying and comparing environmental

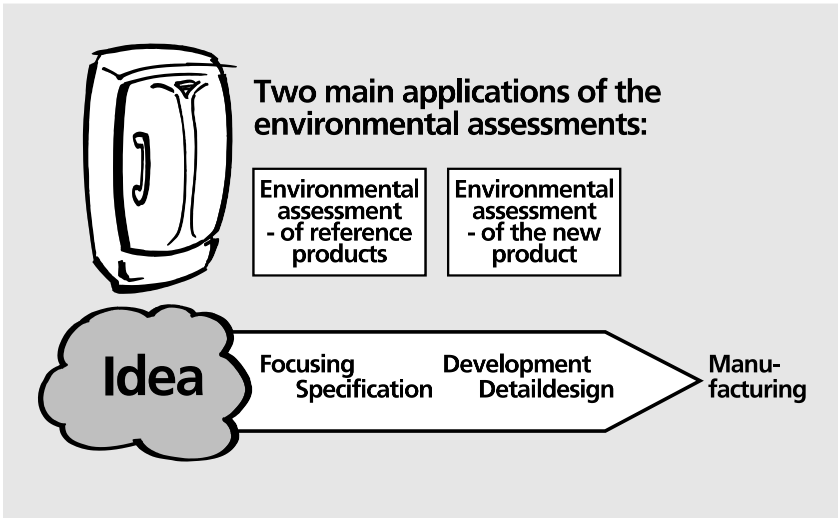

Figure 7. Two main applications of the environmental assessment (Alting *et al.* 1996).

properties for different solutions in product development. The collaborative nature of the research has enabled testing and implementation in companies to ensure the practical applicability. During development of the method, the international work on method development and standardization has been followed closely and the method represents the state of the art knowledge and is built on international consensus. The Institute for Product Development takes part in both ISO and SETAC to ensure the maintenance and lifetime of the method. In the method, the product developers' situation is included so that environmental issues can be considered in the same way as other requirements. The valuation principles are designed according to this and, therefore, working conditions/health issues are also included (see figure 6).

The method has been adopted to the various situations of product development where environmental assessments are relevant. There are basically two main applications, as shown in figure 7. The first one is in the beginning of product development, as a basis for focusing and goal-setting. Here, assessments of one or more reference products, typically the old generation of the product, and one or more competing or alternative products are performed.

The other main application of the method is in the product development stage, where different solutions for the new product are compared. The assessment of the reference product is performed before product development is started, so that it does not become a bottleneck during product development. The assessment of the new product utilizes partly the identified environmentally weak points to focus the development work and partly the collected data.

The assessment methodology/tool includes guidelines for how the environmental impacts are calculated and valuated. The results of the environmental assessment are quantitative pictures of the environmental properties of the product, making comparisons possible. The tool focuses much on simulation and comparison of solutions.

6. The tool: design for environment

In the tool 'Design for environment', the experience from environmental assessments is transformed to terms and design principles that are useful for the designer.

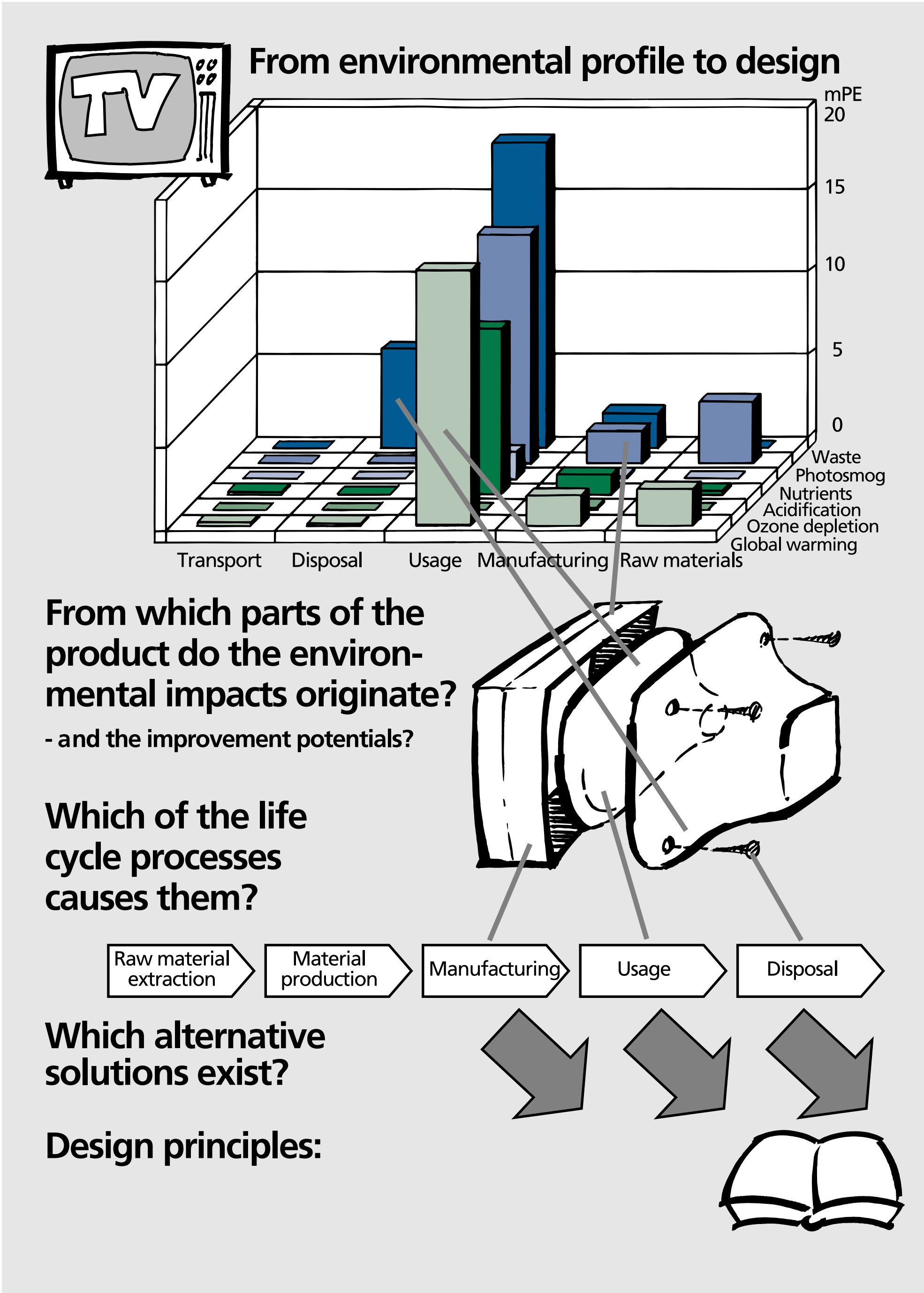

Figure 8. From environmental assessment to design principles (Alting *et al.* 1996).

A description is given as to how the environmental impacts are linked to properties of the product: where in the product is the problem? Figure 8 shows an example for a television. The contribution to photosmog, for example, is linked to the surface

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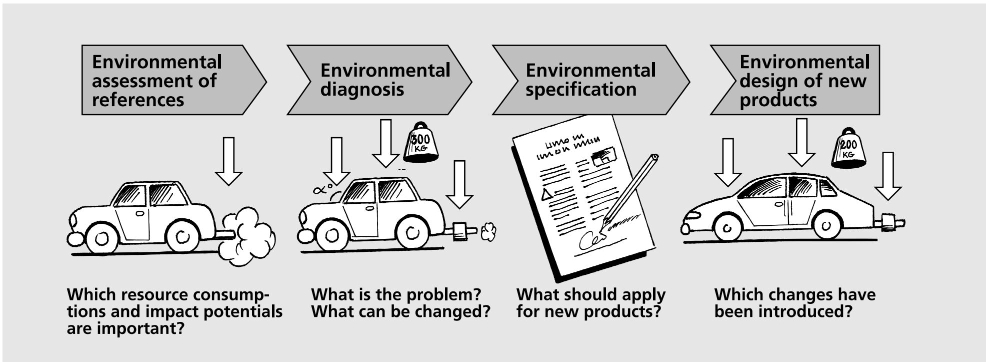

Figure 9. Steps the in application of the environmental assessment in product development (Wenzel *et al.* 1997).

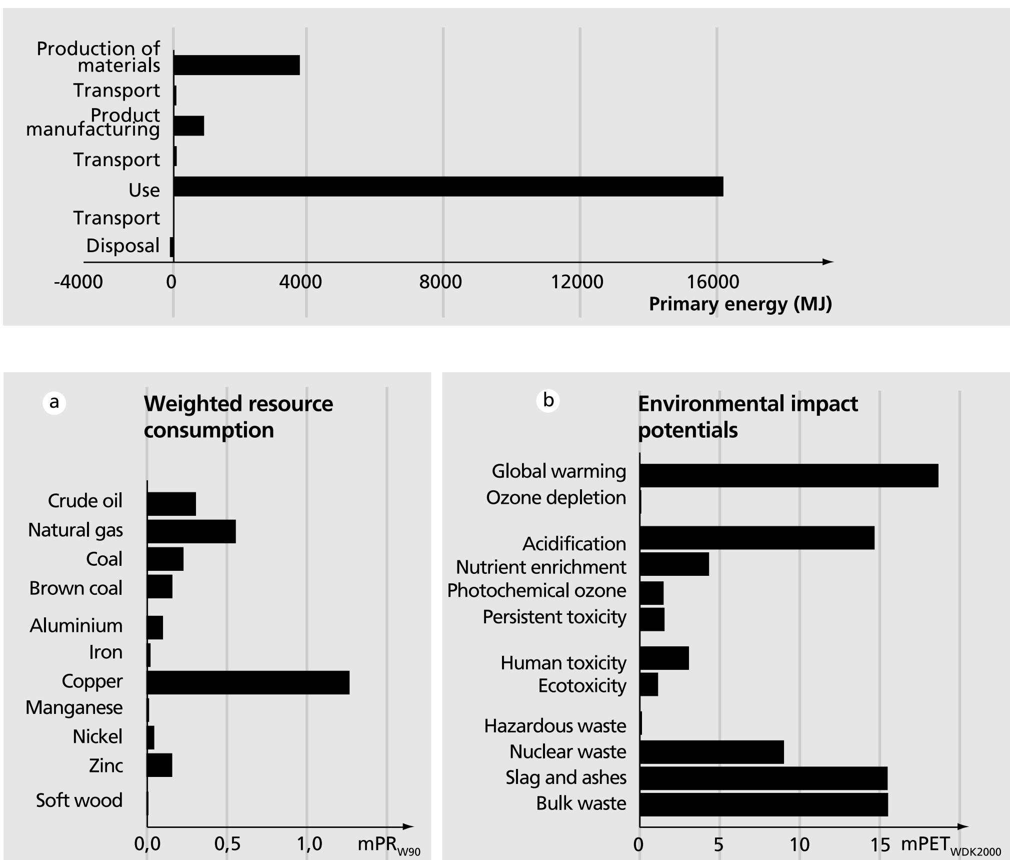

Figure 10. Environmental assessment results for a B&O television, total energy consumption in the various life-cycle phases, resource consumption and environmental impacts (Wenzel *et al.* 1997).

treatment of the front frame, the global warming contribution is linked to the usage phase (due to low efficiency in the picture tube) and the contribution to solid waste to the disposal phase (mainly due to difficult disassembly).

The design tool gives the product developer insight into the life-cycle of the product

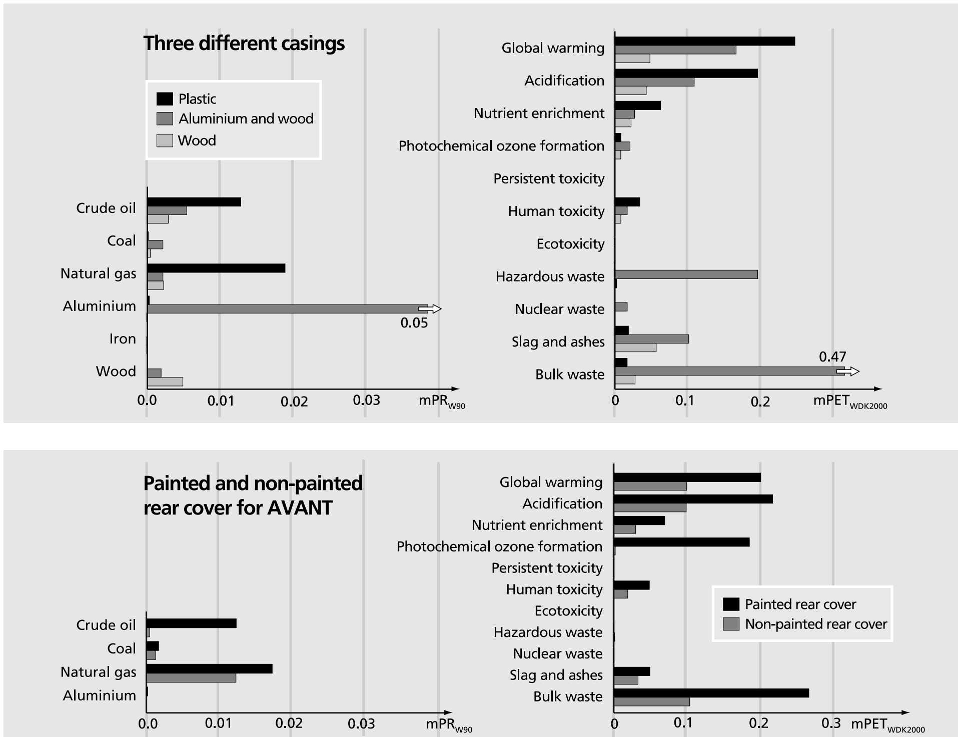

Figure 11. Comparison of resource consumption and environmental impacts for different design solutions (Wenzel *et al.* 1997).

and thus it supports the creation of an environmentally better life-cycle and a better adaptation of the product to the life-cycles. It creates a necessary coherence between the environmental profiles and the alternative solutions in the development.

The tool 'Design for environment' has been developed and presented as other design tools so that the environmental requirements are considered in the same way as other design requirements. In this way it is secured that the environment is given the emphasis that its contribution to the competitiveness justifies.

7. Experience from industrial projects

As mentioned previously, five Danish companies took part in the development of the tools. They each selected a product, which has been environmentally assessed and these assessments are used for developing more environmentally friendly products.

Figure 9 shows how the results in the companies are used. A few comments are given for each step.

(*a*) *Environmental assessment*

Here the main resource consumptions, potentials for environmental effects and working conditions are identified. An identification is also made as to what components and what phases and processes in the life-cycle represent the largest contributions.

Figure 10 shows some of the results for a television (Bang & Olufsen, LX5500):

energy consumption for the different phases in the life-cycles, resource consumption and potential environmental effects. The results can be broken down to each life-cycle phase, components, materials and energy in each process, etc., i.e. full traceability back to the origin.

The units used for resources and environmental effects are so-called personal equivalents (PE). For the resources a personal equivalent is equal to the known reserves divided by the world population (reference 1990). For global environmental effects, a personal equivalent is equal to the world emissions (CO_2 and ozone depletion) divided by the world population. For the regional and local effects, the Danish emissions divided by the Danish population are used as a personal equivalent (reference 1990).

(*b*) *Environmental diagnosis*

In this stage, the environmental improvement potentials are identified and where in the product the problem is located is also identified.

(*c*) *Environmental goal setting*

An analysis of the competitive situation on the market, i.e. the customers' perception of the environmental properties and the competitors' environmental status, is performed.

Based on this and the previous step, a goal for the environmental properties of the product is set.

(*d*) *Environmental improvements of new products*

Here the specific improvements are implanted into new products. Large environmental benefits are achieved both in energy savings, material savings, chemical savings, substitutions, etc.

Figure 11 shows examples from the television. Figure 11*a* shows the consequences of changing the front frame from plastic, aluminium to wood and figure 11*b* shows the improvements when changing from painted to unpainted back cover.

8. Conclusion

The five companies in the programme have implemented the methods/tools and they have all had very good experiences. Environmentally friendly solutions have also shown to be cost effective solutions and the implementations have resulted in material, energy and chemical savings. The companies have focused their environmental policies on products and they all continue the development of environmentally friendly products.

At present, a large programme is being carried out to implement the methodology broadly in Danish industry.

The methodology/tools, the database and the results from the companies have all been reported in a book series (Alting *et al.* 1996).

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Discussion

W. R. Stahel (*Product-Life Institute, Geneva*). In the introduction, Professor Alting mentioned the triple bottom-line of economic, social and environmental efficiency and sustainability. In the following, he only talked about environmental factors. Does he have the same breakdown of data on cost and social factors (employment, quantity and skills)? For example, is the labour input in changing the compressor in a long-life refrigerator higher or lower than in producing a new disposable refrigerator? What about the skills involved?

L. Alting. Our development work has been concentrated on methods/tools to handle environmental and occupational health effects. We have only cost data for some specific cases—we have not developed more general cost models.

S. Roy (*Department of Chemical and Process Engineering, University of Newcastle, UK*). Professor Alting presented a fairly sophisticated systematic analysis on the life-cycle assessment of materials and energy flows for consumer products such as televisions, refrigerators, etc. He showed how more efficient products can be developed by keeping in mind recylability, energy efficiency and disassembling of parts. It is commendable that industries have taken them into account and designed products which fulfil these requirements whilst maintaining low production costs.

The problem regarding this analysis is the absence of the consumer 'processing bloc' (if I may call it so), which is an integral part of the flow sheet of the materials and energy into and out of the system. In fact, he showed that 80% of the energy consumption for a television or refrigerator takes place in that part of the cycle. this essentially means that a 50% improvement in production and recycling efficiencies will result in an overall improvement of only 10%. Worse still, the greater part of energy consumed in the consumer 'bloc' is during the standby time, which for a refrigerator may be understandable but for a television is unacceptable. In any traditional business or process analyses excluding a 'bloc' where largest gains in efficiency can be expected would be unthinkable. Indeed it is conceivable that additional resources invested in manufacturing and/or recycling might be justified, on the basis of improved 'efficiency' of the consumer.

The reluctance to include a consumer 'bloc' in the flow chart is perhaps based on a premise that the consumer's life-style and that no improvements in efficiency can be effected. I also understand that the intractable and variable nature of consumers pose difficulties in interpreting and modelling this 'bloc'. This deficiency in the analysis, however, is a serious flaw and can render gross efficiency improvements in other sectors meaningless. This has been clearly demonstrated in the motor car industry: addressing the production side of car making solely does not and will not solve problems regarding environmental impact of cars. In order to attain better air quality, lower traffic noise, and less greenhouse gases, not only better cars are required but the consumer has to reduce his/her dependence on cars. I hope, that in future life-cycle analyses, greater effort is expended in including this aspect.

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L. Alting. In the process of developing a more sustainable industrial production and consumption culture we have to work on two parallel approaches: (1) environmental improvements of products, i.e. a technological approach; (2) changing our life style, i.e. to change our own perception of quality of life.

We have been concentrating on the technological approach, i.e. how can we develop more environmentally friendly products. In this work it appears for energy consuming products that the usage phase is dominating, which stimulates companies to develop more energy efficient products. Depending on the company policy they may choose to produce products, for example televisions with or without standby so that the user can make his own choice. the companies may decide to influence the consumers' attitudes, i.e. to stimulate a change in lifestyle.

But in my opinion a change of our perception of quality of life needs a broader and public discussion process. The companies produce the products that we want.

G. D. W. Smith (*Department of Materials Oxford University, UK*). This subject is obviously of great importance to the future of all of us. However, I should like to make some comments and ask a couple of questions regarding the quantitative aspects of life-cycle analysis.

(i) Professor Alting mentions copper as being of particular concern. Yet we saw from an earlier presentation by Dr Frosch that this metal is in fact highly recyclable. Also, his concerns about copper stem at least in part from the data for the current proven resource base. However, resource figures are notoriously unreliable. For instance, nearly all the metals considered by Meadows *et al.* (1972) in their book *The limits to growth* now have *larger* proven resource bases than they did in 1970, despite 25 years of further production (data from US Bureau of Mines, Minerals Yearbook). The data on which resource statistics are based all come from commercial sources (largely mining companies), and it is far from clear that they give an accurate overall picture of the situation. Also, of course, exploration is ongoing.

(ii) Life-cycle analysis presupposes a closed system, whereas the situation is more like an open system. For example, take the case of aluminium usage in cars. Where does he draw the limits to the side effects of this? It is quite easy to assess the amounts of metal involved, and the energy required to produce it, but what about the environmental impact of bauxite mining? And the resources required to produce the mining equipment to extract the bauxite? There obviously need to be agreed conventions and standards for this kind of analysis. What process is being made towards establishing these?

(iii) Energy aspects of life-cycle analysis also require qualification. There is, for example, a huge difference in CO_2 production depending on whether electricity is produced from coal, gas, nuclear or hydroelectric plants. What are the conventions for dealing with this? Is there international agreement on how such matters should be dealt with?

L. Alting. (i) Today the yearly consumption of copper (not recycled) is higher than 'the yearly growth' of known resources, which means that they will come to an end in a foreseeable future. My point is that we need to increase recycling of copper to prolong the availability of the resource—it is technologically not difficult.

(ii) In the LCA data all emissions related to materials from extraction to recycling (and disposal) are included, also bauxite in the aluminium production. Equipment for mining (i.e. its manufacture and disposal) is not included but the use is. The environmental impact from the manufacture of equipment is seen in relation to per ton produced material very small. In ISO standards, 14040 series internationally accepted procedures are established.

(iii) Depending on the purpose of the specific LCA, different energy scenarios may be used. It depends on where the energy is used. Each country has their own energy profile and the proper one may be used in the relevant parts of the LCA. The ISO standards also discusses this problem, and so does the SETAC organization.

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