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Selecting problem-related environmental indicators for housing management

Tove Malmqvist[1] and Mauritz Glaumann[2]

[1]Department of Urban Planning and Environment, Built Environment Analysis, Royal Institute of Technology, Drottning Kristinas väg 30, SE-100 44 Stockholm, Sweden
E-mail. tove@infra.kth.se

[2]Department of Technology and Built Environment, Building Quality, University of Gävle, Södra Sjötullsgatan 3, SE-802 57 Gävle, Sweden
E-mail. mauritz.glaumann@hig.se

The performance of environmental management systems is difficult to evaluate due to insufficient methods for measuring their environmental impacts. A procedure is proposed that contains more environmentally relevant indicators for assessing environmental impacts. In addition, theoretical and practical criteria are suggested for evaluating the relevance of different indicators. This scheme was applied to the housing-management sector with the aim of finding more problem-related indicators. Data from three existing Swedish housing estates were collected and indicators calculated for three environmental aspects: energy use, household waste treatment and embedded toxic substances/materials. The results show that problem-related environmental indicators can be used in the housing sector to measure energy consumption and, to a certain extent, household waste treatment. Finding indicators for embedded toxic substances was found to be more problematic, but an example for further discussion is presented.

Keywords: building stock, environmental impacts, environmental indicators, environmental management system, facility management, housing, Sweden.

Il est difficile d'évaluer les performances des systèmes de gestion de l'environnement du fait de l'insuffisance de méthodes de mesure de leur impact sur l'environnement. Cet article propose une procédure contenant davantage d'indicateurs environnementaux pour évaluer les impacts sur l'environnement. De plus, l'auteur suggère des critères théoriques et pratiques pour évaluer la pertinence de ces différents indicateurs. Ce système a été appliqué au secteur de la gestion d'ensembles immobiliers, l'objectif étant de trouver davantage d'indicateurs liés aux difficultés. On a recueilli des données de trois ensembles immobiliers suédois et des indicateurs ont été calculés pour trois aspects de l'environnement: utilisation de l'énergie, traitement des déchets ménagers et, enfin, substances et matières toxiques piégées. Les résultats montrent que les indicateurs environnementaux liés aux difficultés peuvent être utilisés dans le secteur du logement pour mesurer la consommation d'énergie et, dans une certaine mesure, le traitement des déchets ménagers. La recherche d'indicateurs relatifs aux substances toxiques s'est avérée plus difficile mais l'auteur présente un exemple permettant de poursuivre cette discussion.

Mots-clés: parc bâti, impacts sur l'environnement, indicateurs environnementaux, système de gestion de l'environnement, gestion des installations, logement, Suède

Introduction

Quantitative environmental information is a significant component in environmental management systems (EMS) for describing and assessing continual improvement. Environmental performance indicators have developed as one such means for evaluative purposes internally and for communication with external stakeholders (Thoresen, 1999; Olsthoorn *et al.*, 2001).

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Consequently, there has been a proliferation of indicator types.[1] The standard on environmental performance, International Standards Organization (ISO) 14031 (2000), provides some guidelines for organizations when choosing indicators. However, it includes little discussion on the scientific validity of different types of indicators. Studies on the use of environmental performance indicators conclude that the type of indicators currently used are commonly based on aspects that the organization finds easy to measure, rather than those that are most significant to measure in environmental terms (Schaltegger and Burritt, 2000; Olsthoorn *et al.*, 2001; Ammenberg and Hjelm, 2002). A direct consequence is that the environmental improvements of the EMS are difficult to evaluate (Ammenberg and Hjelm, 2002, Schylander and Zobel, 2003).

With respect to housing, a recent study shows that the use of environmental performance indicators in the EMS process is rather rudimentary (Malmqvist, 2004). Initiatives have been taken in the property and construction sector to suggest possible environmental indicators, among which CRISP (2004) might be the most widely known. In addition, many of the tools for environmental assessment of buildings also give suggestions for environmental indicators. Since such systems have generally been developed by or in cooperation with practitioners, the focus has been on their practical use. Consequently, the data availability has often guided the types of indicators suggested, while a more thorough discussion about the validity of different types of environmental performance indicators has often been of secondary importance.

There is a growing awareness of the need to improve the ways of assessing the significant environmental aspects for the development and credibility of EMS (e.g. Thoresen, 1999; Olsthoorn *et al.*, 2001; Ammenberg, 2003). This is reflected in the general trend towards a life cycle assessment (LCA) perspective, national and international initiatives, and a public interest in the environmental impact issue generally. At the same time, there is a wide consensus that indicators must be adapted to the structures and practices in the organization in which they will be used. Schaltegger and Burritt (2000) raise the important issue that the data availability in an organization is very much a question of resource allocation. If stronger incentives are created for measuring environmental impacts, the willingness to pay for extended data collection, etc., will increase. The discussion about the construction of scientifically relevant environmental performance indicators must therefore be kept alive.

Objectives

EMS are meant to minimize environmental problems. In this paper, the limitations of current environmental performance indicators will be considered. A new procedure will be described for choosing problem-related environmental indicators and these are tested on a small-scale study.

The case study is focused on three important issues for housing management: energy use, household waste treatment, and embedded toxic substances/materials. The procedure of using improved environmental indicators for these issues is tested in three Swedish housing estates.

Perspectives on environmental indicators

Definitions of environmental indicators

According to the European Environment Agency (EEA) an indicator is:

> a parameter or a value derived from parameters that describe the state of the environment and its impact on human beings, ecosystems and materials, the pressures on the environment, the driving forces and the responses steering that system.
>
> (EEA, 2005)

This driving force, pressure, state, impact, response (DPSIR) model is used by authorities worldwide in order to choose indicators for the evaluation of different types of environmental objectives at the regional, national or global level. However, to identify and assess organizations' environmental improvements, the commonly used environmental performance indicators are somewhat more narrowly defined than the wider concept of environmental indicators. In the ISO standard on environmental performance (ISO 14031), an environmental performance indicator is defined as a 'specific expression that provides information about an organization's environmental performance' (ISO, 2000, pp. 7–8). The standard gives guidance on different types of indicators and distinguishes between environmental condition indicators (ECI), operative performance indicators (OPI) and management performance indicators (MPI). Some of the indicators that may be generated through the DPSIR model coincide with those proposed by the ISO. The ECI corresponds more or less to State (S), OPI to Driving force (D) or pressure (P) and MPI to response (R). (See Tables 1 and 2 for examples of the mentioned indicator types.) The definitions of environmental indicators presented above demonstrate the broad range of applications of environmental indicators. Depending on their purpose, indicators may be very detailed or highly aggregated.

Table 1 Examples of different types of indicators for the evaluation of environmental performance (after International Standards Organization (ISO), 2000)

Indicator	Example
Environmental condition indicator (ECI)	Concentration of air pollutants related to an exhaust emission
Operative performance indicator (OPI)	Total quantity of consumed fuel
Management performance indicator (MPI)	Number of hours the staff was educated about the advantages of using collective transports

Environmental indicators in business organizations

The indicators proposed by the ISO (2000) for use in the EMS process of business organizations are of the types OPI and MPI. Such indicators are used internally in organizations for the control/surveillance of environmental aspects and to assess environmental objectives/targets. In addition, they are used for communication with external stakeholders or for benchmarking with other organizations (Thoresen, 1999; Olsthoorn *et al.*, 2001).

The general criteria for choosing indicators in the EMS process of business organizations (Advisory Committee on Business and the Environment (ACBE), 1992; Azzone and Manzini, 1994; Verfaille and Bidwell, 2000; Olsthoorn *et al.*, 2001) often include the following:

- ease of measurement
- capability to connect company actions with environmental results
- be understandable and meaningful to the identified stakeholders
- be workable in practice
- support benchmarking over time
- capability to inform decision-making for improving organizational performance
- focus on areas of direct management influence

Table 2 Example of indicators for measuring the environmental quality objective 'Natural acidification only' proposed by the Swedish Environmental Protection Agency (Naturvårdsverket, 1999)

Indicator	Example
Driving force (D)	Transport demand of the society (conveyance of goods, tonnes-km per year)
Pressure (P)	Total emissions of exhaust gases from traffic (tonnes nitrogen oxides per year)
State (S)	Acidification in the environment (number of acidified lakes)
Impact (I)	Distribution of species and age in fish
Response (R)	Liming efforts to counteract acidification (costs per year)

When examining such criteria, it is evident that they are mainly designed from the practitioners' perspective. The same is valid for standardization work aimed at finding indicators to be used in certain industrial sectors for benchmarking (e.g. Tyteca *et al.*, 2002; Zetterberg *et al.*, 2001).

Olsthoorn *et al.* (2001) conclude that the environmental indicators used are a result of what is easily measurable in the organization, but they hardly ever indicate changes in the environmental quality. Since the ISO standards on environmental management and environmental performance are rather vague on this issue, it is not surprising that the choice of indicators is mainly guided by practical considerations.

Environmental indicators in the building sector

One of the most thorough efforts to gather information about environmental indicators in use today in the property and construction sector is the CRISP project (CRISP, 2004). A major outcome of the project, whose aim is to encourage a wider use of indicators is a database containing around 500 examples. There are also a number of environmental assessment tools for buildings and building services providing an assortment of indicators to be used in various contexts related to different life-cycle stages of buildings. These include Leadership in Energy and Environmental Design (LEED),[2] the National Australian Built Environment Rating System (NABERS),[3] the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE),[4] EcoEffect,[5] the Building Research Establishment Environmental Assessment Method (BREEAM)[6] and GBTool.[7] Since all these systems aim at being tools for practitioners, their practical relevance has often received more attention than the theoretical issues.

Procedure for choosing indicators

Relating services to environmental problems

An indicator can be defined as a quantitative measure that can be seen as an approximate value on an explicit environmental problem. However, neither the ISO 14031 standard nor other guidelines on the use of environmental indicators include a discussion about what would be a satisfactory approximation.

In a Swedish project on environmental assessment of buildings, EcoEffect (Eriksson *et al.*, 2005), schematic cause-and-effect chains were used to describe the environmental problems related to building use. An example of energy use linked to the contribution to climate change is given in Figure 1. The left side of Figure 1 shows the demanded services. For example, the need for thermal comfort is fulfilled through heating the building. This produces emissions of greenhouse gases that in turn lead to unwanted end-point problems. Such chains resemble the DPSIR model (European Environment Agency (EEA), 2005). The service approximates the Driving force (D), emissions to Pressure (P), midpoint changes to State (S) and end-point problems to Impact (I). By determining the connections between building services and end-point problems, cause-and-effect chains can also be useful for considering how certain end-point problems can be avoided or reduced.

It is difficult to measure directly end-point problems initiated by building services because of the diffuse relationship between the services and the end-point problems. Figure 2 shows examples of possible indicators related to energy use (both for heating and electricity). The cause-and-effect chain in Figure 1 was used to identify indicators at different levels in the chain. When moving left in the chain, the more easily measurable but less valid indicators are found. Validity is reflected in how far to the right in the cause-and-effect chain the indicator is placed. Hence, special attention should first be given to the validity. If the validity is too low, the indicator should be rejected. In order to choose both a practically and a theoretically relevant indicator, a number of evaluation criteria are proposed in the next section.

Theoretical and practical considerations

There are at least three important scientific considerations to take into account when choosing indicators:

- validity: the indicator measures the end-point problem that it is supposed to measure, to a desired extent
- reliability: the data-acquisition and calculation processes are regulated so that the same value is obtained, independent of who is performing the processes
- accuracy: the desired level of precision in the indicator

A useful indicator must also meet certain practical demands. The following criteria are suggested:

- costs for data acquisition and calculations
- competence demands
- intelligibility (the meaning of the indicator should be easy to communicate)
- influence (the extent to which the organization itself can influence the value on the indicator)

As mentioned above, the indicators commonly used in practice are those that are easy to measure. The time resources needed for data retrieval and calculation procedures are therefore the most important practical criterion and can be translated to direct costs. Further, it can be assumed that it is not desirable to involve external expertise for data acquisition and calculations. This implies that the competence demands should not be too high. Once possible indicators have been deduced, their suitability can be evaluated according to the theoretical and practical criteria proposed above.

Using indicators for comparisons

Absolute figures are important for assessing environmental performance to show whether the total environmental impact increases or decreases. In order to use indicators for comparisons, environmental impacts need to be normalized – preferably related to a functional unit. For buildings, environmental impact should be related to the service produced by the building. Normally, the floor area is used as a basis for comparisons of environmental impacts, flows, costs, etc., i.e. an absolute value is divided by the floor area. However, better measures related to the delivery of services may be the building volume, the number of users for which the building is designed, or the way a building is actually used (e.g. numbers of users*hours). The normalization value should be chosen according to the purpose of the comparison, which normally varies with building type.

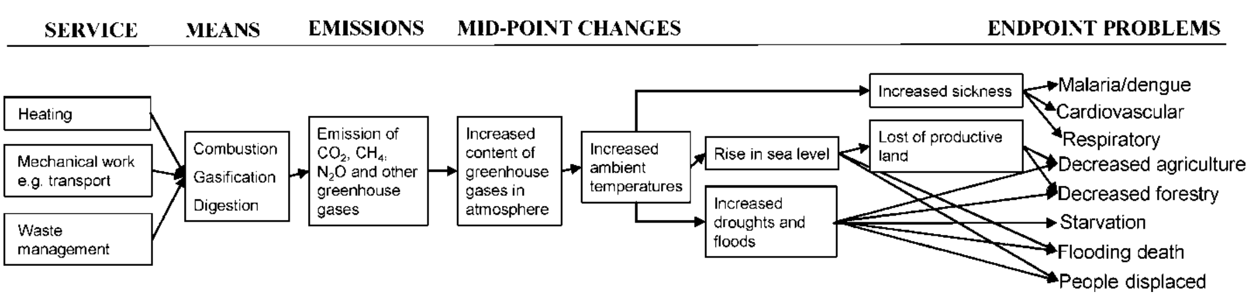

Figure 1 Cause-and-effect chain with possible end-point problems for climate change (Eriksson *et al.*, 2005)

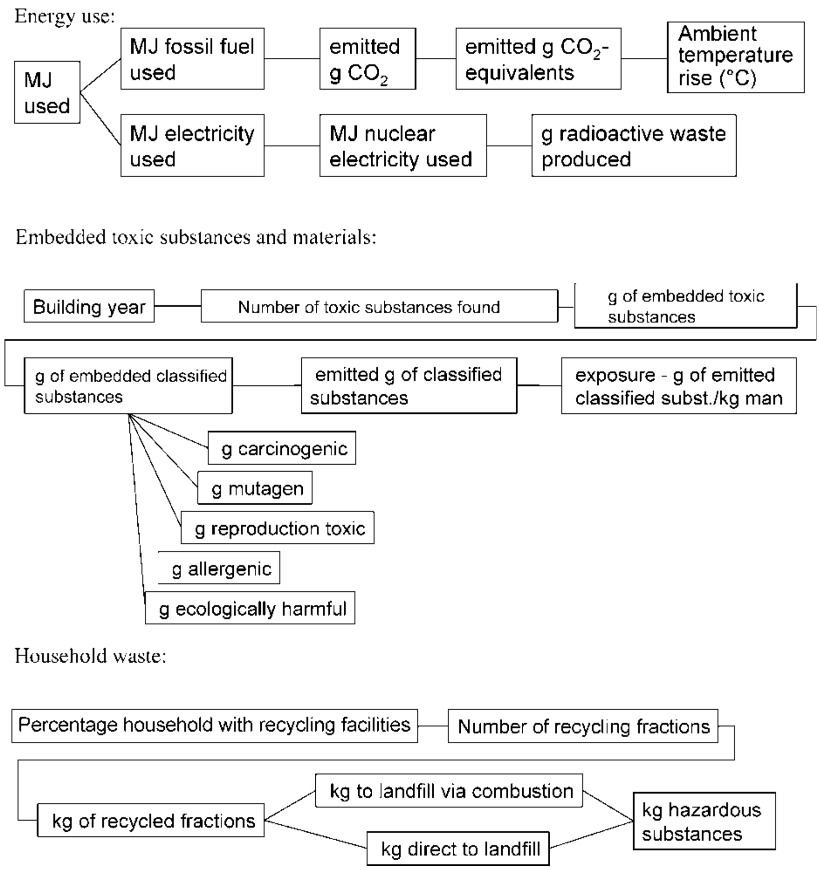

Figure 2 Example of possible indicators for three major significant environmental aspects. Increased problem relevance to the right and increased simplicity to the left in the chains. For comparisons, the chosen indicator has to be normalized by m^2, user or something else. Note that for 'Built-in hazardous substances and materials', the building year refers to when different building materials were used

Case study method

In the case study, the focus was on indicators for use in the EMS process of housing management, specifically on operational indicators (OPI) that can function as approximate values for environmental problems. The study was limited to three important environmental aspects for the property sector: energy use, household waste treatment and embedded toxic substances/ materials. Energy use was chosen since it is seen as one of the most significant environmental aspects in housing management. Waste treatment was chosen since the recycling of waste has been a main topic in the environmental practice of property owners for many years. Embedded toxic substances are also a focus area for both the developers and managers of existing buildings.

Initially, cause-and-effect chains for the three aspects were established. An example related to energy use is presented in Figure 1. The main end-point problems associated with waste were considered to be the unwanted dispersal of toxic substances due to the contamination of household waste; leakage from landfills; the use of scarce land resources for waste disposal; and the consumption of resources that could have been recycled for energy, nutrients or new products. A further problem is related to energy for the transport of different waste fractions. In an earlier study, this was shown to be of less importance (Malmqvist, 2004). End-point problems related to embedded toxic substances are diseases caused by toxic emissions into the environment (e.g. cancer and allergies), while mutagenic and hormone-like emissions may cause reproduction problems and malformations and generally be ecologically harmful.

For energy use, multiple end-point problems can be identified. The most relevant environmental problems related to energy use were identified. These include climate change, ionizing radiation related to the production of radioactive waste, acidification and eutrophication. Each of these causes different end-point problems. For instance, ionizing radiation can cause cancer and reproduction damage. Acidification can cause decreased forestry and corrosion. And eutrophication can cause reduced re-creational values due to the overproduction of algae. Tools for environmental assessments of operation of buildings were reviewed in order to find ideas of possible indicators. Some examples were chosen along with suggestions related to different stages in the cause-and-effect chains (Figure 2). The possible indicators in Figure 2 were then used as a basis for the collection of data.

Data were gathered from three Swedish housing estates (Table 3) in order to examine the possibilities of calculating problem-related environmental indicators from quantitative data in housing companies. The housing estates are fully owned and operated by municipally owned housing corporations. These organizations handle most of the daily operation of the buildings with their own staff and do not differ from privately owned housing corporations in the sense that they have to carry the full costs, i.e. the rents have to balance the costs. One is certified according to ISO 14001, while the other is working with an EMS without being certified.

The data collected included annual quantities of energy use, household waste generation and data about embedded toxic substances/materials. The data were retrieved from data systems in the companies and through interviews with environmental managers and facility managers of the different housing estates. In addition, emission and production data on the local energy production and waste treatment plants were collected. By combining the company-specific data with the external data, indicators were then calculated. Table 4 summarizes the chosen indicators and the necessary data for calculating them.

Results

Environmental indicators for energy use

For the three Swedish housing estates (Viken, Östberga and Sörsedammen), the energy use for heating and electricity for operations[8] (household electricity is not included) was given in kWh/year. These values were easily converted to emitted equivalents by translating kWh to pollution emissions contributing to climate change, acidification, eutrophication and megajoules (MJ) of nuclear electricity, which is proportional to ionizing radiation (Figure 3). Characterization factors from the EcoEffect environmental assessment tool for buildings were used.[9] The contributions to the problems are shown per user of the housing estates, thereby relating the environmental impact to a service produced.

In the Viken and Östberga housing estates, the energy for district heating and electricity is produced in the same way. The energy for district heating is mainly based on energy generated from waste combustion. The electricity is based on water power that does not contribute to the selected problems. In Viken, solar heat collectors are also used for the heating of hot water, which is accounted for as zero in the chosen indicators. In Sörsedammen, the district heating is based mainly on waste heat from the pulp industry. However, the electricity is a Swedish production mixture (mainly nuclear power and water power). Emissions per kWh for district heating were taken from the local district heating company (basically carbon dioxide (CO_2), nitrous oxides (NO_x) and

Table 3 Basic information about the housing estates in the case study

	Sörsedammen	Viken	Östberga
Size	878 apartments/1485 users	126 apartments/333 users	1171 apartments/3153 users
Building year(s)	1967–71	2002	1967–69
Housing manager	Municipal company operating in the south of Sweden, ISO 14001-certified	Big municipal company operating in Stockholm	
Heating system	Year 1: direct electric heating and heat pumps; year 2: district heating based on waste heat from a pulp industry	District heating based mainly on waste combustion; solar heat collectors for heating of hot water	Same delivered district heat as in Viken
Electricity for operation	Swedish production mixture (mainly nuclear and water power)	Electricity produced only by water power	
Recycling facilities on site	Glass, metal, hard plastics, newspapers/magazines, compost, paper packages	Glass, metal, hard plastics, newspapers/magazines, electronics, compost	Glass, metal, hard plastics, newspapers/magazines, electronics, hazardous waste
Municipal waste treatment	Combustion of household waste that is not recycled; bulk waste to landfill		
Documented embedded toxic substances	Only polychlorinated biphenyls (PCBs)	Yes	No

Table 4 Tested environmental indicators for housing management

Activity/ environmental aspect	Environmental impact/problem	Environmental indicator	Internal process data needed	External data needed
Use of energy for heating	Climate change	Carbon dioxide (CO_2) (kg)-equivalents/year	Quantities (kWh or MJ/ year) of energy use for heating and electricity	Emission data for the production of the energy used for heating and electricity
Use of electricity	Acidification	Sulphur dioxide (SO_2) (g)-equivalents/year		
	Eutrophication	Nitrous oxides (NO_x) (g)-equivalents/year		
	Ionizing radiation	Megajoules (MJ) equivalents/year		
Waste production and treatment	Eco/human toxicity	Waste (kg) to landfill/year	Quantities of waste to landfill	Data on the percentage of various waste fractions to landfill (including ash from waste combustion)
Embedded toxic substances	Eco/human toxicity	Carcinogenic substances (kg)	Quantities of embedded toxic substances	List of officially classified hazardous substances
		Reproductive toxic substances (kg)		
		Mutagenic substances (kg)		
		Allergenic substances (kg)		
		Ecologically harmful substances (kg)		

sulphur dioxide (SO_2) and for Swedish electricity production mixture from the electricity supplier Vattenfall.

The district heating can be seen to contribute significantly to climate change, acidification and eutrophication in all three cases. Even though Viken also uses solar heat collectors for the heating of hot water, the energy use per user is higher than in Östberga (Figure 4, year 2), which is the reason for a higher contribution to the environmental impacts shown in Figure 3. However, Sörsedammen generally has lower contributions than the other two estates, which relates to a cleaner production of district heat. On the other hand, only Sörsedammen contributes to ionizing radiation due to the nuclear power used for the production of its electricity in this case.

It can be concluded that the production methods of energy for heating and electricity extensively affect the contributions to the considered environmental impacts. This insight into the environmental consequences related to energy use would be lost if only the indicator of energy use per m^2 is used. However, to study the level of individual housing estates, energy use per m^2 will normally serve as a sufficient indicator for environmental targets, since significant changes in the energy production mixture are uncommon at this level. Figure 4 shows this indicator for the studied estates for two consecutive years. However, for the annual review of the performance of the housing stock as a whole, the indicators in Figure 3 may be more relevant since there might be changes each year somewhere in the housing stock. On company-level formulations of environmental objectives such as contributions to climate change or ionizing radiation may be important. There are housing corporations that have introduced such objectives in their EMS process (Malmqvist, 2004).

The example of Sörsedammen housing estate (Figure 4) shows that a change in the energy production was executed. In year 1, electricity was used to heat the houses, whereas in year 2 the housing estate was connected to a district heating system with a reduction in energy use and a dramatic reduction in the contribution to ionizing radiation. Furthermore, Figure 4 displays the role of the chosen denominator for normalization. For instance, the electricity use in Sörsedammen and Viken can be seen to be higher than in Östberga if normalized with the numbers of users instead of per m^2. This explains why the new housing estate Viken has higher indicator values in Figure 3 than Östberga, even though Viken uses solar heat collectors and has been designed for a low energy use per m^2. The layout plan of Viken shows a less efficient utilization of space than in Östberga (i.e. fewer people are accommodated per m^2).

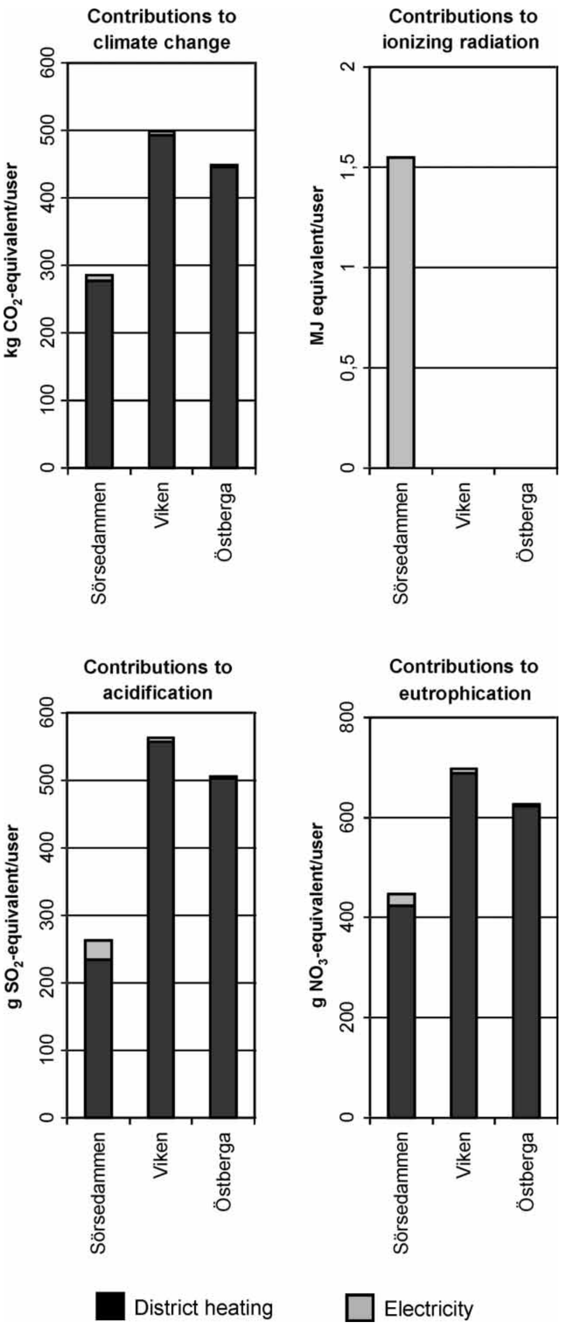

Figure 3 Outcome of four of the tested indicators for energy use calculated for three housing units 2003

Environmental indicators for household waste treatment

For household waste treatment, the indicator 'kg waste to landfill' was tested. It is composed of bulk waste that is directly landfilled and the landfilled ash and slag from the combusted household waste (see the left diagram in Figure 5). It can be debated whether the ash and slag from combustion should be included.[10] The data relate to actual quantities produced during one year and how they were treated in the individual case. The ash and slag from the combusted waste was calculated with the help of data from the combustion plants. A more problem-related indicator would have been the amounts of hazardous substances in the household waste. This was, however, not possible to trace.

It is notable that the ash and slag sent to landfill from waste combustion accounts for a considerable part of the total amount of waste sent to landfill in Sörsedammen and Östberga. This suggests that Viken (in particular) has better recycling facilities. The same data can be used to determine the proportions of the waste treated in different ways (see the right diagram in Figure 5). This can be used to evaluate whether improved recycling facilities were efficient. In Sörsedammen and Viken organic waste is collected and, therefore, included in the column for recycling. A reason for the much higher quantity of waste generated in Viken (including bulk waste) might be the number of restaurants on this housing estate.

Environmental indicators for embedded toxic materials and substances

For the environmental aspect of embedded toxic substances, sophisticated indicators could be tested since the content of the building materials in Viken was carefully documented (Figure 6). The indicators are based on the actual embedded quantities in kg of substances that are officially classified as possessing inherent hazardous properties (carcinogenic, etc.). These indicators show some of the potential problems related to embedded toxic substances that are not commonly appreciated. However, the indicators do not tell us anything about which problem is the most important, or if a value is high or low due to the absence of reference values. Another problem is that substances may, for instance, be more or less carcinogenic. Very small amount of a very carcinogenic substance can constitute a much higher risk than a larger amount of a less carcinogenic substance. The possibility for people to be exposed to toxic substances is also not determined as this depends to some extent on where in the building structure they are located. A further problem is that only a few chemical substances are currently classified. The pattern of results displayed in Figure 6 may generate groundless fears, since Figure 6 does not consider where in the building the substances are to be found or if the quantities and substances are dangerous. It should only be used for further discussion.

Theoretical and practical relevance of indicators

The previous section presents a few indicators that are more problem-related than those used in practice today. In this section, their theoretical and practical

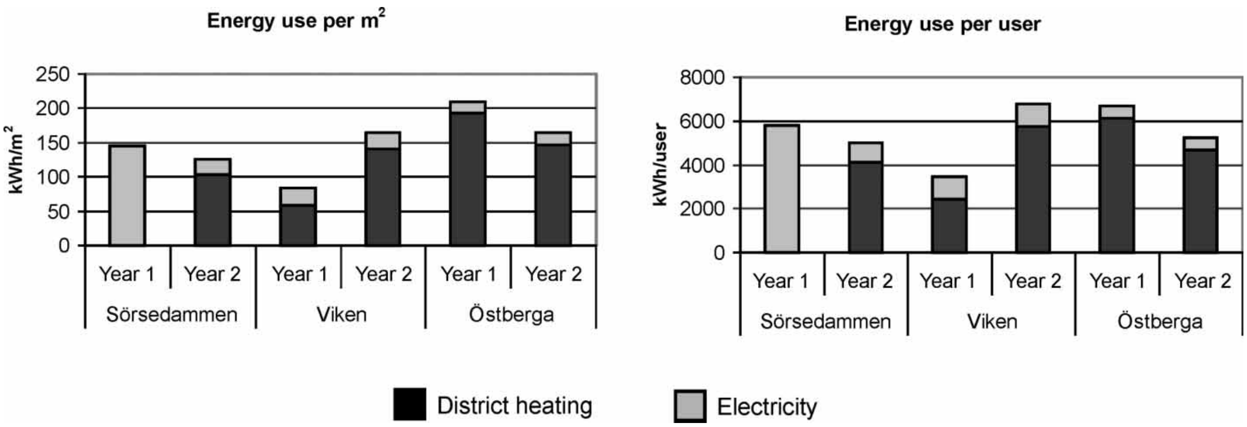

Figure 4 Change in energy use per user and per m^2 in the three housing units between two years

relevance are examined. A number of currently used indicators is discussed and followed by an evaluation of the tested indicators in the project against the practical and theoretical criteria that were suggested above.

Indicators in some existing assessment tools

The indicators for energy use, waste treatment and toxic substances have been examined in the following assessment tools: LEED (US), CASBEE (Japan), EcoEffect (Sweden) and NABERS (Australia). In addition, the most widely used environmental performance indicators related to the three environmental aspects in this study were examined in nine proactive Swedish real-estate companies (SRCs) (Malmqvist, 2004).

Energy

LEED and CASBEE both use kWh/m^2 as the main basis for credits, which has a very poor relationship to the different environmental consequences energy use may cause. They reward many individual measures to save energy, but not the efficient use of space. A satisfactory environmental performance is, however, not guaranteed by several separate measures. The SRC also use kWh/m^2 as a further measure. NABERS and EcoEffect both address the problem of climate change directly through the indicator CO_2-equivalents per person. This indicator favours the efficient use of space, since the impact is calculated per person. EcoEffect also indicates other impacts of emissions from energy use as well as resource depletion.

Household waste

LEED rewards the amount of the total waste that is recycled. CASBEE gives credits for sorting, recycling and composting. NABERS assess household waste from the kg waste per occupant for recycled fractions and landfill fractions, respectively. EcoEffect only rewards sorting, and SRC commonly use a share of households with recycling facilities. This measure is rather a means to prevent toxic substances from reaching nature, but it does not guarantee it. Of the examined systems, NABERS uses the most problem-related method to assess household waste, which is the same one as was tested herein.

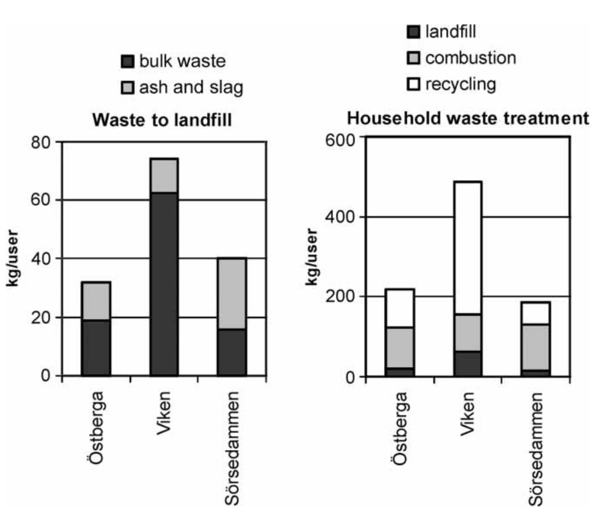

Figure 5 Landfilled waste per user from the three housing units

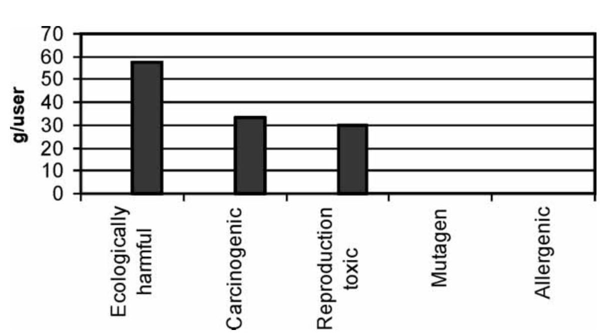

Figure 6 Outcome of the tested indicators for embedded toxic substances for the housing estate Viken

Embedded toxic substances

LEED only addresses mercury in light bulbs, which is quantified. CASBEE rewards using building materials without a number of toxic substances. EcoEffect makes an inventory of materials with toxic substances. NABERS mostly addresses the safe use, storage, and disposal of domestic chemicals and materials during the operation phase. No method gives any measure for the consequence of using building materials with a toxic content. Some SRCs use a percentage of the housing stock that was audited with regard to embedded toxic substances (in many cases only polychlorinated biphenyls (PCBs) and radon).

Evaluating the tested indicators

Table 5 shows an example of how the theoretical and practical relevance of chosen indicators can be simply evaluated and it provides an overview that can be useful. In Table 5, three of the indicators were chosen that are representative for all the tested indicators in the case study.

Indicators on energy use

The tested indicators for energy use can be seen as being more valid indicators for these problems than the commonly used indicator 'used kWh or MJ of energy'. However, related to the end-point problems, they are still rather approximate. Reliability is primarily a matter of developing routines for retrieving data and establishing criteria for data quality. Energy data from the housing estates are trustworthy since these data are also used for charging. As long as the same characterization factors are used, the accuracy of comparisons of buildings will be acceptable. Energy production data are usually easy to retrieve as long as there are legal requirements on reporting the most important emissions. The costs are not particularly high since energy data are easily retrieved and characterization factors are only gathered once. Emission and production data are commonly easy to find.

Once routines are developed, calculating the tested indicators is fairly simple and should be no problem for the ordinary staff working in housing companies. However, initial training is needed since it ensures the ability to identify errors in data and the ability to interpret outcomes meaningfully. The data become intelligible once people have become acquainted with the new units and can relate them to commonly known values.

The possibilities for the housing company to influence the value of the indicator are normally high. However, when district heating is used (as in the examined housing estates), the influence will be indirect since the companies then have to demand 'greener' heat from the producer.

Indicators on waste treatment

The tested indicator for waste treatment is far to the left in the cause-and-effect chain and suggests a weak validity. However, a focus on the landfilled waste implies a clearer focus on the associated end point-problems discussed above than simply stating the recycling facilities in the housing estates.

In Sörsedammen and Viken, combustible waste is weighed when collected. However, for Viken, the data were obtainable from the company collecting the waste. In Östberga, the weight had to be estimated from the volume of the collecting bins in the area. Bulk waste was weighed when collected at Viken and Östberga, but not in Sörsedammen, where it had to be estimated from the volume collected. The accuracy, which in this case coincides with the costs for data acquisition, is therefore fair.

As with the indicator for energy use, the competence demands are low after some initial training. The intelligibility can be considered as fair. It is easy to understand that certain quantities from a housing estate are

Table 5 Tentative evaluation of the scientific and practical relevance of the tested indicators. Note that the values should not be added since cost and competence have reversed values

	Aspect	**Energy use**	**Waste treatment**	**Embedded toxic substances**
	Main problem	Climate change	Landfill	Carcinogenic substances
	Unit	kg CO_2-equivalents/user, year	kg/user, year	g/user
Theoretical relevance	**Validity**	Fair	Fair	High
	Reliability	High	Fair	Low
	Accuracy	High	Fair	Low
Practical relevance	**Cost**	Low	Fair	High
	Competence	Low	Low	Fair
	Intelligibility	Fair	Fair	Fair
	Influence	High	Fair	Fair

landfilled. However, it does not immediately signal what are the end-point problems. As with energy use, the value of the indicator is to a certain extent dependent on the waste treatment plants and/or municipal waste treatment system. However, it tells more about the end-point problems related to waste treatment and it can therefore be argued that at least environmental objectives at a company level should address this problem.

Indicators on embedded toxic substances/materials

The tested indicators for measuring risks related to embedded toxic substances and materials are highly valid since they address the end-point problems directly. However, due to the diverse problems already mentioned, the reliability and accuracy of this indicator must be considered as being low. For instance, only a few chemical substances are officially classified and only a limited selection of materials has an environmental product declaration (EPD), which is used for data retrieval. The latter problem may, however, be addressed by stating the ratio of declared materials.

It is uncommon for data to exist about the toxic substances embedded in older buildings. Such information only exists for special inventories made recently. Furthermore, embedded quantities are seldomly estimated. The cost of making inventories would therefore probably be too high and expertise would be needed. It can thus be concluded that these indicators may only be calculated for new buildings.

Without initial training about the underlying facts, the significance of a certain indicator value is difficult to grasp. However, when this is achieved, intelligibility must be considered as fair. An influence can be considered as fair since the company decides on possible decontamination, but the costs for it are often high.

Conclusions

Since environmental performance indicators in an EMS are chosen and used by practitioners, the practical applicability has typically guided the choice of indicators. The environmental relevance of the chosen indicators can also be difficult to judge. However, a number of studies conclude that an EMS does not necessarily imply improvements in environmental terms (e.g. Tyteca *et al.*, 2002; Hamschmidt and Dyllick, 2002). This is, in part, due to the weak reliability of methods to measure improvements (Ammenberg and Hjelm, 2002; Schylander and Zobel, 2003). The research community must therefore contribute to the discussion about the theoretical relevance of different indicators.

In the present paper, a procedure is proposed that finds indicators that as far as possible satisfy both practical demands and scientific validity. The procedure focuses on approaching end-point problems, i.e. the final consequences for man and nature of environmental problems. To highlight the relation between needed services and end-point problems, the use of cause-and-effect chains was proposed. They make it easier to formulate possible indicators more or less close to the end points, since it is seldom possible to measure end-point problems directly. The final step in the procedure is to test the possible indicators against a number of theoretical and practical criteria among which validity should be considered first since it tells us how well the indicator succeeds in being an approximate value on the specific end-point problem.

The relevance of an indicator can only be judged in relation to the problem it should measure. For this reason, the choice of addressed problems and the description of them is crucial. In the EcoEffect project, cause-and-effect chains for the main external impact categories have been established. If a consensus about such chains could be reached, better indicators could be agreed upon and the collection of relevant data could be improved successively.

Further, if indicators are used for comparisons of the normalization value (e.g. floor area, building volume or the number of occupants), it will have a great influence on the result. It is recommended that normalization values should be chosen as far as possible to reflect the service the building offers. This would allow the amount of service per environmental impact to be optimized.

The present study illustrates that the routines for collecting existing quantitative information are not well developed and need to be better organized. More problem-related indicators that are also perceived as trustworthy by practitioners may support such a development. A mutual exchange of knowledge between practitioners and researchers is needed. Lützkendorf and Lorenz (2005) argue for the establishment of better building information systems, which also include the transfer of information from the design stage. For instance, the dense information appearing on computer drawings makes it possible to develop much more sophisticated indicators in the future.

The case studies show that the indicators tested for energy use, contributions to the four impact categories, can be used today. The data are readily available and the calculations are easy to make. The indicator tested for waste treatment (kg of waste to landfill) is rather rough and would benefit from further refinement and the employment of complementary indicators on the dispersal of toxic substances and the utilization of resources. However, it is an improvement compared with only considering recycling fractions, which is the current indicator. The data needed are available in the studied companies, but the accuracy and documentation vary. If better routines are introduced for the documentation of waste quantities, this indicator could be used in practice. The charging of waste production per quantity supports this development.

Acceptable indicators on embedded toxic substances are difficult to formulate. The tested indicators clearly indicate potential risks for people's health and ecosystems. However, the data used were based on a recently built housing estate where special efforts had been made to document toxic substances in building materials. For existing buildings, it is impossible to collect the corresponding data from an inventory. Known and debated toxic materials can be found in inventories of existing buildings.[11] However, usually only the existence of toxic materials is documented today, not the quantities. If quantities were estimated, the tested indicators could also be calculated for existing buildings. The low accuracy of the tested indicators suggests, however, that they be used only as examples for further discussion.

The values of the tested indicators for energy use and waste treatment depend to a certain extent on external actors such as the district heat supplier and the waste treatment company. This limited influence on the outcome of the indicator may reduce companies' interest in using them. On the other hand, the use of these indicators may put pressure on external actors in the long-term. It is important, at least at the company level, that environmental objectives have a clear relationship with the reduction of environmental problems.

It can be questioned whether the studied SRCs are representative with respect to what environmental data they can provide. In an international context they may be seen as rather special in the sense that these companies both own and operate the buildings, which implies that they have accumulated knowledge about the buildings. However, there are examples of facility managers who can produce a great deal of environmental data if the property owner demands it (and pays for the service). Incentives such as demands for information from external stakeholders, for instance for sustainability indexes, have also been shown to increase the willingness to pay for collecting data (Malmqvist, 2004). Since at least both the tested indicators for energy use and waste treatment are included in a few international environmental assessment systems for buildings, for instance NABERS, it can be assumed that Swedish conditions are no different with respect to data availability.

The choice of environmental indicators for the EMS practice is always a balance between what is theoretically possible and what is practically most desirable. Different indicators will be important in different situations. What is suitable for communication at various organization levels may not be relevant when communicating with the outside world. However, this balance needs to be directed successively towards problem orientation and the more accurate measurements of those problems. The EMS practice in the building sector will benefit from more problem-related indicators, even though some of them at first sight may seem less relevant to an organization.

References

Advisory Committee on Business and the Environment (ACBE) (1992) *A Measure of Commitment*, ACBE, London.

Ammenberg, J. (2003) Do standardised environmental management systems lead to reduced environmental impacts? Dissertation No. 851, Environmental Technology and Management, Linköping University, Linköping.

Ammenberg, J. and Hjelm, O. (2002) The connection between environmental management systems and continual environmental performance improvements. *Corporate Environmental Strategy*, **9**(2), 183–192.

Azzone, G. and Manzini, R. (1994) Measuring strategic environmental performance. *Business Strategy and the Environment*, **3**(1), 1–14.

BREEAM: Anderson, J., Shiers, D.E. and Sinclair, M. (2002) *The Green Guide to Specification*, 3rd edn, Blackwell, Oxford.

CASBEE (2003) *CASBEE Manual 1*, Institute for Building Environment and Energy Conservation/IBEC, Tokyo.

CRISP (2004) *A European Thematic Network on Construction and City Related Sustainability Indicators*. Final Report, Publishable Part (available at: http://crisp.cstb.fr/default.htm).

Eriksson, O., Glaumann, M. and Assefa, G. (2005) Life cycle impact assessment – a damage-based weighting method for environmental impacts, in Proceedings of the International Conference 'Sustainable Building 2005', Tokyo, Japan, September 2005.

European Environment Agency (EEA) (2005) *EEA Multilingual Environmental Glossary*, EEA, Copenhagen (available at: http://glossary.eea.eu.int/EEAGlossary).

Glaumann, M. and Malmqvist, T. (2004) *Miljövärdering av bebyggelse – EcoEffect-metoden* [Environmental Assessment of Buildings – The EcoEffect Method), Högskolan i Gävle, Gävle, and Royal Institute of Technology, Built Environment Analysis, Stockholm.

Hamschmidt, J. and Dyllick, T. (2002) ISO 14001: profitable – yes! But is it eco-effective? *Greener Management International*, **34**, 43–54.

Hauschild, M. and Wenzel, H. (1998) *Environmental Assessment of Products (EDIP). Scientific Background*, Chapman & Hall, London.

International Standards Organization (ISO) (2000) *Environmental Management – Environmental Performance Evaluation, Guidelines*. ISO 14031:1999, ISO, Geneva.

International Standards Organization (ISO) (2002a) *Environmental Management – Life Cycle Assessment – Life Cycle Impact Assessment*. ISO 14042:2000, ISO, Geneva.

International Standards Organization (ISO) (2002b) *Environmental Management – Vocabulary*. ISO 14050, ISO, Geneva, Annex A.5.

Lützkendorf, T. and Lorenz, D. (2005) Alleviating asymmetric information in property markets: building performance and product quality as signals for consumers. *Building Research & Information*, **33**(2), 182–195.

Malmqvist, T. (2004) *Fastighetsförvaltning med fokus på miljöproblemen – om miljöstyrning och uppföljning av miljöpåverkan i fastighetsförvaltande företag* [Real estate management focusing on environmental problems – environmental management and follow up of environmental impact in real-estate companies), Licentite thesis, Department of Infrastructure, Royal Institute of Technology, Built Environment Analysis, Stockholm.

Naturvårdsverket (1999) *System med indikatorer för nationell uppföljning av miljökvalitetsmålen*. SNV Report No. 5006, Naturvårdsverket, Stockholm.

Olsthoorn, X., Tyteca, D., Wehrmeyer, W. and Wagner, M. (2001) Environmental indicators for business: a review of the literature and standardisation methods. *Journal of Cleaner Production*, **9**, 453–463.

Schaltegger, S. and Burritt, R. (2000) *Contemporary Environmental Accounting – Issues, Concepts and Practice*, Greenleaf, Sheffield.

Schylander, E. and Zobel, T. (2003) Environmental effects of environmental management systems: evaluation of the evidence, in Proceedings of the EASY-ECO II Conference, 15–17 May 2003, Vienna, Austria.

The Intergovernmental Panel on Climate Change (IPCC) (2001) *Third Assessment Report. Climate Change 2001. The Scientific Basis*, IPCC, Appendix VIII. Technical Summary, Table 3, Cambridge University Press, Cambridge.

Thoresen, J. (1999) Environmental performance evaluation – a tool for industrial improvement. *Journal of Cleaner Production*, 7, 365–370.

Tyteca, D., Carlens, J., Berkhout, F., Hertin, J., Wehrmeyer, W., Wagner, M. (2002) Corporate environmental performance evaluation: evidence from the MEPI project. *Business Strategy and the Environment*, **11**, 1–13.

Verfaille, H.A. and Bidwell, R. (2000) *Measuring Eco-efficiency – A Guide to Reporting Company Performance* (available at: http://www.wbcsd.ch/DocRoot/sB8NSMPNP52ho8gXunY6/MeasuringEE.pdf) (accessed on 1 October 2003).

Zetterberg, L., &Angst;hman, M. and Hansén, O. (2001) *Sveriges branschers miljöpåverkan – indikatorer för uppföljning mot nationella miljömål*. Report No. B 1430, IVL Svenska Miljöinstitutet AB, Stockholm.

Endnotes

[1]Indicators are quantitative, qualitative or descriptive measures that when periodically evaluated and monitored show the direction of change (International Standards Organization (ISO) 2002b).

[2]See http://www.usgbc.org

[3]See http://www.deh.gov.au/settlements/industry/construction/nabers

[4]See CASBEE (2003).

[5]See http://www.ecoeffect.org and Gaumann and Malmqvist (2004).

[6]See BREAM *et al.* (2002).

[7]See http://www.iisbe.org

[8]Electricity for operation includes that for lighting in entrances, collective stairs and basements, and for the operation of ventilation, collective laundry machines, pumps and elevators in the building.

[9]A characterization factor is a factor from a model that is applied to convert life cycle inventory data to the common unit of the impact category indicator (International Standards Organization (ISO) 2002a). In the EcoEffect environmental assessment tool for buildings (http://www.ecoeffect.org), characterization factors from The Intergovernmental Panel on Climate Change (IPCC) (2001) and Hauschild and Wenzel (1998) are used.

[10]However, the aim was to illuminate that it remains as waste.

[11]A Swedish system on how to make inventories of a number of known toxic materials is Miljöstatus (http://www.miljostatus.se/).