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Tools and methods for environmental assessment of building products—methodological analysis of six selected approaches

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Abstract

Six approaches to the environmental assessment of building products were analysed, using floorings as an example. The approaches were an LCA study, an eco-label, two ecoguides, a product declaration and an environmental concept (The Natural Step). The analysis focused on the nature of each approach, the types of decision-maker targeted, the overall purpose, the object analysed, the perspective, the dimensions investigated, the character of the approach, the basis for comparisons, system boundaries, types of data, and the evaluation and interpretation of results. It was found that different approaches answer different questions and that stakeholders may need to use different tools for external communication, external decision-making support, and internal development.

1. Introduction

1.1. Background

There have long been complaints about the lack of sufficient information for the environmental assessment of buildings and their components. Now the number of tools and methods for environmental assessment is increasing. However, the available methods differ as regards the input data used, the environmental impacts addressed, and how the information is evaluated, the procedure documented, and the results presented. Consequently, different methods may give different and sometimes contradictory answers to seemingly similar questions about, say, the choice of materials. Hence, users of environmental information face the new problem of how to interpret this information and select the appropriate approach for a specific situation. To help the users, and to avoid duplication of effort when creating assessment tools and methods, comparative analysis is called for. This need is borne out in my own work as I apply Life Cycle Assessment (LCA) to building materials and present the results. Questions frequently arise about how these results can be used when ranking and recommending specific products. This indicates a need to be able to compare LCA with other approaches to the environmental assessment of building products.

1.2. Aims and objectives

This paper analyses and compares six approaches to the environmental assessment of building products with the aim of helping users interpret the information provided and select the most appropriate approach for a specific situation. A further objective is to suggest improvements to enhance the usefulness of the different approaches. The approaches studied were specifically chosen to cover the spectrum of ways of dealing with environmental issues in relation to building products as thoroughly as possible. Priority was given to methods that are already available and currently in use. While the list is by no means complete, the selected approaches constitute a representative sample of methods that are, or can be, used in assessing building materials.

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Table 1
Total environmental load of 1 m^2 linoleum (2.556 kg, including laying waste) [3]

Parameter	Amount	Dominant activity
Use of resources		
Acrylate[a]	2.5 g	Linoleum production (raw material)
Titanium dioxide[b]	102 g	Linoleum production (raw material)
Limestone	460 g	Linoleum production (raw material)
Resin	204 g	Linoleum production (raw material)
Wood[c]	767 g	Linoleum production (raw material)
Cork	128 g	Linoleum production (raw material)
Hessian	280 g	Linoleum production (raw material)
Linseed[c]	588 g	Linoleum production (raw material)
K_2O	13.5 g	Flax cultivation (fertiliser)
P_2O_5	16.5 g	Flax cultivation (fertiliser)
Forest land[c]	4.52 m^2, year	Tree cultivation
Arable land[c]	9.82 m^2, year	Flax cultivation
Use of energy		
Electricity	16.3 MJ	Linoleum production (44%), Titanium dioxide production (30%)
Fossil fuels	25 MJ	Linoleum production (67%)
Calorific value	45.2 MJ	Calorific value of flooring material
Recovered energy	−28.8 MJ	Incineration
Emissions to air		
CO_2	1.6 kg	Linoleum production (58%)
CO	1.06 g	Transport (80%)
SO_2	4.3 g	Transport (62%)
NO_x	12.8 g	Incineration (40%), Transport (31%), Linoleum production (20%)
VOC	5.87 g	Linoleum production (87%)
Solvents	3.12 g	Linoleum production
Terpenes	34.5 mg	Powdered wood production
Dust	34.5 g	Powdered limestone production (96%)
Emissions to water[d]		
Oil	2.38 mg	Transport (65%)
Phenol	0.034 mg	Transport (65%)
COD	6.96 mg	Transport (65%)
Tot-N	1.14 mg	Transport (65%)
Waste		
Ash	555 g	Incineration
Sector-specific waste	17.2 g	Hessian production
Hazardous waste	238 g	Titanium dioxide production

[a] Only accounted for as resource use (no other environmental loads are included).
[b] According to one titanium dioxide producer, 6.25 kg ilmenite ore is required for production of 1 kg titanium dioxide.
[c] Wood and linseed are included both as mass and as land use. This is in a sense double accounting, but both parameters have to be represented in the impact assessment which follows.
[d] Emissions occurring during precombustion processes of fossil fuels (refining, etc.).

1.3. Method

It was decided that a focus on a specific application would do more to enhance understanding of the differences between approaches than a general discussion of different approaches. *Flooring materials* were chosen for the example, with priority being given to linoleum, vinyl, and solid wood flooring in order to facilitate comparison with the results of a specific LCA study.

It should be noted that the aim of this analysis is not primarily to compare the contexts (background, organisation, stakeholders, etc.) of the information about floorings; rather the focus is on the content of the information. Nor was the aim to study how the tools and methods are actually applied in practice; the tools and methods were evaluated according to their *intended use*. The focus thus fell on *methodological aspects*, analysed using a *framework* created by Baumann and Cowell [1], rather than on the environmental performance of floorings.

The information provided by the different methods was generally intended for *external* communication, although some approaches may also be used internally in a company for improvement analysis.

1.4. Organisation

Section 2 gives a brief, general description of the selected tools and methods for assessing the environmental performance of building products, using floor-

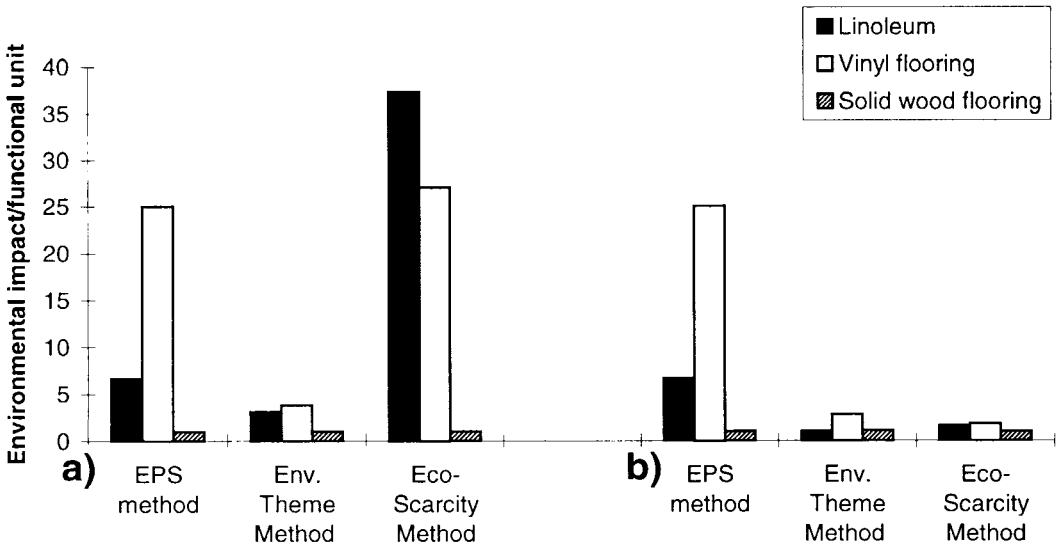

Fig. 1. Comparative environmental assessment of linoleum, vinyl flooring and solid wood flooring according to three weighting methods [3]: (a) first set of results; (b) second set of results, with no hazardous waste generated in the production of titanium dioxide. The results have been normalised in relation to the lowest scores within each method and application.

ing materials as an example. This is followed by a methodological analysis of the approaches in section 3. Finally, section 4 contains a general discussion of the methodological differences and similarities examplified by the selected approaches.

2. Description of approaches

2.1. LCA (Life Cycle Assessment)

Life Cycle Assessment (LCA) is a method for analysing and assessing the environmental impact of a material, product or service throughout its entire life cycle, usually from the acquisition of raw materials to final disposal. Traditionally, the main focus in LCA has been on regional and global environmental impacts on the external environment. All data are related to a basis for comparison; a *functional unit*, defined as the quantified performance of a product system. LCA results are normally presented in the form of aggregate environmental loads or impacts related to the functional unit, without regard to their distribution in time and space. The studies are mostly comparative. According to the ISO [2], the general categories of environmental impacts to be considered in an LCA include

- resource use
- human health
- ecological consequences.

While it would have been possible to discuss the LCA method in general terms, a lack of detailed data would have meant that few methodological aspects could have been covered. However, LCA has been applied to various building products, including flooring materials [3–5]. Study [3] (which was also published in full detail in [6]), is used as an example below. However, it should be noted that the features of this LCA case study are not necessarily relevant to LCA in general or to other case studies, as the method allows for variations in methodological choices.

The objective of the LCA study [3] was to compare environmental impacts over the life cycle of selected flooring materials (linoleum, vinyl flooring, and solid wood flooring) and to develop a methodology for the LCA of building materials. The scenarios used assumed that the flooring was installed in residential buildings in a Swedish location. The functional unit chosen was *the covering of one square metre of flooring during one year of operation*. The environmental impacts of the use phase (cleaning and maintenance) were omitted. The average lifetime of the floorings was estimated. Data on environmental loads were gathered for production processes and transportation over the life cycles. The parameters considered were resource use, energy use, emissions to air and water, and waste generation. Manufacturing companies and literature were the main sources of data. The results of the inventory analysis were calculated per square metre over each flooring's life cycle. As an example, Table 1 shows the total environmental load of linoleum.

Similar inventory tables were developed for vinyl and wood flooring. For each type of flooring, the environmental loads were divided by the estimated lifetime. The inventory results were evaluated as such, and by using three quantitative weighting methods:

- the *Environment Priority Strategies in Product*

Design (EPS) method, developed in Sweden [7]
- the *Environmental Theme Method*, developed in the Netherlands [8] and adapted to Swedish conditions [9]
- the *Ecological Scarcity Method*, developed in Switzerland [10] and adapted to Swedish conditions [9].

The initial results of the impact assessment are presented in Fig. 1a. All the methods identified solid wood flooring as the most environmentally sound, whilst the ranking of linoleum and vinyl flooring varied. The quantity of hazardous waste, stemming mainly from the production of titanium dioxide, was an important parameter affecting these results. Further data on the environmental load of titanium dioxide production were subsequently made available by the suppliers. Use of the more recent data reduced the weighted values for both linoleum and vinyl flooring, as shown in Fig. 1b. Vinyl flooring then scored the highest environmental impact for all three weighting methods.

The conclusion drawn from the findings of both the inventory and the first set of results in the impact assessment was that, under the given conditions, solid wood flooring is clearly the most suitable of the three materials studied from an environmental point of view. Based solely on the quantitative inventory results, no definite conclusions could be drawn as to whether linoleum or vinyl flooring was preferable. When new data was taken into account, it emerged that, under the given conditions, linoleum is probably preferable to vinyl flooring from an environmental point of view (see Fig. 1b). Conclusions were also drawn on such topics as the main areas for possible improvement from an environmental point of view for each type of flooring.

2.2. Eco-labelling

The purpose of *eco-labelling* is to provide information to consumers to enable them to select those products that are the least harmful to the environment, and to stimulate environmental concern in product development. The label itself has to be easy to understand and should provide very *compact* information. Labelling is a variant of rating, where a product passes or fails instead of getting graded. Environmental labelling to date has chiefly been restricted to short-lived consumer products such as detergents and printing paper, but is now also beginning to be applied to building products. One eco-label scheme is the *EU eco-label award scheme*, symbolised by the EU flower. Among building products, several indoor paints and varnishes have already acquired this label, and criteria documents for floor-cleaning products and insulation materials are currently under development. A Nordic eco-labelling scheme, *the Swan* (Fig. 2), has been initiated by the Nordic Ministers of Consumer Issues through the Nordic Council of Ministers. Swan criteria documents have been developed for various building products (e.g. closed toilet systems, building boards, floorings, floor-care products, adhesives, wall coverings, wooden furniture and fitments). This paper looks at the Swan criteria document for flooring materials.

Fig. 2. The Swan eco-label.

The Swan criteria document for floorings [11] applies to all types of non–load-bearing flooring, although it also includes requirements applicable only to specific types of flooring. A number of Swedish floor coverings have already acquired the Swan label, among them both solid wood flooring and several types of linoleum. No vinyl flooring is yet labelled. The document does not clearly state what environmental issues are of primary concern. Instead, the criteria concentrate on factors that are *of major importance during the life cycle* of the flooring, that are *easy to measure* and that are *relatively easy for flooring manufacturers to influence*. These are:

- energy consumption during production
- recycling of raw materials and superfluous waste during production
- the use of renewable raw materials
- the content of certain heavy metals and substances officially classified as harmful to health or the environment
- discharge of organic substances during production and use, with particular requirements as regards organo-chlorine compounds.

Most of the criteria focus on the manufacturing process. Although no quantitative LCA is conducted, a life cycle perspective is adopted, as shown by the requirements for the choice of raw materials, durability and final disposal. Fixed threshold values are used in several criteria: for instance, substances classified as environmentally harmful must not be present in the raw materials in concentrations exceeding 2%. Both health issues and other environmental issues are addressed. A weighting procedure is avoided by requiring that all criteria must be met. Applicants also have to provide detailed information on issues not addressed in the criteria, such as the production tech-

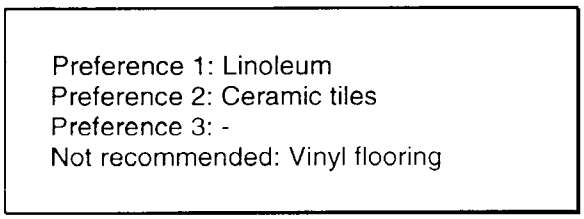

Fig. 3. Environmental assessment of floor coverings according to Anink et al. [12].

nology used, all constituent substances, monitoring procedures used etc. The criteria documents are published and easily available, but product specific input data are confidential.

2.3. The Environmental Preference Method

The *Environmental Preference Method* (EPM) was created in the Netherlands to help in the selection of materials for use in construction and refurbishment [12]. It is accepted as a guideline in the building process by more than 50% of the Dutch local authorities. This method attempts to compare available building materials and products and rank them according to their environmental impact. The goal is to recommend the 'best practical solutions' on the basis of current knowledge. A building component with a specific lifetime is used as the basis for comparison. Considerations such as cost and aesthetics are not involved in the assessment. A life cycle perspective is used, and the main issues considered are:

- scarcity of raw materials
- ecological damage caused by the extraction of raw materials
- energy consumption at all stages (including transportation)
- water consumption
- noise and odour pollution
- harmful emissions, such as those leading to ozone depletion
- global warming and acid rain
- health aspects
- risk of disasters
- repairability
- reusability
- waste.

The method compares products within product or construction groups, and then makes recommendations about what products should be used, or not used. Thus, the assessment works as both a positive labelling and a black list. Matrices are created for each product, and the product is assigned plus-signs, zero and minus-signs for each issue addressed. Subjective decisions are then made by those reviewing the data. The matrices are not published, and no detailed description is given of how a specific product was assessed. General environmental information is also available about a number of materials used in the building industry. The assessment of floor coverings for use in the construction and refurbishment of buildings is as follows (Fig. 3):

Linoleum is recommended because it consists of renewable raw materials and its degradability is good, depending on the finish. The reasons given for not recommending vinyl flooring are that harmful substances such as asbestos and mercury are released in the production of PVC, that the storage and transportation of chlorine involves a risk of accidents, that potentially harmful softeners are used in the product, and that waste with a chlorine content is produced. Solid wood is not mentioned, possibly because it is not

Table 2
Environmental assessment of three floor coverings, according to the Folksam Guide [13][a]

Flooring type	Vinyl flooring	Linoleum	Solid wood flooring
Natural resources	●	○	○
Work environment (production)	◒	◒	◒
Work environment (building/construction)	◒	◒	◒
Use phase	○	◒	○
Waste (building site)	○	○	◒
Waste (product after use)	●	◒	○
Content of substances restricted by the Swedish National Chemicals Inspectorate	●	○	○
Eco-labelling	Yes	Yes	Yes
Labelled products available	No	Yes	Yes
Final judgement	●	○	○

[a] ● Red (not recommended).
◒ Yellow (acceptable for the present).
○ Green (best choice).

as commonly used as the listed floorings. No other types of flooring were assessed.

2.4. The Folksam Environmental Guide

The *Folksam Environmental Guide* [13], commissioned by the Swedish insurance company Folksam, aims to assess and present information about the environmental impact of building products in a way that is *easy to interpret* in order to *guide their clients* on how to renovate and build in a less environmentally harmful way. This is done by using a 'traffic light system' in which each product gets a green, yellow or red mark depending on its environmental performance. The information used for the evaluation was obtained from questionnaires sent to flooring manufacturers. Table 2 presents the assessment of three types of flooring.

The assessment form is divided into nine categories (see Table 2), on the basis of which a final judgement is made. No reasons are given as to why these categories were selected. Two of the categories deal with whether ecolabels are available and, if so, whether any labelled products are yet on the market. The remaining categories are divided between health issues (work environment and use phase) and other environmental issues (resource and waste issues). Both health issues and other issues are sometimes addressed within the same category.

Information is available on the general criteria within each category. For example, the background information on the category 'natural resources' states that 'red' stands for limited, scarce resources; 'yellow' for limited but abundant resources, while 'green' signals that a product uses renewable or limited but very abundant resources. These criteria are then used to justify specific assessments. Table 3 shows how these criteria are applied in relation to resource use.

There is no indication of the basis on which resources are classified as finite, scarce, or abundant. The final judgement is not the product of any formal quantitative weighting process, but is a subjective assessment of results. It is not clear how this is done in detail.

2.5. Environmental declaration sheets for building products

The building sector in Sweden has collaboratively developed a system of providing environmental information about the contents of building materials and products, and their environmental impact during their life cycle [14]. This system is intended to be uniform and easily accessible to users. The primary purpose of these *declaration sheets* is to provide information that will decrease negative effects on the external environment. In the interests of complete information, indoor environment issues are also addressed on separate declaration sheets. The work environment is not considered, and normal use is assumed.

The declaration sheets are based mainly on ISO recommendations for Type II product declarations (ISO 14021/CD). The information consists of environmental data about the product over its life cycle (energy use, raw material use, emissions to air and water, and impact on land), without reference to a defined value system. For example, under the heading *distribution of product*, the data relate to the location of the production site, the mode of transportation, the organisation of distribution, and the packaging system used. Similarly, the heading *use phase* addresses such issues as installation and maintenance, and possible emissions to air and water as a result of these activities. Information is also given on the durability and lifespan of the product. A basis for comparison, or functional unit, is specified for each product group to make the declaration sheets comparable within that group. All environmental loads or information regarded as relevant are reported, regardless of whether threshold values can be specified or not, or whether data are quantitative or qualitative, etc. This is possible because the environmental impacts presented are not weighted against one another nor aggregated. It is left to the user to interpret the information. Declarations for flooring materials are under development.

2.6. The Natural Step

A Swedish institute called 'The Natural Step' was

Table 3
Reasons for assessments of selected flooring materials under the category 'Natural resources' in the Folksam Guide [13]

Flooring type	Vinyl flooring	Linoleum	Solid wood flooring
Natural resources	● *Petroleum based.* Finite and scarce resource. Also, dolomite is used, which is a finite but abundant resource.	○ *Linseed oil, powdered cork and powdered wood.* Renewable resources. Also, dolomite is used, which is a finite but very abundant resource.	○ *Wood.* Renewable resources. An oil-based surface treatment is often used.

founded in 1989, with the aim of resolving the polarisation of the environmental debate in society by reaching a consensus about current environmental problems. It suggests four basic system conditions that should as far as possible be met if the environment is to be preserved. The scientific justification for the principles underlying these system conditions is given in Holmberg [15]. The four system conditions are [16]:

1. *Minimal use of underground mineral deposits*. The use of stored mineral deposits must not exceed the very slow sedimentation processes of nature. Since no matter disappears, present consumption will cause systematic accumulation of molecular waste in the biosphere. In practical terms, this requires an almost complete halt to mining.
2. *Persistent, artificial compounds must not be used*. Nature's tolerance level for particular substances cannot be foreseen because of the complexity of the ecosystem. If the production of persistent, artificial compounds exceeds the slow processes by which nature destroys them, they will accumulate in the biosphere. In practical terms, this means a complete phasing out of such compounds.
3. *The physical condition of the ecosystem must be preserved*. Productive natural areas must be allowed to expand to preserve the diversity and capacity of nature. In practical terms, this implies ecologically sustainable farming and forestry, powerful measures to deal with water scarcity, and a halt to the expansion of the infrastructure of large cities.
4. *The energy use (metabolism) of society must be reduced equitably*. The use of energy and materials must be reduced to match the capacity of ecosystems to process waste into new resources. In practical terms, this implies a less energy-intensive lifestyle in the Western world, in combination with powerful measures to regulate population growth and to improve the quality of life in the Third World.

To examine the application of The Natural Step approach to building products, the performance of linoleum, vinyl flooring, and solid wood flooring was assessed in terms of the four system conditions. The data were drawn from the LCA study [3].

1. Both linoleum and vinyl flooring depend to some extent on stored mineral deposits in the form of energy and raw materials. In regard to raw materials, linoleum fares better than vinyl flooring, owing to its higher content of renewable materials. Wood flooring involves some degree of dependence on fossil fuels, mainly for transportation.
2. The most persistent artificial compounds are found in the life cycle of vinyl flooring, the content of which includes chloro-organic compounds.
3. Both linoleum and wood flooring use productive land for the production of raw materials. If this farming and forestry are not ecologically sustainable, linoleum and solid wood flooring have a higher impact on the diversity and capacity of nature than vinyl flooring. On the other hand, the extraction, transportation and refining of crude oil may affect the physical conditions of the ecosystem. It is thus difficult to say which of the three floorings is most or least suitable in terms of this system condition. All three floorings could be improved in this regard.
4. The solid wood flooring has the lowest energy use, is locally produced, and uses mainly renewable fuels, and thus appears to best meet the fourth system condition. It is more difficult to rank linoleum and vinyl flooring. Both use raw materials produced far from where they are used, which indicates possible exploitation of the Third World, and they also use non-renewable energy sources. However, for both linoleum and vinyl flooring, some of the raw materials could also be acquired close at hand.

None of the three floorings manages to fulfil all four system conditions. There is, for example, always some transportation involved in the life cycle, which implies a consumption of fossil fuels. However, the solid wood flooring seems to be better qualified to meet the system conditions than the other two floorings.

The system conditions in The Natural Step are qualitative and absolute. There is no ranking of these conditions. The basis for the evaluation is easy to grasp, but the results are more difficult to use for an improvement assessment when it comes to weighing several possible improvements against one another. Thus, this approach gives little guidance as to whether linoleum or vinyl flooring is preferable from an environmental point of view, but points out environmental improvements for all three floorings. Andersson et al. [17] give a more detailed description of how the system conditions may be applied in LCA for product development.

3. Methodological analysis

The six approaches described in section 2 were analysed and compared using a framework created by Baumann and Cowell [1]. This framework distinguishes between *generic* aspects, relating to the overall nature of the approach; *contextual* aspects, which describe the situation in which the approach is used (i.e., the decision-making context); and *methodological* aspects, which describe the structure of the approach, including which issues are considered, what constitutes the basis for comparison, and how the results are eval-

Table 4
Abbreviations used in the methodological analysis

Approach	Abbreviation
LCA case study of floorings [3]	The LCA study
The Swan ecolabel applied to floorings [11]	The Swan
The Environmental Preference Method [12]	The EPM
The Folksam Environmental Guide [13]	The Folksam Guide
Environmental declaration sheets for building products [14]	Declaration Sheets
The Natural Step [16]	The Natural Step

uated. Table 4 gives the abbreviations used for the different approaches in the discussion which follows.

3.1. Generic aspects

Baumann and Cowell divide approaches to environmental management into *concepts* and *tools*. A concept is defined as an idea about how to achieve sustainability, while a tool involves a more systematic, step-by-step *procedure* and a mathematical *model*. All the selected approaches except for The Natural Step are tools rather than concepts, as they all follow more or less well-defined procedures and models for obtaining their results, although the models are not always mathematical.

3.2. Contextual aspects

3.2.1. Type of decision-maker

Four general categories of decision-makers make use of environmental information: *governments/authorities, companies, NGOs* and *individuals* [1]. Some approaches are directed at clearly defined user groups, either professionals (the EPM, Declaration Sheets) or laymen (the Swan). The other approaches are less explicit about the intended users, mainly because several user groups are addressed (Table 5).

3.2.2. Overall purpose

The overall purpose of all approaches is to contribute to decreasing the environmental problems caused by human intervention. Baumann and Cowell identify two main purposes underlying different approaches to environmental management: *decision support* (either *operative* or *strategic*) and *communication*. All the selected approaches have decision support and communication as common goals. In some cases, *education* was also identified as a crucial purpose. Table 6 outlines the main purposes of the selected approaches.

The approaches that do not focus on one clearly defined user group place greater stress on communication and education. The goals of the LCA study included developing LCA methodology for application to building materials, which may be categorised as education.

3.2.3. Object analysed

All the approaches focus on the output of technological systems, i.e., the *technosphere*, rather than on effects in the *ecosphere*. All except The Natural Step are *product oriented*. LCA and The Natural Step are applicable to all products, although here they are applied to floorings. The Swan is applicable to all products for which criteria documents have been developed. The remaining approaches apply specifically to building products. Non-professionals are mainly in need of information on the building product level, as choices of materials at higher system levels are made by professionals, such as architects. Consequently the EPM, which is the tool most explicitly directed at professionals, is the only approach that also includes building elements. The approaches aiming to cover all building products assess each product group (e.g. flooring materials) separately.

Table 5
Targeted decision-makers in approaches to the environmental assessment of building products

Approach	Targeted decision-makers
The LCA study	All groups, focus on flooring manufacturers
The Swan	Private consumers
The EPM	Designers of buildings and their service systems, political authorities
The Folksam Guide	Folksam clients
Declaration Sheets	Not specified in detail; all groups
The Natural Step	Not specified in detail; all groups

Table 6
Main purposes in approaches to the environmental assessment of building products

Approach	Overall purpose
The LCA study	Decision support (operative and strategic), communication, education
The Swan	Operative decision support, communication
The EPM	Operative decision support, communication
The Folksam Guide	Operative decision support, communication, education
Declaration Sheets	Operative decision support, communication, education
The Natural Step	Strategic decision support, communication, education

3.2.4. Perspective

Two perspectives can be distinguished: *prospective* (for making choices with regard to predicted consequences) and *retrospective* (monitoring past actions) [1]. LCA may clearly be used in both ways, Declaration Sheets are primarily used with a retrospective perspective, while the tools most directed to decision support tend to be prospective. The Natural Step is most suited to future actions and is therefore prospective.

3.3. Methodological aspects

Because The Natural Step is a concept rather than a tool, and therefore has no defined procedure for its application to floorings, this approach was left out of the analysis of methodological aspects.

3.3.1. Dimensions investigated

All the tools share a *life cycle perspective* and address only *environmental issues*, unlike other approaches that also address economic and social issues.

The ISO states that three general categories of environmental impacts need to be considered in an LCA, namely, resource use, human health, and ecological consequences (see section 2.1.). All of the approaches address these three categories in one way or another. However, the focus on activities in the technosphere (see section 3.2.3.) means that the data included refer to activities early in the cause-effect chain, i.e. environmental loads, and relate these to some basis for comparison. All approaches include environmental loads related to energy use, raw material use, emissions to air and water, and waste generation, but it is not often clearly stated what effect categories are in view in relation to a specific load. Those tools aiming more at decision support than communication (the EPM, the Swan, and the Folksam Guide) include environmental interventions selected partly on *pragmatic* grounds, such as adequate evidence of the environmental problems caused, performance criteria that can easily be defined, understood, and measured, and information that is easily available. Consequently, the issues addressed are a mix of loads, effects, product properties, and other data. The selection may also be based on what parameters the intended user group can influence. Using floorings as an example, the Swan, the Folksam Guide and the Declaration Sheets primarily use data from flooring manufacturers, and this choice is reflected in the impacts addressed. The LCA study has a broader span as several data suppliers are used.

The LCA study focuses on products' *global* and *regional* environmental impact, while other tools also may include *local*, site-dependent issues. For example, the Folksam Guide addresses *work environment issues*. *Indoor climate issues* are taken into account to some extent by all tools, except the LCA study. The use of *tropical wood* is explicitly considered in the Swan and the EPM.

Normal use is generally assumed, or in other words, the risks of accidents, misuse, etc. are not considered. The EPM certainly states that the *risk* of disasters is considered in the assessment, but it is not clear how this is done.

3.3.2. Character of the approach

Tools may consist of both a *procedure* and a mathematical *model* of some kind. All the tools studied focus on the procedure rather than on modelling, and only in the LCA study are mathematical models used in parts of the procedure. Typical stages in a procedure are [1]:

- problem identification
- problem formulation
- modelling
- interpretation
- implementation
- feedback
- education

In LCAs, the framework for the procedure is fixed (goal and scope definition, inventory, etc.) but an LCA practitioner goes through all the steps in each new study, for example, when deciding what parameters should be taken into account. If LCAs are regularly performed for a specific product system, the same problem formulation, etc., may be re-used. In the Swan, the details of the procedure to get a label (stages a–c) are first established by a third party, and then each

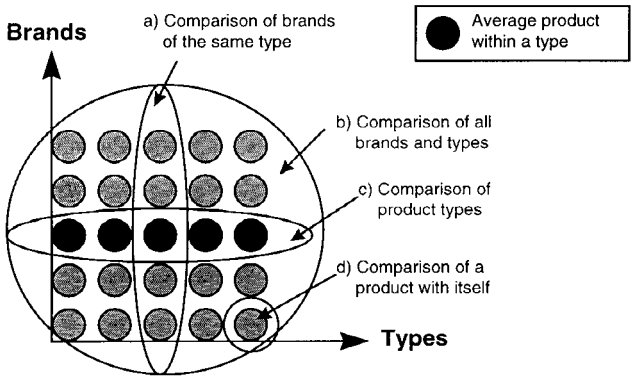

Fig. 4. Relevant comparisons in environmental assessment of building products.

manufacturer decides whether to follow this procedure to get a label. Thus all applicants share the same problem identification and formulation. In the Declaration Sheets, the presentation of results is standardised, but not the procedure by which they are obtained. The EPM and the Folksam Guide use frameworks which apply to all assessed products. For example, in both these tools the interpretation consists of a subjective weighting based on matrices presenting the environmental impacts for fixed problem areas. LCA is flexible in its initial stages (problem identification, etc.), and the intention to proceed through all steps is more explicit than for the other tools, which are used more for external communication of environmental impact than for internal product development.

3.3.3. Basis for comparison

The *basis for comparison* is the unit that is kept constant when alternatives are compared. When looking at floorings as a product group, four types of comparisons are relevant from the environmental point of view, as illustrated in Fig. 4.

The comparison of a product with itself (d) may be made over the product's life cycle to locate 'hot spots' or to evaluate suggested changes. For consumers and designers, the most relevant comparison would be between types (c). An important reason for comparing products of the same type (a) is competition between manufacturers. Both consumers and manufacturers may be interested in the environmental performance of all types and brands (b). For a manufacturer, it would also be relevant to compare his/her product with other brands within the same type (a), or to compare an existing product with itself after a change (d). Table 7 outlines the bases for comparison used in the selected tools, using floorings as an example.

The LCA study and the Declaration Sheets, both of which quantify the environmental impacts in relation to the basis for comparison, have the most specific definitions. The basis for comparison is less clearly defined in the approaches that use indicators instead of formalised weighting and therefore do not need to quantify the impact in relation to such a basis. All the approaches studied compare different types of flooring, and a few introduce further specification by assessing and comparing specific trademarks. Although all tools are applicable to all flooring types, the number of assessed products is limited either by choices made by the practitioner or by the manufacturer. Comparisons of type (a) are not represented in the selected approaches but have been undertaken by researchers such as Leclair and Rousseau [18].

3.3.4. Geographical and temporal system boundaries

Environmental management tools have *geographical* boundaries. The Declaration Sheets are created by the Swedish building sector and thus are intended mainly for products from Swedish manufacturers; the LCA study and the Folksam Guide focus on products used in Sweden; the Swan is created for Nordic conditions. The EPMI, although initially created for the Dutch building market, is stated to be applicable throughout Europe.

There are also boundaries in *time*. All approaches use data representing the present situation, and all results therefore lose their relevance with time, although this is seldom explicitly stated. Only the Swan defines a period of validity for its label: labels are valid for 3 years from the date when acquired. The Swan also specifies that the set of criteria should be

Table 7
Bases and types of comparisons used in tools for the environmental assessment of building products (specifically floorings)

Approach	Basis for comparison	Alternatives compared or addressed	Type
The LCA Study	'The covering of 1 m^2 of flooring over one year'	Selected types for residential use in Sweden (linoleum, vinyl flooring, and solid wood flooring)	(c),(d)
The Swan	'Flooring, excluding the load-bearing function'	All flooring types, application by trademark	(b)
The EPM	Building component with a specific lifetime, e.g. 'floor covering'	Linoleum, ceramic tiles and vinyl flooring	(c)
The Folksam Guide	'Flooring'	Six most common types, including linoleum, vinyl flooring and solid wood flooring	(c)
Declaration Sheets	'1 m^2 flooring'	All types, declaration by trademark	(b)

Table 8
Main sources of data in tools for the environmental assessment of building products (specifically floorings)

Approach	Main sources for input data
The LCA Study	Manufacturers, other LCA studies, literature, statistics, etc.
The Swan	Flooring manufacturers, norms, laws, standards
The EPM	Not accounted for
The Folksam Guide	Flooring manufacturers, eco-labelling, lists of chemicals, etc.
Declaration Sheets	Manufacturers

updated every 2 to 3 years. It can be assumed that the more quantitative and detailed the data used in the assessment, the shorter the period of validity.

3.3.5. Type of data

Tools require *input data* and produce *output data*. This study considered the sources and types of input data, and the format in which output data are presented. Input data here refers to data recalculated or adjusted to suit as input data in the assessments, and not to the primary data obtained from the data suppliers. As the Swan only states the requirements for input data, the information asked for is regarded as the input data. The EPM does not present input data and gives only a general description of data requirements and the assessment procedure. The environmental impacts reflected in the data are outlined in section 3.3.1. Table 8 outlines the main sources of data.

Data may be either *quantitative* or *qualitative*. The tools studied mainly used the types of data as shown in Table 9.

There are several ways to present *quantitative* data, as shown in Fig. 5. All are represented in those tools that use quantitative information. Of these, the LCA study and the Declaration Sheets use absolute values (a), whereas the Swan uses mainly relative and threshold values (b, c) but also uses intervals (d) to some extent.

There is even greater diversity in the types of *qualitative* input data used in the tools. Like quantitative data, these may be *absolute* (e.g. 'based on fossil resources', 'manufactured in Gothenburg'), or *relative* (e.g. 'based on scarce resources', 'easy to dismantle'), or based on *intervals* or classes (e.g. 'low/average/high emissions'). In addition, these data sometimes refer to complementary information (e.g. 'is labelled by the Swan eco-label', 'satisfies European norms for wear-resistance requirements'). For qualitative data, the Declaration Sheets use mainly absolute data. The Swan often refers to norms and standards, whereas the input data used in the EPM and the Folksam guide are mostly relative and classified by level.

Data describing the same issue are often addressed in different ways by different approaches, as can be illustrated by the data on the use phase. Three types of data about the use phase may be relevant when comparing the environmental impact of floorings: the probable lifespan, impacts from cleaning and maintenance, and emissions from materials. The tools handle these issues as shown in Table 10.

The above examples indicate that different strategies are chosen for handling issues for which data are not available, or for which there is no commonly agreed upon judgement of the hazard they pose. In the LCA study, such data were estimated if possible or else omitted, whereas the EPM and the Folksam Guide make a subjective valuation. The other approaches referred to external criteria or required that more information be attached. When using quantitative data, the conditions studied have to be specified in detail, whereas approaches using mainly qualitative data can address a broader range of impacts and also make estimations of issues for which no detailed information is available. This was reflected in the tools studied.

3.3.6. Evaluation and interpretation of results

This study also investigated the extent to which aggregation and weighting procedures are incorporated in the evaluation and interpretation of the results; the form in which the results are presented; whether there is a ranking, and if so, what it is; which environmental impacts are most clearly identified by the tools; and, finally, the degree of transparency of the selected tools.

Aggregation makes results easier to grasp but often implies use of a subjective *weighting* procedure. The need for aggregation is generally acknowledged in the tools studied, but the degree of aggregation and

Table 9
Main data types used in tools for the environmental assessment of building products (specifically floorings)

Approach	Main types of input data		Main types of output data	
	Quantitative	Qualitative	Quantitative	Qualitative
The LCA Study	X	–	X	–
The Swan	X	X	–	X
The EPM	–	X	–	X
The Folksam Guide	–	X	–	X
Declaration Sheets	X	X	X	X

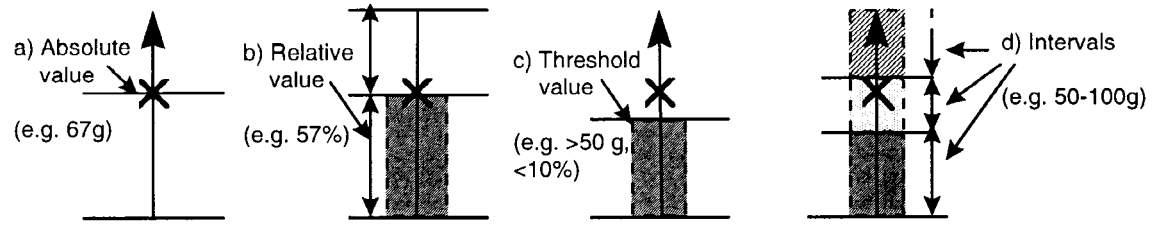

Fig. 5. Four ways to present quantitative data: (a) as absolute values, (b) as relative values, (c) relative to a threshold value and (d) as belonging to an interval. Intervals (d) is a further elaboration of thresholds (c).

weighting varies. The only tool which did not include some kind of aggregation was the Declaration Sheets. In the LCA study, the results were presented at several levels of aggregation. The Swan has the most aggregated result: the label. It specified in advance what parameters should be addressed and how these were to be aggregated and interpreted. Additional models may be used in the weighting procedure, such as the weighting methods used in the LCA study. Weighting could also be performed by expert groups such as practitioners, as in the EPM and the Folksam Guide. The Declaration Sheets present the selected information without any explicit value judgements, but still involve prioritising in terms of what information is included. It should be noted that not all users require aggregated information; on the contrary, detailed rather than interpreted information is more useful in some applications.

The ways in which the different methods define and present their *results* were described in section 2. The LCA has the broadest definition of the results, as there are several possible users, but the most striking results are the aggregated comparative results (Fig. 1). The result of the Swan is the label, and that of the EPM is the ranking and recommendations. The Folksam Guide presents two levels of results, and the Declaration Sheets shows all selected information as results. The results can be *absolute* or *relative*, and *thresholds* and *intervals* can be used, as described in section 3.3.5. The LCA case study presents the results both as absolute data and as a comparison of alternatives. The EPM and the Folksam Guide do a relative ranking by placing the products in predefined groups, some positive and some negative. The Swan label in itself symbolises an aggregate of thresholds. In the Declaration Sheets, the results are mainly absolute. The tools differ in the number of *intermediate steps* shown between input data and output data (i.e. results). In the LCA study, data are given for several steps, and conclusions can be drawn at different levels of aggregation. The Swan and the EPM base the results on input data on only one level. In the Declaration Sheets, the input data are identical with the output data. Input data presented in the Folksam Guide form part of the results, but are also used for an overall assessment of each product. The results are sometimes organised in relation to the life-cycle stages at which the loads occur (the Folksam Guide, the Declaration Sheets).

The intention to *rank* results is more or less explicit

Table 10
Data used to address the use phase in tools for the environmental assessment of building products (specifically floorings)

Approach	Lifespan	Cleaning and maintenance	Emissions from materials
The LCA study	Average lifespans are estimated, and environmental loads are distributed over this time	Omitted because of a lack of appropriate data	Omitted (investigated in a separate study)
The Swan	Specified wear resistance requirements (category specific norms and standards) have to be met	Omitted, as the manufacturer has no means of influencing the way in which flooring is maintained. Does require information about recommended methods of maintenance	Requires that emissions be in accordance with defined standards
The EPM	Building products with a specific lifespan are compared	?	Considered, but not stated how this is assessed
The Folksam Guide	Omitted	Comments upon that odours may occur when wet-cleaning linoleum	Assessment based on two classes: high or low emissions
Declaration Sheets	Requires information about the expected lifespan of product subject to normal use, in accordance with category specific standards	Requires that information on correct use (detergents, surface treatment, etc.) be attached	Requires that expected emissions be accounted for

Table 11
Classing and/or ranking of three flooring materials in tools for environmental assessment of building products[a]

Approach	Comparative results	Ranking
The LCA Study	(a) Solid wood flooring > vinyl flooring = linoleum, (b) Solid wood flooring = linoleum > vinyl flooring	X
The Swan	Wood flooring = linoleum	–
The EPM	Linoleum > ~~vinyl flooring~~	X
The Folksam Guide	Solid wood flooring, linoleum > ~~vinyl flooring~~	X
Declaration Sheets	–	–

[a] > Stands for 'is environmentally preferable to'; = means 'is equivalent to'; scoring-out symbolises 'is not recommended'.

in the approaches. The results were next evaluated according to whether they rank the products, and, if so, where selected floorings fall in this ranking.

Table 11 shows that three of the five tools rank floorings. Vinyl flooring is generally regarded as having a higher environmental impact than the other two types of flooring, while solid wood flooring is either equivalent to or preferable to linoleum. In the LCA, the second set of results (b) were obtained after getting new and more relevant data as a consequence of presenting the first set of results (a), which demonstrates the frequent use of LCA results as interim results in improvement analysis. In the Swan system, a labelled product is estimated to have a relatively low environmental impact, but this does not necessarily imply that an unlabelled product has a higher impact than a labelled product. Hence, this approach classifies materials, but does not rank them. In the Declaration Sheets, ranking is deliberately avoided. Ranking or classification is the primary goal in the Swan and the EPM and one of the expressed goals in the LCA and the Folksam Guide.

What environmental issues weighed heavily in the assessment of floorings? This is not always clear, although in some cases the tools did mention which parameters were important in determining whether products were 'good' or 'bad'. The most important contributors were easiest to identify in the LCA study which used a formalised and quantitative weighting procedure. Analysis of the results suggests that the following properties or parameters were important in assessing low or high impacts (Table 12).

The impacts identified as important have more to do with material and energy flows affecting the global and regional environment than with local problems. Although there are parameters (such as the type of resources used) that are recognised as being important by several tools, there seems to be greater uniformity on the main contributing issues within a tool rather than within a product type.

Transparency is a measure of the reproducibility and control of the procedure and results. The transparency of selected tools was assessed (Table 13).

Most approaches give an account of the basic assumptions (environmental issues addressed, basis for comparison, grouping of products, etc.) that underlie the assessment, and they also describe the general procedure used. Only two tools present the input data used in the assessment of specific products, and consequently only these two are transparent enough to enable someone else to reproduce a specific assessment. Three tools have transparent results in the sense that they provide explicit information on how a specific product was assessed. Not surprisingly, product-specific data are the least likely to be published, apparently for reasons of confidentiality. Ultimately, the

Table 12
Main properties that affect the environmental performance of three flooring materials in tools for environmental assessment of building products

Approach	Parameters standing out in the results		
	Linoleum	Vinyl flooring	Solid wood flooring
The LCA study	Hazardous waste (−)	Hazardous waste (−), use of scarce and limited resources (−)	Use of renewable resources (+), long lifespan (+)
The Swan	–	–	–
The EPM	Renewable raw materials (+), good degradability (+)	PVC: releases of harmful substances (−), requires many additives (−)	–
The Folksam Guide	Uses renewable resources (+), building waste may be recovered (+), contains no chemicals listed as hazardous (+)	Uses scarce and limited resources (−), contains phtalates (−)	Uses renewable resources (+), low emissions (+), reusable (+), contains no chemicals listed as hazardous (+)
Declaration Sheets	–	–	–

Table 13
Transparency of tools for environmental assessment of building products

Approach	Basic assumptions	Procedure	Product specific input data	Results	Reproducibility
The LCA study	X	X	X	X	X
The Swan	X	X	–	X	–
The EPM	X	–	–	–	–
The Folksam Guide	–	X	–	–	–
Declaration Sheets	X	X	X	X	X

LCA study and the Declaration Sheets have a higher, and the EPM a lower, transparency than the other tools.

3.4. Relationships between the approaches

On the basis of their framework, Baumann and Cowell define five basic relationships between approaches to environmental assessment. The relationship between approaches can be:

- *consecutive* (the results of one approach become the input data for another approach)
- *complementary* (two approaches use the same basis for comparison but give different results because they investigate different dimensions)
- *competing* (two approaches use the same basis for comparison and investigate the same dimensions but give different results because different assumptions are made about the scope of the analysis)
- *encompassing* (an approach forms an integral part of another approach)
- *overlapping* (both approaches give the same result because their methodology is identical).

LCA inventory data may be used as input data in all other tools, and LCA and other tools may therefore be used consecutively. Similarly, The Natural Step may be used as a basis for the selection of relevant input data in the other approaches, and is therefore consecutive in relation to them. The Natural Step and LCA are consecutive in the sense that the first may be used for strategic decision making and the second for implementation of these decisions and evaluation of the results, but they are also complementary as they are used at different levels of decision making. No approaches were found to be competing. The Swan label and the Folksam Guide both provide decision support for consumers and were found to be overlapping rather than competing, although their results are presented in slightly different formats. The EPM is also used for decision support but has another target group and is thus complementary to the previous two. The LCA study focuses on global and regional impacts with a life-cycle perspective, and the other tools address these impacts but also address local issues. Thus, in the sense of what issues have been covered, the other tools encompass the LCA study. However, some tools prioritise the manufacturing and building phase whereas the LCA study treats all impacts equally regardless of where they occur, and in this sense the LCA study encompasses the other tools. Hence, no entirely encompassing relationships between the selected approaches were found.

4. Discussion and conclusion

Producers in the building sector supply information on the environmental performance of their products in advertising and product information. Apparently, this information is not sufficient as both the building sector itself, organisations, researchers, consultants and actors outside the building sector, such as insurance companies, have launched initiatives to supply environmental information on building products. The different approaches resulting from these initiatives demonstrate the need for environmental information that is selected and interpreted or aggregated in a systematic way. The variety among the supporters of these initiatives demonstrates that there are a number of relevant suppliers of environmental product-related information. Variations in how the information is handled by different sources also indicates the need for tools adjusted to specific environmental concepts or use situations.

All the selected approaches share a *life-cycle perspective*, and primarily address *environmental issues,* unlike other approaches to environmental assessment that also address economic and social issues. All also aim to be *comprehensive* by covering all the environmental impacts assumed to be relevant. They are used for answering seemingly similar questions, but on closer inspection they differ considerably regarding their scope. However, the differences in *transparency* made it difficult to compare them in regard to such things as which impacts weighed most heavily in the results. The *organisation* of information also influenced the degree of comparability. The most common organisational pattern was based on the stage in the life cycle at which the impact occurs. None of the approaches address any *uncertainties* in the *data* used.

Some, but not all, tools explicitly *rank* the products. All of those tools that support ranking reach similar

conclusions that, in my view, coincide with public opinion on the selected flooring types. This raises the question of the extent to which the popular view of what constitute the most important environmental problems and of the environmental performance of a specific product influence the shaping of a method and the results obtained, especially for tools using a non-formalised weighting procedure.

On the whole, the Baumann and Cowell *framework* [1] proved useful for the analysis. For most features analysed, differences were found between some approaches and similarities between other. In general, it was not always the same approaches that were similar or different through the analysis. Of the five basic relationships defined in the framework, one feature alone was seldom sufficient to describe the relationship between two approaches. Thus, it appears that few approaches have intentionally positioned themselves against other approaches.

It was found that the relationships between the groups of actors involved in the creation and use of a tool and the stakeholders they represent affect the design of a tool. Four main groups of actors were identified: *designers* of the procedure or model, *data suppliers, practitioners* (the ones applying the tool) and the *users* of the results. For example, if data suppliers and users belong to the same stakeholder group, the information needs to be detailed and specific, but if they do not belong to the same group (e.g. if consumers are the users), aggregated and easily interpreted information is needed. Commonly the designers of a tool or the practitioners are independent of the data suppliers, presumably to enhance the credibility of the tool. If the data suppliers are also the practitioners, interpretation and ranking seem to be avoided. Another relevant feature is whether a tool is oriented to the '*sender*' (data supplier) or the *'receiver'* of information (the user of the results), in other words, whether the primary goal is to provide information *from* a specific viewpoint (a stakeholder's view or an environmental concept) or *for* a specific use situation. It is possible to do both within the same approach. Those approaches which are more oriented to the sender than the receiver, and thus mainly defined in terms of the information they seek to convey, are the most *flexible* in application and have a broader definition of what constitutes the results. Approaches focusing mainly on decision support in specific use situations have a narrower scope, but also present the most *unequivocal* and *easy-to-use results*.

The approaches are all concerned to enhance the external credibility of their results. They attempt to do this by such means as ensuring that those commissioning the approach, those applying it, and those responsible for the assessment have high credibility (e.g. by letting a third-party do the assessment); by striving for high transparency in general; by standardising the model and the procedures; and by avoiding interpretation. Choices of scope and procedure have implications for the use of the tools:

- Concern for high *transparency* limits the *applicability* of an approach, as potential data providers may want to keep parts of the environmental information confidential.
- If the results are *comprehensive* and interpretation is avoided, their use will be limited as the results are not easily understood. On the other hand, if the results are highly *interpreted* and *aggregated*, the user may not be aware of underlying assumptions, which may lead to a misuse of the results.
- An approach using a *standardised* procedure or model has high credibility, but may suffer from low flexibility. A less standardised approach is more *flexible*, but the results may have lower formal status.
- The use of *specific* data generates detailed results, but they are only applicable to defined conditions. On the other hand, if a tool describes only the *average* situation, there is a possibility that no one can use the results.

All approaches share the problem that although comprehensive information on environmental impacts is available, there is no general scientific agreement on the relative importance of different environmental impacts. In response, the tools either include only impacts that may be assessed in the chosen format or address all impacts assumed relevant and then interpret and aggregate the information without having an adequate scientific basis for this. It seems to be impossible to issue a general statement on what data are detailed enough, what impact categories should be addressed, and the right level of aggregation, for these choices depend on the intended use situation. The inevitable conclusion is that no one approach can be optimised to meet the demands of all possible users at the same time, and hence the same stakeholder may need different tools for external communication, external decision support and internal product development.

At this stage, the differences in scope between the approaches are regarded as useful. However, in some approaches the scope could be defined more clearly, for example by explicitly positioning themselves in relation to other approaches. A high degree of transparency is also recommended.

It should also be noted that in this paper the tools and methods were evaluated according to their *intended use*. For further improvement of the approaches, there should also be study of how they have been applied *in practice*.

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