Technical Report No. 1

Comparing Environmental Impact Data on Cleaner Technologies

Prepared by: Karen Leffland, COWI
Henrik Kærsgaard, COWI

Ingvar Andersson, Project Manager
European Environment Agency

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European Environment Agency
Kongens Nytorv 6
DK-1050 Copenhagen K
Denmark
Tel: +45 33 36 71 00
Fax: +45 33 36 71 99
E-mail: eea@eu.int

FOREWORD

The need for proactive new approaches in environmental management is obvious. Cleaner technology and cleaner production are technologies aiming to be clean, energy-saving and waste-minimising. There is also a need to assess in a life cycle perspective the real improvement of a cleaner technology in quantitative or at least in semi-quantitative terms.

The European Environment Agency (EEA) has the mandate 'to provide the Community and the Member States with objective, reliable and comparable information at the European level'. Among its goals, the EEA shall provide information for environmental policy development and implementation and ensure broad dissemination and accessibility. Important principles in this context are pooling existing information and know-how and facilitating data harmonisation.

This report describes a concept for Comparable Environmental Impact Data on Cleaner Technologies (CEIDOCT). The aim of the concept is to provide a framework for systematic evaluation of cleaner technologies with the use of environmental performance indicators. The concept primarily can be used by industrial sectors and for reporting to environmental authorities, but it also has a wider scope in evaluating products, environmental statements of companies, organisations and local communities.

Case studies from the paper, textile and surface treatment industry demonstrate the usefulness of the concept.

The report is one of the outcomes of the Danish support programme to the EEA. Its production has involved many contributors other than the authors: it has been reviewed by the Scientific Committee of the EEA and the National Focal Points. The EEA is grateful for all these contributions.

The EEA hopes that this publication will encourage wider use of environmental performance indicators and this concept, to make it operational.

Domingo Jiménez-Beltrán
Executive Director
European Environment Agency

AUTHOR'S PREFACE

Aim of report

This report presents a concept for Comparable Environmental Impact Data on Cleaner Technologies (CEIDOCT). The aim of such a concept is to provide a framework for a systematic evaluation of cleaner technologies with the use of Environmental Performance Indicators (EPIs). The concept is aimed for use by industrial sectors and for reporting to environmental authorities, which have supported Cleaner Technology projects. The framework may be used by the authorities to structure environmental information when reporting to the public on environmental effects from use of Cleaner Technology, *or from any other activity with a positive or negative impact on the environment*.

The concept has not been finalised to an operational level with this report, but a basic framework has been defined.

The life cycle perspective

Cleaner technologies in this project are seen in a life cycle perspective, implying that it is necessary for the industry not only to look at EPIs for manufacturing at its own facility, but to include impacts from the whole product life cycle; i.e. from raw materials, manufacturing, use and disposal.

Structure of report

The executive summary and conclusions and recommendations are found in Chapter 1.

The idea behind the development of the CEIDOCT concept is described in Chapter 2. The backbone of the CEIDOCT concept developing EPIs inside four focus areas for environmental measures is also introduced. The four focus areas are: use of mineral resources, use of energy, use of chemicals and use of biological resources.

Search of literature for the use of EPIs, indicators used in connection with LCAs and assessments of cleaner technology are presented in Chapter 3.

The four focus areas are reviewed in Chapter 4. For each focus area, possible indicators at different levels of aggregation are discussed and identified.

In Chapter 5 the use of the concept is described for different levels and types of decision support.

The concept is tested in examples for three industrial sectors; the paper industry, the textile industry and surface treatment (zinc plating). Examples can be found in Chapter 6.

Extent of report

In the report the basic concept is described and illustrated via examples. The concept demonstrates a systematic way to illustrate and evaluate the environmental effects of cleaner technologies. The focus is on environmental problems relevant to the state of the environment in Denmark and Europe, but also on a global scale. The concept also includes a calculation, with the use of a life cycle approach, of the companies'/sector's environmental performance and recommends definition of technology-specific indicators for operational use.

Industry-specific indicators not included

The report does <u>not</u> contain a catalogue of environmental performance indicators or key data for industrial sectors; this remains to be developed. The examples stated represent, but do not fully cover, processes within the sectors mentioned and are thus only illustrative of the applicability of the developed concept. Involvement from the sectors in question has not been part of the terms for the project. This should be included in a later phase for development of industry-specific indicators.

A multi-purpose approach to Environmental Performance Indicators (EPIs)

The concept outlined in this report may be used much more broadly than for Cleaner Technology evaluations. It consists of a somewhat new approach to the development of Environmental

Performance Indicators in general, and may thus be used for many purposes such as environmental evaluation and declaration of products, environmental statements for companies, organisations and local communities.

Steering Committee

The accomplishment of the report has been followed by a Steering Committee consisting of the following:

Peter Schaarup,	Miljøstyrelsen (chairman)
Ingvar Andersson,	European Environment Agency
Henrik Kærgaard,	COWI
Karen Leffland,	COWI
Allan Herrstedt Jensen,	Institut for Produktudvikling, IPU

Project Organisation

The project has been carried out in co-operation between COWI and IPU. It has involved several specialists from both organisations. The focus areas have been described by the following: Mineral Resources; Nina Caspersen, IPU and Erik Hansen, COWI, Energy; Allan Herrstedt Jensen and Henrik Wenzel, IPU, Chemicals; Stig Olsen and Michael Hauschild, IPU, Karen Leffland and Jesper Kjølholt, COWI, Biological Resources; Hans Riber and Ulla V. Andersen, COWI.

Examples, based on LCAs, have been made by Christian Kofod, IPU in co-operation with Hans Henrik Knudsen and Allan Herrstedt Jensen, IPU.

Report

The main report has been prepared by Karen Leffland and Henrik Kærgaard, COWI and reviewed by IPU.

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1. EXECUTIVE SUMMARY

Project ambitions

The ambition of this project has been to develop a concept for environmental comparison of different technologies used for similar purposes, i.e. environmental performance indicators for comparison of different technologies to evaluate which one is 'cleaner'. These indicators in this project are called CEIDOCT/EPIs. This ambition level is high and may not be achieved without certain professional compromises.

Environmental comparison between technologies may include evaluation between different emissions to different media, e.g. carbon dioxide to air and heavy metals to water, as well as waste. Methodologies to do this are being developed within LCA concepts and are used, but not described in detail, in the present project.

Important prerequisites

The most important prerequisites for the project are:

evaluation of technologies to decide if one is 'cleaner' than another must be seen in the *product lifecycle perspective*. Changes at one stage of the lifecycle, e.g. the production stage, cannot be called 'cleaner technology' if the changes adversely affect the environmental impact at another stage, e.g. the use/consumption stage.

the concept to be developed is a proposal for a common, general and rather simple set of *comparable environmental impact data/indicators* (CEIDOCT/EPIs), which encompasses resources consumption and environmental effects of relevance on national, regional and global levels (Chapter 4). This can only be achieved by developing EPIs on a high level of aggregation, thereby mak-ing compromises between the level of details and accuracy inside specific issues and the demand for a general overview.

the concept includes a proposal for a systematic working approach and overall methodology for the development of Comparable Environmental Impact Data on Cleaner Technologies inside specific branches of trade (Chapter 5). A key element in this working approach is the use of *reference technologies*.

The problem of developing operational EPIs

Up to now the general approach to development of overall sets of Environmental (Performance) Indicators has been based on classification of environmental impacts, i.e. one indicator for each type or category of impact. This is scientifically and professionally correct but does not lead to easily operational concepts because of the very wide spectrum of environmental impacts existing, the broad knowledge of which is generally limited to environmental specialists.

The present project attempts to overcome this difficulty by developing the basic indicators inside important focus areas for environmental measures on a national, regional and global scale and in a future-oriented perspective.

Choice of focus areas

Based on assessment of areas of importance in Europe as well as globally, 4 focus areas have been chosen, which cover a very wide spectrum and volume of both consumption of resources and potential environmental effects. The 4 focus areas chosen are:

M) Consumption of mineral resources, excluding energy purposes (*M*ineral resources)

E) Consumption of fossil fuels (*E*nergy)

C) Consumption and dispersion of chemicals hazardous to the environment and human health (*C*hemicals)

B) Consumption of biological resources, including biological production as its basis, biodiversity and land use (*B*iological resources).

The focus areas M, E and C are generally covered in normal practices within LCAs. B, however, is included to account for the increased impacts on biological systems resulting from the many direct utilisations of these systems by mankind, which are not accounted for in existing LCA practices and methodologies.

Aggregation

Each of the focus areas has been worked through systematically with the aim of choosing indicators, which are aggregated from detailed investigation levels, e.g. LCAs, Environmental Impact Assessments or the like. A specific aim was to search/create indicators that can be used for a top-down approach not requiring a detailed knowledge of all aspects of environmental impact.

Level 0 is the most aggregated level, comprising only 4 indicators to serve as a first level in a top-down approach. Level 1 is more detailed and is aggregated from level 2, which is the level of an LCA or similar. Levels 0 and 1 represent the CEIDOCT approach:

Level 0 - one parameter for each of the focus areas- aggregated or directly estimated

Level 1 - 2-4 parameters for each focus area - aggregated

Level 2 - parameters from an LCA or similar (in the present project the EDIP method has been used).

The CEIDOCT concept is further illustrated in the following Figure 1.1

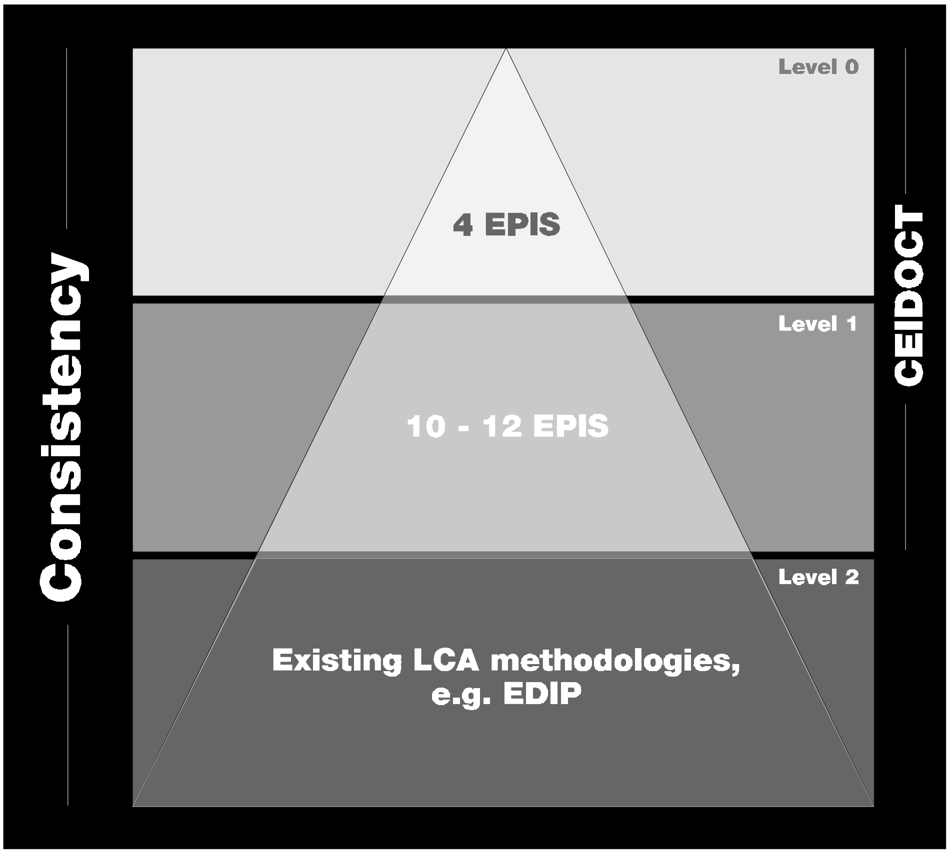

Figure 1.1: *Illustration of the CEIDOCT concept and relation to existing LCA - methodologies as a basis*

Normalisation

In order to make EPIs comparable between different technologies and different media it is necessary to normalise. This may be done as milli-person equivalent units to make indicators comparable for the society as a whole (at national or international level). It is also possible to normalise per produced unit and product lifetime in order to make key Figures comparable at trade level. **Normalisation is necessary in order to use the CEIDOCT concept.**

Weighting

Weighting is here used as a measure for 'closeness to target' and is necessary for decision making. In the Danish EDIP project, which is used to calculate the cases in Chapter 6, Danish and European political targets are used for weighting. In this report the development of sustainable targets for each focus area is advocated because the overall target for the concept of cleaner technologies is 'sustainable industrial production'. **Weighting is not necessary in order to use the CEIDOCT concept** and to calculate indicators, but weightings have been applied to a certain extent in the design of the concept framework, i.e. choice of focus areas, indicator types, etc.

An overview of the indicators recommended for the CEIDOCT concept is shown in the following table, Figure 1.2:

Figure 1.2: *Overview of indicators at aggregated levels in CEIDOCT*

EPIs	**Focus area M**	**Focus area E**	**Focus area C**	**Focus area B**
Level 0	EPI = Loss of mineral resources per unit (normalised) from inputs (material content) and disposal stage; aggregation of all contributions from mineral resources.	EPI = Energy consumption per unit (normalised) measured as primary energy	EPI = Potential effects from chemicals per unit (normalised), evaluated as scores, using classifications for labelling: $EPI = S_{amount} * ((S_{persist}.$ $or\ S_{bioaccumulation}) + S_{toxicity})$	EPI = Area requirements per unit (normalised) evaluated from cultivation and exploitation
Level 1	EPI = Aggregation of normalised losses of mineral resources from the LCA in groups as: • of fossil origin • metals • other minerals	EPI = Aggregation of normalised energy consumption in groups as: • non-renewable resources (% of total and MJ) • renewable and lasting resources (% of total, MJ)	EPI = Potential effects from chemicals, calculated as critical volumes, normalised and aggregated for the categories • photochemical ozone formation • persistency, bioaccumulation • human toxicity • ecotoxicity	Cultivation: • Index for normalised, aggregated area requirement. Exploitation: • Normalised index for degree of exploitation of sensitive species, transformed into an area index
Level 2	Environmental effects and use of resources as calculated in an LCA method (in this report is used the EDIP method) Resources: single types of fossil fuels, single minerals, etc. Effects: GWP, POCP, acidification, eutrophication, persistency, human toxicity., ecotoxicity etc.			Indicators corresponding to LCA-level (Amounts and types of resources, land use, water availability, nutrients etc.)

Key product properties, TSIs

It has been found necessary to define *key product properties* related to environmental impact. These key product properties cannot be changed with a change in technology without seriously affecting the environmental impact throughout the lifecycle. The importance of these indicators for cleaner technology evaluations is obvious and has been shown in the cases in Chapter 6. They are termed *Technology Specific environmental Indicators (TSIs) in the* ***product dimension***.

Product and process dimensions

In daily operation of production and manufacturing the process management is generally not governed by EPIs or the key product properties, but primarily by direct process parameters linked to the EPIs and product properties in various ways. The direct process parameter may be process temperature, use of raw materials per unit of product, calibration of machinery etc. and are termed *Technology Specific environmental Indicators (TSIs) in the **process dimension**.*

Reference technologies

Inside a specific branch of trade/industry the approach to cleaner technology will consist of a combined use of EPIs and TSIs in the product and process dimension, expressed through *reference technologies* for the industry in question. These reference technologies must be documented in terms of

- LCA-data,
- EPIs on levels 0 and 1,
- sets of key product properties/TSIs and
- process management TSIs.

Such reference technologies' life cycle data sets will create an important platform for cleaner technology management of product and process development as illustrated in the following Figure 1.3:

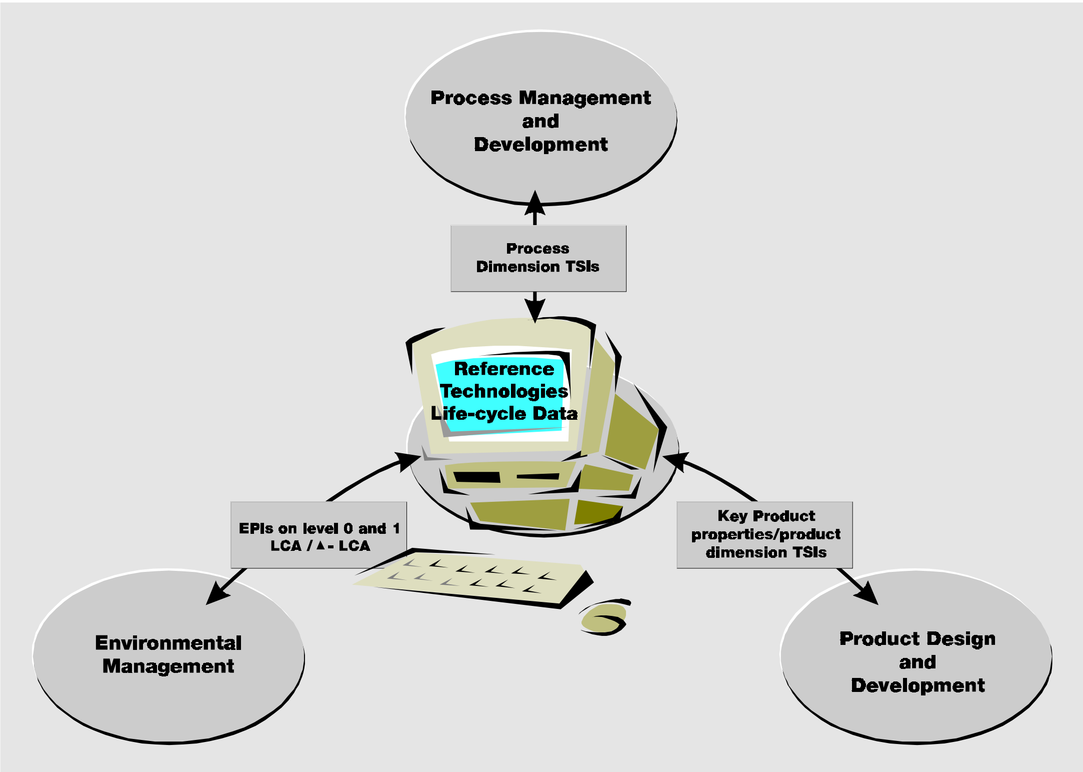

Figure 1.3: *Illustration of the role of reference technologies in cleaner technology approaches in specific branches of industry*

This figure is a general illustration of the relations between EPIs and TSI in the product and process dimensions exemplified in Chapter 6 of this report.

Recommendations

The following recommendations can be made based on the evaluations and conclusions in this project:

- to further develop and test the framework presented here, focusing on the four areas: mineral resources consumption, energy consumption, dispersion of chemicals and biological resources consumption (MECB).

- to further develop and test the indicators (CEIDOCTs) suggested at levels 0 and level 1 for comparison of different technologies covering the product lifecycle.
- to further develop the proposed concept into a manual, which will give more detailed directions for development of sector-specific indicators. The manual should encompass technology-specific indicators (TSIs) and Environmental Performance Indicators (in the form of CEIDOCTs). In this context it is necessary to further develop and operationalise the biological indicators.
- to evaluate how the ESEPI (environmental pressure indicator) programme initiated by Eurostat can be linked to environmental performance indicators developed in industry. The framework presented in this report can be used as a means for development of this link.
- support for the development and necessary research for eco-toxic, persistent and bioaccumulation classification of chemicals. This is still required in the future in order to provide data for investigations of effects from dispersion of chemicals and improve our knowledge of chemicals used.
- to support work for integration of the consumption of biological resources into the LCA concept, as a means of making the intentions from the Rio conference operational.

2. BACKGROUND AND PREREQUISITES FOR THE DEVELOPMENT OF A CEIDOCT CONCEPT

2.1 Important Prerequisites for the CEIDOCT Concept

Project ambitions

The task of this project is ambitious and is basically to "develop a concept for environmental comparison of different technical solutions to the same problem", e.g. environmental comparison of two different technologies for manufacturing of the same product or two similar products.

Evaluation of different emissions to different media may include, e.g. carbon dioxide to air and heavy metals to water. Methodologies to do this are being developed within the LCA concept, but are not yet operational on a general level.

Important prerequisites

It is important that the approach is realistic, pragmatic and operational. This also demands a number of important prerequisites to the job, which are stated as follows:

- Methodology development for the environmental comparisons of different technologies is *not* included, but is limited to the development of a concept for generation of suitable data/indicators for such comparisons.
- The aim is *not* to develop <u>the</u> concept for comparable environmental impact data on cleaner technologies, as this will be an impossible task. The aim has been to develop <u>a</u> concept to constitute a sound framework for further development in the field.
- Specific development of comparable environmental impact data on cleaner technologies inside specific branches of trade are assumed to be dealt with as future projects. Such projects may be initiated by EU or national authorities and performed in close co-operation with representatives of the specific trades and other relevant organisations, but may also be initiated and performed by the trade organisations themselves.

  A framework for future projects is suggested in the form of

  - a proposal for a common, general set of comparable environmental impact data/indicators to constitute a minimum data set, which encompasses use of resources and environmental effects of relevance on national, regional and global levels (Chapter 4). For specific purposes this data set should be supplemented by data of particular relevance to the branch of trade in question, the prevailing local conditions, etc., but should in itself be able to serve as a common platform on the national levels and EU level for evaluations of environmental performance.
  - a proposal for a systematic working approach and overall methodology for the development of comparable environmental impact data on cleaner technologies inside specific branches of trade (Chapter 5). This proposal will be exemplified by tests of the methodology in three specific trades (Chapter 6).
- The concept for Comparable Environmental Impact Data on Cleaner Technologies (CEIDOCT) developed in this project must be as simple and operational as possible to be able to achieve a widespread use in practice. This demand is considered extremely important and has been given a very high priority in the project. The demand has been met by developing a hierarchy of datasets/indicators with very few, aggregated data/indicators in the top of the hierarchy and more detailed datasets at lower levels.

  This implies that the "scientific correctness" of the concept developed may be affected - in other words - the resulting concept will be a pragmatic compromise between "simplicity" and "professional correctness" at the top of the indicator hierarchy. On the other hand - on the detailed levels of the hierarchy the professional traditions from international LCA work and similar activities can - and should - be maintained.

These prerequisites have been regarded as key presumptions in the project, which has focused on development of the 2 upper levels - levels 0 and 1 - of CEIDOCT/Environmental Performance Indicators (EPIs).

2.2 How does CEIDOCT Compare with EPIs and LCA Three Elements of the Same Issue

It has already been stated that the concept developed in this project is of a rather general nature and therefore closely linked to many other basic problems of environmental impact assessments, e.g. environmental audits, product life cycle assessments, environmental labelling of products, environmental statements of companies, etc.

Environmental Performance Evaluation (EPE)

A very relevant and useful concept to relate to is the concept of Environmental Performance Evaluation (EPE) as it is used and defined in the ISO work on standardisation inside the field of Environmental Management.[1] Here EPE is defined as: *"A process to select environmental indicators and to measure, analyse, assess, report and communicate an organisation's environmental performance against its environmental performance criteria"*: This task will generally be accomplished by the use of a set of Environmental Performance Indicators (EPIs) agreed upon as a useful way to measure Environmental Performance (EP) for the company in question.

In the ISO draft standard environmental indicators are defined as: *"A specific expression that provides information about an organisation's environmental performance [2] efforts to influence that performance, or the condition of the environment.* [3]*"*

CEIDOCT is a common set of EPIs for many purposes

The basic, present philosophy regarding EPE is that any company chooses its own EPIs based on an evaluation of its environmental aspects and specific environmental conditions. CEIDOCT could thus be considered as a proposal for a common, minimal set of EPIs to be used on national and EU/international levels for cleaner technology EPE and other similar purposes. CEIDOCT is thus equivalent to a “common set of EPIs on national and international level”.

Basic EPE-principles

The concepts of EPE and sets of EPIs have been elaborated upon in the ISO sub-committee on EPE[1] and in development of a general EPE tool[4] in Denmark. These references have been used in the present project.

Having made the parallel between CEIDOCT and EPIs, some of the basic principles of EPE, as developed during the ISO work[1], may be transferred to the present project. These basic principles are stated as follows:

- EPIs should be developed inside specific branches of trade, but based on a common methodology framework.
- In developing EPIs inside specific trades, the use of *"reference technologies"* is recommended. A *reference technology* is a well-known and widespread process technology inside the trade in question, which is thoroughly documented concerning its environmental aspects. Each branch of trade should thus choose a set of relevant reference technologies as a basis for developing EPIs on branch level. Individual companies can use their own present technology as the reference technology for practical purposes.

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[1] ISO/CD 14031: Environmental Management - Environmental Performance Evaluation - Guidelines Committee Draft ISO/TC 207 / SC4N207.

[2] Environmental Performance Indicators (EPIs) are a type of environmental indicators used in relation to the organisation's management and operations.

[3] Environmental Condition Indicators (ECIs) are a type of environmental indicators used to describe the local, regional/national or global condition of the environment in relation to the organisation.

[4] Development of a general tool for Environmental Performance Evaluation (EPE) of small and medium sized enterprises. For the Danish Environmental Protection Agency via Danish Society of Consulting Engineers. 1994-95.

- EPIs in general - and thus also the concept developed in the present project - must be based on a *life cycle perspective*. This does not mean that complete LCAs are always necessary, but implies that a new - and presumably cleaner - production technology should *not* be evaluated based on its Environmental Performance in the production stage only.

  A new production technology often influences EP in other product life cycle stages, e.g. manufacture of raw materials, product use or product disposal. CEIDOCT must therefore include data concerning all important changes of environmental characteristics throughout the product life cycle compared to the relevant reference technology.

  This demand does not imply a full LCA of a new technology, but a Δ-LCA related to the reference technology; Δ-LCA implying that only environmentally different elements of the two technologies are considered. The reference technologies should therefore be described and documented in a full life cycle perspective covering all life cycle stages to facilitate the use of Δ-LCAs.

Other methodologies

In addition to the CEIDOCT relations to the EPE/EPI concepts and other references mentioned in this Chapter, the approach and methodology of the present project have been based on references stated in Chapter 3.

CEIDOCT as a common umbrella for a variety of detailed environmental evaluation concepts.

It is specifically noted that a number of methods and concepts have been or are developed internationally to carry out environmental assessments, LCAs etc. at rather detailed levels of documentation. Such methods should generally all be able to provide inputs to the CEIDOCT-concept, elaborated in this project. Thus, the CEIDOCT/EPI concept could constitute a possible common umbrella for all such detailed assessment methods.

The EDIP-project

In Denmark, special emphasis is put on the detailed assessment method of the EDIP-project[5] (*E*nvironmental *D*esign of *I*ndustrial *P*roducts), ref. Chapter 3, which has been developed to an operational level as a detailed assessment method. Other data formats like the SPOLD format could be used. The EDIP is based on international standards for data formats, and has been used as the general methodology basis for detailed environmental assessments in the present project and thus also been applied in the examples for practical purposes (Chapter 6).

2.3 The CEIDOCT/EPI Concept the Four Focus Areas

The main challenge of the present project has been to identify the common, general set of CEIDOCT or EPIs on a high level of aggregation.

Previous EPI-approaches - impacts or inputs/outputs

Numerous approaches to common sets of EPIs on various aggregation levels have been made in many contexts over the last decade, ref. Chapter 3. These approaches may be grouped into two main categories as follows:

- Development of common indicators via *impacts*, e.g. structures in environmental effects, health effects and “resource effects”.
- Development of common indicators via *inputs/outputs* or *environmental pressures*, e.g. structured in air emissions, wastewater effluents, solid and hazardous waste production, consumption of raw materials and semi-manufactures, etc.

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[5] Wenzel, H., Hauschild, M., Rasmussen, E.: “Environmental assessment of products” Danish Environmental Protection Agency and Confederation of Danish Industry. (In Danish, the English version is published by Chapmann and Hall, spring 1997).

The impact approach

The *impact* approach is easy to make general on a professional environmental basis, but almost impossible to make operational on company and process level and at high levels of aggregation (few EPIs). It is necessary as a basis, however, as the choice of environmental indicators must always be based on assessments of impacts.

The input/output approach

The *input/output* approach is a good basis for developing operational concepts in individual companies and organisations, but is very difficult to make general in a useful way. Either it becomes too general to be of any significant value, or it becomes extremely detailed and thus unoperational in practice.

The combined approach!

It is generally necessary to combine the impact approach and the input/output approach to develop EPIs in a company or production facility. The input/output approach is used in the inventory of potential environmental impacts and the impact approach in the assessment of the potential impacts and the choice of focus areas for the company action plan.

- but on a large scale!

This combined approach, however, results in company individual focus areas and action plans and thus not necessarily in any comparable EPIs or other common data sets. To accomplish this, the combined approach has to be contemplated on a large scale, e.g. national, regional/EU or global scale. This way a minimal set of common, general EPIs may be generated.

Four focus areas for initiatives - integrated product policy in Denmark

Such an approach has been applied in the development of a concept for an integrated product policy in Denmark[6]. The aim has been to identify focus areas of critical importance to secure sufficient "ecological space" on a global scale in the coming 3-5 decades. The focus areas identified have been stated as follows:

M) Consumption of mineral resources, excluding energy purposes (*M*ineral resources)

E) Consumption of fossil fuels (*E*nergy)

C) Consumption and dispersion of chemicals hazardous to the environment and human health (*C*hemicals)

B) Consumption of biological resources, including as well biological production as its basis, biodiversity and land use (*B*iological resources).

Why the four focus areas?

These four focus areas (M, E, C, B) are suggested as the basis for development of general EPIs for the following reasons:

- They are rather general, but also sufficiently specific to be operational and action-oriented in real-life situations.
- They are intended to be strategic and future oriented and not mainly professional/scientific and historically based as is usually the case.
- They include the majority of important issues in existing international conventions, regulations, agendas, etc.
- They are based on regional and global environmental impact considerations and thus constitute important priorities all over the world.
- They can be developed into further details on many levels and thus be adjusted to virtually any regional, local and trade-specific conditions.

[6] Danish EPA, Proposal for an Integrated Product Policy in Denmark, 1996.

MECB and the MECO principles of EDIP

Further, the proposed focus areas M, E, C, B are very similar to the focus areas M, E, C, O (*M*aterials, *E*nergy, *C*hemicals, *O*thers) as applied in the EDIP-project to arrange and simplify the results of LCAs. The Dutch Ecodesign Manual uses a similar simple matrix of M(aterials) E(nergy) and T(oxics) as presented briefly in Chapter 3.4. The "MECO" principle has already proven to be very useful and operational in practice and is built on the fact that the focus areas M, E, C and O each represent categories of resource consumption and environmental impacts that are to some degree complementary: This is illustrated in Table 3.1 in Chapter 3.4.

"Biological resources consumption" to be integrated in LCA methodology

The four focus areas, MECB, proposed for the CEIDOCT concept are thus similar to the MECO except for the fact that "Others" has been replaced by "Biological resources consumption", including the biodiversity issue - a focus area that is not generally made operational in LCAs, but nevertheless is of utmost importance in assessments of environmental impacts in general. This issue has been given high priority in Agenda 21 of the Rio Summit 1992; however, this fact has not yet been reflected in the methodology developments of environmental assessments including LCAs. It is therefore an important recommendation of the present project to develop "Biological resources consumption" as an integrated part of normal LCA methodologies.

Generally, it is not difficult to develop the four focus areas, MECB, into a large number of detailed indicators, e.g. one or several indicators per individual chemical substance applied in a product life cycle. This is, however, still not very useful as a general approach.

The CEIDOCT-approach

The important task is therefore to develop one or a few relevant and meaningful aggregated indicators inside each of the four focus areas. A lot of basis work exists to build upon regarding the focus areas M, E and C, whereas the biological resource-issue must be addressed in a more in-depth fashion. It is, however, also very important that the aggregated, upper level indicators are consistent with indicators at the lower level, so that aggregation can take place up through the levels in a simple and straightforward fashion. It goes without saying, however, that information will be lost in aggregation from level 2 to level 0 - this is part of the price for the simplicity at level 0. In Chapter 4.1 an overview of the environmental effects included and the important effects excluded at level 0 is given.

CEIDOCT: Indicators at levels 0 and 1

Within the four focus areas, MECB, it has been attempted to develop proposals for four upper-level indicators (called level 0) and 10-12 indicators at the next level (level 1). To the extent possible also a methodology for a pragmatic and approximate quantitative assessment of these indicators has been outlined at a preliminary stage. Such a top-down approach for a preliminary quantification of the upper level indicators can make it possible to identify the priority areas where detailed assessments are necessary/important, thus making it unnecessary always to start on a rather detailed assessment level for all environmental aspects. The CEIDOCT concept is schematically illustrated in Fig. 2.1:

The CEIDOCT concept demands normalisation of environmental impact data

Development of the CEIDOCT concept into a common set of general indicators requires agreement on a common routine for normalisation of environmental impact data from LCAs. This way all compute the level 0 and level 1 indicators in the same way and the indicators can be interrelated. A possible routine for such normalisation has been used, e.g. in the EDIP-project through the use of "person equivalents" for all environmental impacts.

Normalisation inside specific branches of trade may be developed by units of typical products or functional units as a reference, equivalent to the normal procedures for LCA methodologies.

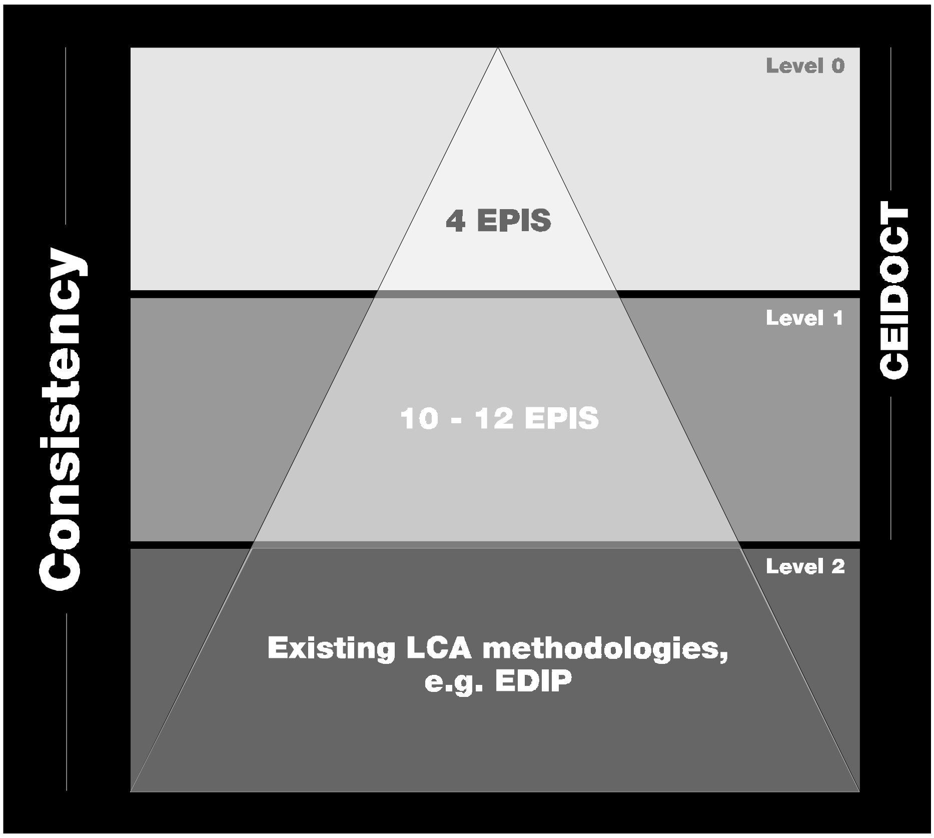

Figure 2.1: *Illustration of the CEIDOCT concept and relation to existing LCA methodologies as a basis*

CEIDOCT as a "common language"

If a common normalisation routine can be obtained, the CEIDOCT concept may constitute a "common language" or a "common yard stick" in the environmental field. This could be of importance to the discussions of environmental priorities and weightings at EU-level both inside the cleaner technology field and inside the environmental field in general. The prioritising and weighting issues are not solved with the CEIDOCT-concept, but will be facilitated to a certain degree. Consequently, this project does not contain weighting recommendations for the CEIDOCT indicators, although it is considered natural on a general level to assign equal weightings to the indicators at level 0.

Data acquisition problems

Data quality requirements must be addressed when carrying out an LCA. These requirements are defined to enable goals and scope of an LCA to be met.

Data requirements are made to assure appropriate coverage in time, geography and technology as well as precision, completeness and representation of the data. These issues and more, as required in the standards for LCA (i.e. ISO/FDIS 14040), are as relevant to the CEIDOCT concept as to LCAs.

Therefore, the general data acquisition problems from the LCA field of work will also hamper the development and use of the CEIDOCT concept at levels 0 and 1. From experience, these data acquisition problems are especially serious regarding production, use and evaluation of chemical substances.

2.4 Potential Use of a CEIDOCT/EPI Concept

EPIs for decision support

EPIs may be used for many different detailed purposes on various levels of society, but the basic purpose behind use of EPIs is always to provide an overview of environmental aspects of a given activity to serve as decision support regarding initiatives towards this activity.

EPIs should be regularly evaluated

It is very important to observe that any set of EPIs for any purpose should always be re-evaluated regularly. This is necessary because changes take place all the time. New environmental priorities occur from environmental science, new policy initiatives are taken nationally or regionally, and technology and local conditions also keep changing. So even the most well-argued set of EPIs is never a pillow to sleep on!

EPIs for local purposes

EPIs at levels 1 and 2 may be developed by companies, organisations and local communities. EPIs at these levels may also be relevant to national governments to a certain extent. EPIs at such lower levels represent a choice of environmental parameters considered important for the body that defines them today and in a foreseeable future. They therefore represent environmental aspects, which the body finds it important to deal with. The EPIs may be seen as important for e.g. image, successful performance, records etc. or because they are considered of environmental importance. They thus constitute a decision support basis in relation to development initiatives inside the body in question.

EPIs in branches of trade - for benchmarking or as a common frame of reference

Companies within the same branch of trade, local communities etc. may apply the same set of EPIs on a detailed level - or partly the same set. When this is done by several bodies, these common EPIs may be used for benchmarking or just as a common frame of reference for environmental performance records and reporting. This may be an advantage, especially if the development of the EPIs and the necessary framework of documentation and strategy considerations constitutes a too complicated and expensive task to handle for the individual body.

The value of a common set of EPIs/CEIDOCT

Trade-specific EPIs on a detailed level is developed today for any company or any branch of trade, but this produces a rather confusing overall picture. With the CEIDOCT concept as a framework of EPIs at level 0 and level 1, all sets of EPIs might be developed based on this framework and thus use a common “language” or “yard stick”, facilitating reporting and communication in general in the environmental field.

EPIs for strategic and political purposes

The CEIDOCT/EPIs at level 0 and partly at level 1 are suggested for a common reporting format on environmental performance in individual trades, but also between various trades and in society as a whole. They could to a certain extent serve as decision support at strategic level for companies and branches of trade and at strategic and political level for local and national governments and international organisations and co-operation bodies.

EPIs and cleaner technologies at company and government levels

In a cleaner technology perspective the EPIs at levels 0 and 1 could be applied by companies for a first preliminary assessment of the environmental performance of a change in technology. This assessment could constitute the decision basis for a more comprehensive development project including LCAs, and thus define the objectives and ambition levels of such a project. The general nature of the focus areas opens the possibility for national and regional governments to use the focus areas as a standard format for company environmental reporting and evaluation of national cleaner technology and environmental management initiatives and programmes.

Preconditions for successful development of CEIDOCT/EPIs

Important preconditions to achieve these advantages will be

1) Tools for environmental assessments, LCAs and development of lower level EPIs become more operational and more widely used than they are today. They will be based on common and internationally accepted principles and guidelines.

2) A set of CEIDOCT/EPIs at levels 0 and 1 is defined which may serve as a common umbrella for these more detailed assessment methods.

3) The upper-level CEIDOCT/EPIs may be assessed quantitatively on a preliminary level without always going through a detailed assessment process first.

1) is in rapid development these years. A proposal for 2) is given in Chapter 4 of this report and at the same time some possibilities to fulfil 3). Further, the development of more detailed tools with still more extensive databases also provides an important future potential for rapid assessments; this potential already exists to a considerable extent e.g. with the EDIP tools and database.

3. THE CURRENT STATUS OF CONCEPTS RELEVANT FOR CLEANER TECHNOLOGY ASSESSMENT AT EUROPEAN LEVEL

Concepts and/or methods for assessment of cleaner technology (cleaner production, waste minimisation etc.) are very scarce, so other areas of relevance have been studied as well.

Two areas in particular are mentioned here;

1. Environmental Performance Indicators at corporate, national and international/EU levels and
2. LCA developed as an internationally accepted methodology.

Cleaner technology initiatives are mentioned and available data on evaluation are described.

Environmental Performance Indicators

'Green accounting' and development of Environmental Performance Indicators is being widely accepted as a means of keeping account of the development towards a more sustainable society. Integration of environmental issues into the accounts of companies or states has been debated and different models have appeared at national and corporate level.

3.1 International Initiatives

International initiatives

The following initiatives have been identified:

UN and the World Bank have published a Handbook for a Satellite System for Integrated Environmental and Economic Accounting (SEEA) in 1993.

OECD has developed a 'Pressure-State-Response' system, which is gradually being accepted also by the EU[7]. In this concept 'pressures' are pressures on the environment from human activities, e.g. emissions of VOC, CO_2 etc., 'state' refers to the state of the environment, i.e. the resulting quality of the environment and 'response' are the answers from society to solve the problems (e.g. energy-saving measures, development of pollution prevention concepts and options, cleaner technologies, etc.).

The Dobrís Assessment[7] published by the *EEA* mentions that the Commission is taking initiatives to focus on chemicals and their fate and toxicity in the environment. In the assessment (Chapt.17) it is noted that: The general lack of toxicological information should be seen against the fact that almost 80 per cent of hazardous waste comes from the chemical industries. A number of chemical substances have attracted a great deal of attention over the past few decades and monitoring programmes are being carried out. The properties which are of concern are low degradability (persistence), carcinogenicity, possible infertility effects, neurotoxic effects, respiratory allergens and eutrophication effects (from nutrients). Recently the occurrence of pesticides and their residues in the groundwater has caused great concern (in Denmark and other countries).

The European Community sees chemicals as one of the prominent environmental problems. Council Regulation 93/793/EEC set up a long-term strategy to identify and control risks from some existing chemicals. This is to be reached through a three-step approach (Dobris Assessment[7], Chapt. 38):

1. The initial phase (June 1993-June 1994) included the assessment of approximately 1800 chemicals produced or imported in amounts above 1000 tonnes per year (high volume chemicals). Fewer data are required for chemicals manufactured or imported in quantities between 100 and 1000 tonnes per year.

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[7] Stanners, D. and Bourdeau, P. (ed.): 'Europe's Environment', The Dobrís Assessment, European Environmental Agency, 1995

2. Phase two, which began in 1994, aims to publish at regular intervals a priority list of substances 'requiring immediate attention because of their potential effects on human health and the environment' involving a co-operative procedure among the Member States. Special attention will be given to substances having chronic effects, those toxic to reproduction and mutagens.
3. The third step includes risk assessment and the development of a control strategy. The priority chemicals have been divided between Member States in order to perform individual risk assessment.

As part of the chemical risk control strategy the aim is to strengthen environmental research with the aim of improving, among other things: the understanding of processes whereby chemicals are distributed between the various compartments, their fate once there, how they affect the structure and functioning of ecosystems, the search for ways to prevent pollution effects and to restore damaged ecosystems, etc.

EU and Eurostat

EU has in the Fifth Environmental Action Programme taken several initiatives as regards environmental indicators. Some of those are in preparation but they are described because they are relevant in this context:

- A common European framework and reference for accounting for all activities of the EU in the area of green accounting; a Handbook on a European System for Integrated Environmental and Economic Accounting (ESEA), which will be comparable to the UN handbook but will take into account European specificities and already existing activities[8].
- A system of integrating indices for economic performance and environmental pressure is being developed to form a European System of Integrated Economic and Environmental Indices (ESI), with the aim of providing comparable systems of integrated environmental and economic indices in the EU.
- A European System of Environmental Pressure Indices (ESEPI)[9] is being developed. Eurostat is responsible for this programme and the intention is to collect indicators, set priorities and establish sets of European Weighting Coefficients for the aggregation of such indicators into environmental pressure indices. The process is carried out in two steps: 1) collecting suggestions for indicators and selection of indicators and 2) weighting the indicators.

  At this stage Eurostat operates with directly expressed indicators within the following ten policy areas:

  - Resource depletion
  - Water pollution and water resources
  - Waste (which includes life cycle assessment)
  - Climate Change
  - Air pollution and acidification
  - Ozone layer depletion (was omitted in the first round since it is heavily regulated)
  - Dispersion of toxins
  - Loss of biodiversity
  - Marine environment and coastal zones
  - Urban problems, noise and odours

Water pollution is placed in a specific group and care should be taken to avoid calculation of the same effects here and as regards the marine environment, acidification and dispersion of toxins. Distribution of the effects between the themes air pollution and dispersion of toxins should also be considered carefully. How intra-theme weighting is taken care of is not yet published.

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[8] 'Sustainable Accounting' - support document for preparation of the conference 'Taking Nature into Account' Brussels 31 May - 1 June 1995.

[9] Eurostat “Pressure Indices Project”, second expert survey. Long lists of indices within policy areas.

The ISO/CD 14031 draft standard on Environmental Performance Evaluation includes suggestions for Environmental Performance Indicators. The standards include suggestions for deciding when it will be appropriate to select indicators that are: absolute, relative, normalised/indexed, qualitative, aggregated or weighted. It is recommended to use care when aggregating and weighting data to ensure verifiability, consistency, comparability and understanding.

Examples of different types of indicators are shown, corresponding to identified significant environmental aspects of a particular industry.

3.2 National Initiatives

Environmental Policy Performance Indicators

The *Netherlands* has a system of Environmental Policy Performance Indicators within 7 themes and goals set for each of these. The themes are:

- climate change
- stratospheric ozone depletion
- acidification
- eutrophication
- dispersion of toxic substances
- disposal of solid waste
- disturbance of local environments

From these themes, seven target groups are singled out and within each target group the main polluting agents responsible for environmental damage are identified. The target groups are: agriculture, traffic and transport, industry, the energy sector, refineries, building and construction, and consumers. Several agents belong to more than one theme, so intra-theme weighting factors are set. The EPI is then expressed as closeness to goal, i.e. theme equivalent/goal for theme equivalent.

A relatively new system in the Netherlands is NAMEA, which aims at integrating indicators into the National Accounting Matrix including Environmental Accounts.

This system does only to a limited degree take the state of the environment into account.

France has a system of National Patrimony Accounts which includes economic, ecological and social environments in a multi-level data system. In this system raw statistics and data summaries are used on lower levels and aggregated indices of welfare are used on the highest level.

Environmental-Economic Accounting

Germany has started a system of Environmental-Economic Accounting, for which the German Statistical Office in Wiesbaden is responsible. In this system the environmental themes included are:

- material and energy flow accounts, raw materials, consumption and polluter structure
- use of land and space
- state of the environment - indicators
- environmental protection measures
- avoidance/prevention costs for attaining a (sustainable) standard

The German system includes provision for the UN system SEEA.

State-of-the-environment indicators

In *Denmark* the Ministry of the Environment and Energy each year since 1994 has published a booklet on environmental indicators for the country (in Danish).The booklet covers the following areas (1995)[10]:

- Climate change

[10] Environmental Indicators,"Miljøindikatorer" Miljøministeriet, 1995, in Danish

- The ozone layer
- Acidification
- Urban problems
- Landscape
- Drinking water/groundwater
- The Sea

The policy areas used correspond with the ones chosen by Eurostat, but a slightly different angle is chosen since the aim is to protect the state of the environment. The following indicators are used:

- For the first three policy areas the indicators used are total emitted tonnes per year of the relevant substances and for some of the effects also deposition per hectare.
- Urban problems are evaluated for a variety of areas. The percentage of green areas in the cities is stated, amounts of municipal waste as tonnes per year and wastewater as the percentage treated (by different methods). Traffic is shown as indexed development and air pollution as measured concentrations of relevant agents.
- Landscape is evaluated in terms of areas allocated for different purposes. For each type of area environmental effects on species are expressed as a decrease in the number of hunted animals or counts of indicator species.
- Groundwater is evaluated in terms of total amounts used and pollution of groundwater is compared with standards.
- Indicators for the sea are expressed as total emitted amounts of eutrophicating substances to the sea and coastal areas, effects are expressed as oxygen contents, etc. compared with goals. The effects on fished species or counts of indicator species are used.

3.3 Industry Initiatives

Environmental Performance Indicators

Environmental Performance Indicators (EPIs) are used for environmental reporting and several examples can be seen from the large industries' environmental reports[11]. Up till now the environmental reports seen have been mainly from large international groups and from industries, with a verified environmental management system, mainly the Environmental Management and Auditing Scheme, which requires published environmental reports.

In Denmark the law on 'green accounting' requires a number of listed industries to produce an environmental report each year. When presenting the environmental pressures from the industry it is allowed to use EPIs instead of actual physical emissions. No specific method of presentation is required but the major amounts of pollutants must be stated as far as they are a part of production processes, are emitted to air, water and soil, are part of the products or part of the waste. Information on chemicals/pollutants can be collected into groups determined e.g. by risk - this could be done according to classification for labelling.

Environmental Indicators for consumption of raw materials

The EU project 'Environmental Indicators for the Sustainable Utilisation of Raw Materials'[12] includes a discussion of development of indicators at company level. The background is that materials are becoming more scarce. The project attempts to define what is 'sustainable use of materials'. It evaluates which indicators could be useful to describe interactions between the company, the economy and the environment. It attempts to make the most of data companies already have (or can easily collect) and to ensure consistency between internal and external reporting.

Three elements of sustainability in the use of materials are identified:

- Minimising environmental impacts that are associated with the use of materials, at all stages in their lifecycles, especially long-term, local and irreversible impacts.

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[11] "Environmental Performance Indicators in Industry" , European Green Table, August 1993.

- Developing less material-intensive products and services - 'doing more with less'.
- Closing material loops - moving from a linear flow of materials from cradle to grave to a system in which they circulate with less dissipation and losses.

Indicators are suggested for each of these elements, but the indicators suggested are not grouped according to any overall idea of areas important to ensure a sustainable development (except the elements mentioned above), which are relevant for sustainable production.

3.4 Tools for Lifecycle Assessments

LCA tools

The Danish EDIP method used in the present project is supported by the Danish EPA, the Ministry of Energy and Environment and the Association of Danish Industries. EDIP is an acronym for Environmental Design of Industrial Products[5]. The EDIP method is a handbook and a computer programme/package aimed at product development with the use of LCA. One of the possible applications of EDIP is environmental evaluation of product and production concepts and one of these could be cleaner technology evaluation. The method is not explicit in explaining how this can be done and the concept developed in the CEIDOCT project is an illustration of this application as well as a further development of the method.

The EDIP method is in agreement with the guidelines outlined by SETAC[13]. The method is made operational with the aim of having professionals making conscious choices along the way and leaving any weighting to the last step in order to keep results as transparent as possible.

Priority areas in the EDIP method are divided into groups of environmental effects and resources consumption:

Environmental Effects

- Global warming
- Acidification
- Photochemical ozone formation
- Human toxicity
- Ecotoxicity
- Persistent toxicity
- Nutrient enrichment (eutrophication)
- Nuclear waste
- Slag and ashes
- Bulk waste

Resources Consumption

- Crude oil
- Coal
- Natural gas
- Brown coal
- Water
- Single minerals (Fe, Mn,...)

For specific purposes in EDIP the indicators above are divided into four groups as shown in the Figure 3.1:

[12] Environmental Resources Management:'Establishing Environmental Indicators for the Sustainable Utilisation of Raw Materials' for European Commission Directorate-General for Industry, June 1996

[13] SETAC-Europe (1992): Life-Cycle Assessment. SETAC-Europe, Brussels, Belgium

Figure 3.1 *Assessment parameters in LCA, covered by M, E, C and O*[5]

	Environmental Impacts	Resource consumption	Impacts on the working environment
Materials	Bulk waste Slag and ashes	Resources used in materials Mainly reversible consumption	
Energy	Global warming Photochemical ozone formation Acidification Nutrient enrichment Bulk waste Slag and ashes Nuclear waste	Energy carriers, especially fossil resources and wood. Mainly irreversible consumption.	
Chemicals	Ozone depletion Photochemical ozone formation Persistent toxicity Ecotoxicity Human toxicity Hazardous waste	Resources used in the production of chemicals	Impacts related to chemical exposure: cancer, damage to the reproductive system, allergy and damage to the nervous system
Others			Monotonous repetitive work, noise, work accidents

The Dutch Eco-design manual uses the concept of a MET Matrix as a way of structuring the environmental analysis of a product. The letters MET stand for *M*aterial cycle, *E*nergy use and *T*oxic emissions. The power of the matrix is that it can be used as an aid to a project team to focus on all stages of the project lifecycle and on the simplified environmental aspects linked to the lifecycle stages for the particular product. This is also referred to in the PROMISE manual.

In the Dutch application the materials are input and output of *materials* that are exhaustible or create a lot of emission during production (examples are copper, lead and zinc), incompatible materials and inefficient use or non-reuse of material in all stages of the product lifecycle.

Input and output of *energy* not only include energy from production itself, but also from transport, operation and maintenance as well. No division is made between the energy sources used.

Toxic emissions cover identified toxic emissions in all stages of the lifecycle, emitted to land, water and air. Identification of toxics is done for chemicals used at all stages of the lifecycle.

Another guideline is the Nordic Guidelines on Life-Cycle Assessment[14] which also is in accordance with the SETAC principles. This guideline aims to develop a Code of Practice for LCA built on Nordic Consensus and to provide industry and other practitioners with a set of guidelines for LCA, mainly 'key issue identification' LCAs, which might be used when results are to be communicated to authorities. The conclusions of technical reports in general are that shortcuts are rarely possible without a change in results. This means that one should be careful if simplifying data in an LCA (use of average data, leaving out data etc.), but it is allowed, provided the data are transparent and the consequence of shortcuts are analysed.

3.5 Cleaner Technology Initiatives

Cleaner Technology in the Member States

Cleaner Technology Strategies in EU Member States have been described in a report to the Commission DG XI[15]. Cleaner Technology principles are included in command and control legislative measures still in only a few countries. The cleaner technology concept is included in several policy documents in the EU Member States, but actual enforcement is very weak.

The promotion of the cleaner technology concept in general seemed to be executed by voluntary incentives, like grant schemes, subsidies and information activities rather than compulsory incentives like approval schemes and financial instruments, e.g. taxes.

[14] 'Nordic Guidelines on Life-Cycle Assessment', Nordic Council of Ministers, Nord 1995:20.

[15] RENDAN, Krüger and tme, 'Cleaner Technology Strategies in EU-Member States', European Commission, DG XI, 1994.

Education, training programmes and information on the topic is widespread. In countries like Denmark, the Netherlands, the United Kingdom and Belgium demonstration projects have been carried out, with possibilities to get consultancy assistance. More countries are starting up demonstration programmes, e.g. the Irish EPA is launching a programme for 1997-1998. Of the above mentioned, Denmark was the first to actually carry out an evaluation of the cleaner technology programme[16].

Evaluation of the Danish programme

The evaluation of the Danish programme included conclusions, which to some degree resulted in the present project. Some of the conclusions of interest for this project were that the environmental effects of cleaner technologies have been estimated relatively as well as absolutely. It was found that pollution reductions per unit produced were substantial, while the absolute outcome varied from sector to sector. One result was that the effects obtained in certain sectors with the introduction of cleaner technologies were of a size to ensure quick compliance with the voluntary agreements on VOCs.

It was found necessary, in order to better verify the effects of cleaner technologies, to get better and more systematic environmental data. The documentation of achieved environmental results need improvement. It was concluded: 'that the increased interest for environmental performance reviews underline the necessity to develop key environmental parameters, which can be used also in a broader context.'

In the report on Cleaner Technology Strategies[15] a definition of cleaner technology has been suggested to the Commission:

'Cleaner technology is the conceptual and procedural approach to the development, purchase and use of processes and products preventing and reducing internal and external environmental problems throughout the product life cycle by integrating options to:

- minimise amounts and hazards of gaseous, liquid and solid wastes,
- minimise accidental risks from chemicals and processes,
- minimise consumption of raw materials, water and energy, and
- substitute chemicals and processes less hazardous to human and ecological health.'

This definition conforms with the ideas behind the CEIDOCT project and largely with the definition by the Danish EPA[16].

Conclusions of relevance for the CEIDOCT concept

It can be concluded that cleaner technology assessment tools have not yet been developed. It would in particular be of interest to have tools which could also be used in a broader context. Attempts have been made at EU level to define cleaner technology in a lifecycle perspective, and to define sustainable use of materials in a way which involves the use of cleaner technologies.

Assessment tools and indicators have been developed within areas in close connection with the concept of cleaner technologies, e.g. LCAs and EIAs. Indicators are being developed at national and international level for control and presentation of the pressures on and the state of the environment.

From the indicators listed in this Chapter it can be seen that there is considerable international consensus on the indicators used as regards global and regional problems. More discrepancy is seen with indicators for local effects.

The international priority areas, the growing tendency to look at cleaner technologies in a lifecycle perspective and the recognised need 'to do more with less' using materials in a sustainable way are used as basis for the development of the CEIDOCT indicators suggested in this project.

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[16] Information from the Danish EPA no. 5/1995, 'Evaluation of the achievements reached with cleaner technology, 1987-1992', In Danish, with English summary.

4. IDENTIFICATION OF ENVIRONMENTAL PERFORMANCE INDICATORS TO BE USED FOR COMPARISON OF CLEANER TECHNOLOGIES

4.1 Overview of the Four Focus Areas

The areas of activity in industrial society considered to create the most critical environmental impacts in the future are identified by:

- roughly assessing and evaluating the existing, available knowledge of today's environmental impacts on a global scale and their causes, combined with
- the scenario of global economic growth during the coming decades. This is based on present growth rates in South East Asia especially and various forecasts, implying a possible growth factor of 6-10 in global resource consumption and environmental impacts in the next century.

The result of this combination is the well-known "factor 10 challenge": it is necessary to increase the environmental performance of all activities in industrial society by a factor of 10 during the coming decades in order to obtain sustainable development on a global scale. Further, the combination indicates certain focus areas as being especially important in order to preserve the "environmental space" on Earth. These focus areas may be expressed in many different ways. In the present context it has - for various reasons - been chosen to present four focus areas as follows:

Four focus areas on a global scale

M) Consumption of mineral resources, excluding energy purposes (*M*ineral resources)

E) Consumption of fossil fuels (*E*nergy)

C) Consumption and dispersion of chemicals hazardous to the environment and human health (*C*hemicals)

B) Consumption of biological resources, including biological production as its basis, biodi versity and land use (*B*iological resources).

The four focus areas above do not represent individual environmental effects; rather, they represent a proposal for key elements in an overall global environmental programme. Each of the four focus areas represents important activities of industrial society associated with a number of important effects on environment and health.

The four focus areas are proposed, because major reductions in impact on environment and health will be accomplished if these areas are addressed in an efficient and targeted manner all over the world. In the following, each of the focus areas are briefly discussed and reasoned in a global strategic perspective.

Exploitation of mineral resources

No acute problems, but future lacks to be expected

For the time being consumption of mineral resources does not seem as important and acute as the next three focus areas. This is basically because no important lacks are currently present in mineral resources. On the other hand, with the growth rates of especially South East Asia, a very heavy draw on the world’s mineral resources will soon be the result. This will again imply a large increase in environmental problems, as the exploitation of mineral resources generally consists of very heavy and energy-consuming production processes. Moreover, the unexploited resources become still less rich, which will increase the energy use and environmental problems per ton of mineral resources produced.

Exploitation of mineral resources causes several different environmental effects. However, in the present context, the effects of energy consumption are dealt with in Section 4.3, toxic elements in Section 4.4 and deterioration of habitats in Section 4.5. Therefore, this focus area is mainly considered as the use of resources and the direct effects thereof.

Consumption of fossil fuels

Fossil fuel reserves

Fossil fuels today contribute to 75% of the total energy consumption on a global scale. Known resources are sufficient for a period of about 50 years ahead, and known coal reserves for a period of 200-300 years ahead. This is, however, provided that the consumption rate stays the same as it is now. With the growth rates in South East Asia, this can definitely not be expected, so even though considerable supplementary reserves may still be found, it must be assumed that the reserves will terminate in a considerably shorter time than normally indicated[17]. Moreover, the combustion of fossil fuels is contributing heavily to a number of the most important effects measured in local, regional and global scale.

In the CEIDOCT concept, all environmental effects of energy consumption are represented under this focus area. The main effects are related to fossil fuel combustion and must be calculated separately at aggregated levels, from e.g. chemicals in cases where the same types of effect occur for both focus areas.

Consumption and dispersion of substances hazardous to the environment and human health

This focus area deals with dispersion of chemicals, e.g. dispersions of toxic heavy metals and numerous chemicals alien to the environment resulting from industrial societies' activities. This is a complex area involving chemicals, which cause a number of damages to the environment and human health today and there is a significant probability that these damages will increase in the future.

Scientific proof is not feasible

The Danish EPA in its recent report on chemicals has stated that it is very important to cut down as much as possible on the consumption and dispersion of toxic chemicals and also on the number of such chemicals in use. The problem is so complex that it is not possible to establish scientific evidence behind every element of such an initiative. This implies that the principle of caution must be applied if an efficient action programme for this focus area is to be implemented.

Successful experiences exist

In the Danish EPA's assessment of cleaner technologies[16] it is stated that it has often been possible to substitute toxic chemicals with less dangerous ones or even shift to production technologies with a much lower application of chemical substances. Similar experiences have been made all over the world.

In the present context, all effects of hazardous substances to the environment and health are related to this focus area, except for the effects from combustion products from energy use, which are calculated separately at aggregated levels as stated in Section 4.3 and represented in focus area E.

Toxic effects are the main effect group under this focus area.

Overexploitation of biological resources

The factors considered under this focus area include agriculture, landuse for urban development and infrastructure, forestry and fishing, considerations on production of wood for energy purposes, etc. Generally, environmental effects in all the focus areas result in impacts on biological resources. In this specific focus area, we therefore deal with the relevant effects not accounted for in the other areas. These effects are mainly due to our exploitation of the biological systems and alternative land-use schemes to natural habitats, i.e. it is a question of "space".

This is an effect category, which is in a high position on the international agenda but is generally not accounted for in such assessments as life cycle assessments of products or cleaner technology considerations.

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[17] Scientific American: Managing Planet Earth, 1989

Other factors of relevance to cleaner technology

Parameters normally considered when assessing cleaner technology options are water consumption and waste generation.

Water

In this concept water is included at lower levels, i.e. at the level where LCAs are performed. Water is considered of major relevance for biological production and may be part of an indicator at more aggregated levels for biological resources. Effects of exploitation and mismanagement of water resources are not included in the concept at aggregated levels.

The effects from overloading of nutrients (eutrophication) from municipal/industrial wastewater and agriculture are included at the LCA level. These effects are considered of local interest and are not used at aggregated levels.

Waste

Waste is mainly considered as generation of bulk waste from energy production and is included in indicators for energy at levels of lower aggregation. Municipal waste is excluded at levels 0 and 1. Waste is, however, necessary to consider at lower aggregation levels, when identifying indicators for specific industrial sectors.

Occupational health

Occupational health is not included in this concept, which considers ambient effects primarily. In some cases the major achievements of cleaner technologies are lowered impacts on occupational health, e.g. in the case of reduced levels of VOCs. When identifying indicators for individual sectors occupational health should be considered, and some help can be found in this concept since toxic effects on humans are included, but not e.g. physical damages.

Management indicators

When developing indicators for individual sectors or industries it is recommended to include development of indicators for management performance. These could include issues like training for increased environmental awareness and/or environmental management, stage of environmental management, environmental investment levels etc. but are outside the scope of the present concept.

Normalisation

Use of indicators implies normalisation and weighting. For all focus areas the normalisation suggested is a conversion to milli-person-equivalents (mPEs), where:

1 mPE =

$$\frac{\text{global annual emission or global annual consumption of a resource}}{\text{world population } x \text{ } 1{,}000}$$

For individual sectors other normalisation methods may be considered, such as:

$$\frac{\text{annual emission or consumption of resources}}{\text{no. of produced units or no. of employees}}$$

No general rule can be stated in individual sectors since normalisation is production dependent but normalisation should be agreed within an industrial sector.

The Normalised Environmental Impact Potential (NEP(j)) is expressed as:

NEP(j) =

$$\frac{\text{environmental impact potential (emission) per product}}{\text{duration of service (years) } x \text{ normalisation reference (e.g. mPE)}}$$

Weighting

Weighting should be done as a basis for priority ranking and decision making. Several types of weighting can be used, e.g.:

Resource weighting =

$$\frac{(\textit{normalised resource consumption})\ x\ \textit{annual production}}{(\textit{total reserve})}$$

The Weighted Environmental Impact Potential (WEP(j) used in the EDIP method is expressed as:

WEP(j) = weighting factor (WF(j)) x normalised environmental impact potential (NEP(j))

where the weighting factor (WF(j)) is:

WF(j) =

$$\frac{\textit{Environmental impact potential of emissions in } 1990}{\textit{Environmental impact potential of year } 2000 \textit{ emission goal}}$$

Sustainability

The ambition behind the development of cleaner technologies is a progression towards a sustainable industrial culture. Therefore, an obvious choice for the target situation will be a sustainable societal impact on the environment, i.e. an impact that does not cause more severe environmental effects than can be accepted according to an overall goal of sustainability.

In this concept this overall goal has been applied for the choice of the focus areas, but concrete goals remain to be developed for weighting in specific applications of the concept.

The weighting factors would reflect the actual distance to a sustainable environmental impact giving greater weight to those of the indicators, which represent areas where the actual impact is farther from the sustainability level.

However, except for some non-renewable resources and the greenhouse gas CO_2, the sustainability levels are at present not defined in an operational manner. To facilitate the development of sustainability-based weighting factors, thus, there is a strong need to initiate consensus-building (and possibly research) to establish operational sustainable targets for the most important compounds and (preferably) for the different environmental impact categories, e.g. along the lines of the environmental latitude or space as developed by the project “Sustainable Europe” co-ordinated by the German Wuppertal Institute.

The definition of sustainability implies that some (although generally mild) effect is acceptable (as long as it does not reduce future generations’ possibilities for fulfilling their needs). Therefore, an inherent problem in the operationalisation of the sustainability concept is to reach consensus on, for each type of environmental effect, what the acceptable level is. To overcome this problem, an alternative might be to replace “sustainability” as the target impact with the “no effect level” equivalent to the environmental “carrying capacity”, the “critical load”, defined as the impact that does not cause any detectable effects or the "factor 10 improvement" of environmental performance.

In any case, it seems an appropriate task for the European Environment Agency to initiate work on the development of sustainability levels or carrying capacity levels for different environmental impacts in Europe.

4.2 Mineral Resources

4.2.1 Description of the focus area

Mineral resources covers all materials developed in nature from inorganic processes without any contribution from human beings. The mineral resources can be divided into three groups:

- Resources extracted from ore minerals, e.g. metals.
- Other mineral resources, such as e.g. sodiumchloride or gravel. Water and air also belong to this group.

- Resources based on fossil fuels. Fossil fuels like mineral oil, coal and natural gas may be used as raw materials for the manufacturing of plastic materials and chemical products as well as for energy production. In this context only the utilisation for manufacturing of plastic materials and chemical products is included. Utilisation for energy production is covered by Section 4.3 on energy.

Typical minerals

A list of typical mineral based materials is given in Figure 4.2.1. It should be noted, that focus is given to the materials and not to the minerals (e.g. iron containing minerals), from which the materials originate. The resources are considered as the raw materials from which the materials are extracted or produced.

Figure 4.2.1: *Selected materials*[18] .

Group	Material	Renewable Yes/No
Iron and steel	Cast iron Construction steels Stainless steel Steel for magnets Sintered steel	No No No No No
Other metals	Aluminium Lead Cadmium Copper Mercury Nickel	No No No No No No
Other metals	Silver Tin Brass Hard metal Other metals and alloys	No No No No No
Glass	Window glass Quartz glass Glass wool	No No No
Stone materials	Granite Marble Calcium carbonate Sand and gravel	No No No No
	Cement Rock wool Porcelain	No No No
Rubber materials	Butyl rubber Ethylene propylene rubber	No No
Plastic materials	Acrylnitril butadiene styrene (ABS) Thermoplastic polyester (PET, PBT) Polycarbonate(PC) Polyethylene(PE)	No No No No
Chemical materials	Carbon* Nitrogen Oxygen Ammonia Water	No Yes Yes No Yes

* Carbon as a chemical material is typically produced by combustion of mineral oil - for this reason carbon is considered a non-renewable material

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[18] Hansen, E.: Environmental ranking of industrial products (In Danish: Miljøprioritering af industriprodukter). Danish Environmental Protection Agency, environmental project no 281 (In Danish).

4.2.2 Use of mineral materials in industrial production - the life-cycle perspective

Mineral materials are utilised as raw materials or ancillary substances in the manufacturing of industrial products, and will for many products constitute the dominant part of the final product.

Life-cycle for minerals

The life-cycle for mineral materials may be briefly outlined as follows:

Mineral materials are extracted from virgin mineral resources, utilised for manufacturing of industrial products and to the extent they are not recycled, dissipated into the environment or disposed of in landfills or other kinds of deposits for waste and residual products.

Main environmental effect

In this context the dominant environmental problem is taken to be the loss of mineral materials, which will occur when mineral materials are emitted to the environmental compartments or disposed of in landfills. This means that the resources are spread in the environment, and as a consequence of this, extraction of them is no longer economically favourable. In environmental terms this is called resource depletion.

Other impacts

It is noted, that in the life-cycle perspective a number of other environmental impacts are related to mineral resources:

- By the extraction of ore minerals from the earth crust or the bottom of the sea, ecosystems within a certain area may be affected. This may have consequences for the biodiversity. Furthermore mining activities occupy large areas for deposition of waste rock and tailings(waste products). Similar impacts are related to other stages in the life-cycle for mineral materials like refining, manufacturing and disposal operations.
- All industrial processes involving mineral materials including extraction, refining, manufacturing and disposal require energy. Environmental impacts related to energy production and utilisation are described in Section 4.3.
- The environmental impacts of hazardous substances emitted during the life-cycle of materials are described in Section 4.4.

In which stages are the mineral materials used?

Loss of mineral materials may take place at all stages of the life-cycle of the mineral materials.

Material stage

When extracting and refining there is a loss of materials, because the waste products from these processes will contain materials not economically feasible to extract. Some losses of material will occur as emissions to soil, water or air.

Manufacture

During the manufacturing stage materials may be emitted to soil, water and air, and materials may end up in waste products, which are not recycled. Even for waste products being recycled some losses of materials may take place, as the recycling processes in many ways resemble the extraction and refining processes.

Use stage

The use stage involves the use of industrial products. Depending on the application of the material, some materials may be consumed completely (e.g. zinc anodes for steel protection in sea water), while others may be only partially lost due to wear and corrosion.

Disposal stage

Materials which are not put forward to recycling may be lost to soil, water or air in e.g. incineration processes or the material will be disposed of in landfills.

It should be noted, that even if the material is recycled, it may be degraded by the process, as it may not always be possible to separate all undesired elements during recycling. These can be found as impurities in the recycled material and may affect the strength or other performances of the material. An example is too much copper in secondary steel which will seriously reduce the strength.

The importance of the individual life-cycle stages with respect to loss of materials may vary considerably for different materials and products and it is not possible to establish general rules. However, for many industrial products the losses taking place during the disposal stage are significant, and attention should be paid to whether the industrial products have been designed to facilitate recycling (the materials are easy to separate from each other).

4.2.3 Environmental effects

Material loss

The severity of the material loss when considering it as an environmental effect depends on the actual material and in particular on:

- Whether the material is renewable or non-renewable
- The amount of existing global reserves and ore grade
- Ease of material substitution

Renewable/non-renewable

Renewability

A renewable material is a material that can be regenerated naturally within a reasonable period of time. An obvious issue of discussion is which time period should be regarded. However, it seems logical to accept that all materials extracted from water and air should be regarded as renewable while materials extracted from the Earth's crust should be regarded as non-renewable, since the regeneration of ground and rocks is only possible within a geological time scale. Resources of biological origin are, of course, also renewable; these will be dealt with in Section 4.5 on biological resources.

The reason behind distinguishing between renewable and non-renewable materials is that non-renewable resources in principle may be depleted and therefore at present are taken as far more valuable to the society than renewable materials. On the other hand, the effects of over-exploitation of biological resources may be/are severe to the global environment as regards the continuous extinction of species resulting in losses in the gene pool.

Energy consumption to regain "lost" materials will be huge

One may argue that e.g. the iron ending up in landfills or being dissipated in the environment is not really lost, since it can be extracted, implicating that iron is a renewable resource. This argument is only partially true. It is correct that iron never will be lost completely. In principle, it is possible to extract iron from sea water or other environmental compartments in which iron may end up. However, the energy consumption required to do this will be significantly higher than the energy consumption used today to extract iron.

This discussion illustrates the very close links between the status of a material as being renewable/non-renewable, the technological state of the extraction technology and the related energy consumption. When a material like iron is assessed as non-renewable, it is justified by the fact that extraction of iron for the time being is based on ore minerals that cannot be regenerated within a reasonable period of time and that energy resources for the time being are regarded as limited. Figure 4.2.2 shows the connection between energy consumption and ore grade for the extraction of copper.

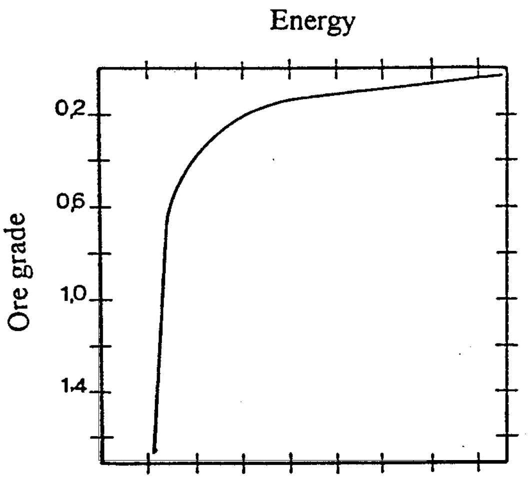


Figure 4.2.2: *Connection between energy consumption and ore grade for the extraction of copper[19].*

Fossil resources

A parallel to this is the plastic materials which are also classified as non-renewable materials, because the raw materials for production of plastic materials originate from mineral oil or natural gas. These mineral resources are not likely to be regenerated as the geological conditions leading to the creation of these resources like hot climate and very limited utilisation of biomass production may never occur again. In principle, however, plastic materials and other petrochemical products may be produced from vegetable raw materials. This does not happen today, as it is too expensive and requires too much energy. If, or rather, when the production of plastic materials is changed to be based on vegetable raw materials, these materials will change status and be classified as renewable materials. At that stage it will be extremely relevant to consider depletion of biological resources for food.

Existing global reserves

For non-renewable resources it is relevant also to consider the size of the global reserves and the number of years it is likely to last. The rationale behind this consideration is that the society should regard a scarce resource as more valuable than a non-scarce resource.

Resources definition

When discussing amounts of reserves, it is necessary to state some definitions. These are illustrated in Figure 4.2.3. The total amount of resources is the “geological resource”, i.e. the total amount of an element in the Earth’s crust. This term is not shown in the figure, which only deals with the technical resources defined as “A concentration of naturally occurring material in or on the Earth’s crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible”.

[19] Sørensen, H.: Raw materials (In Danish: Råstoffer). Geografforlaget (In Danish).

Technical resources

The technical resources are the total of all classes shown in the figure.Cumulative production	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES
	Demonstrated		Inferred	
	Measured	Indicated		
Economic	Reserves		Inferred reserves	
Marginally economic	Marginal reserves		Inferred marginal reserves	
Subeconomic	Demonstrated subeconomic resources		Inferred subeconomic resources	
Other occurrences	Includes non-conventional and low-grade materials			

Figure 4.2.3: *Classification of mineral resources[20].*

Discovered and undiscovered resources

The technical resources, from now on called resources, can be divided into the identified and the undiscovered resources. The identified resources are those where grade, quality and quantity are known (demonstrated) or can be estimated (inferred). *The reserve base is framed on the figure*, and is the part of the identified resources that meets specified minimum physical and chemical criteria related to current and expected mining technology. The reserves are the part of the reserve base which can be economically extracted or produced at the time of determination.

Available data normally state global reserves or world reserve base. Data for selected resources can be seen in Figure 4.2.4. The last column states the world reserves life index, which is the amount of reserves versus the annual production. All data are for the year 1990. In other words the worlds reserves life index expresses the number of years that a certain resource is supplicable on the assumption that the production rate is constant. Since the amount of reserves is very time dependent it should always be stated in which year the index was made. It should also be noted that production rates will be far from constant in the future due to the economic growth in South East Asia and elsewhere. The real world reserves life index will therefore be smaller than indicated in Figure 4.2.4.

Ore grade

Another aspect is the grade of the ore, or the rate with which the grade decreases. For some metals there is a almost linear relation between grade and amount of ore to a certain point. In some cases the line is steep, in others it is almost flat. Figure 4.2.5 shows hypothetical curves for these relationships.

[20] USBM, 1995: Mineral Commodity Summaries 1995, U.S. Government Printing Office, Washington.

This means that even if we become much more energy-efficient in the extraction of the ore, the available amounts of the resource may still be small. The connection between energy consumption for extraction and grade of ore can be seen in Figure 4.2.1. If we can divide the resources into groups of steep correlation, moderate and flat, this could be a way of adding a factor to the weighting. We should not only take into account how much can be exploited economically today but add a “probability factor” for how much is likely to be available in the next decades. It is, however, difficult to state exactly for all resources which curve they belong to. Therefore these aspects should not be included in the current evaluation concept. On the other hand the aspect of ore quality and not only ore quantity has become increasingly more common and as a consequence it is necessary to keep an eye on the development of the subject in order to incorporate it at a later stage.

Resource	Annual production 1,000 tons	Reserves 1,000 tons	Reserve base 1,000 tons	World reserves life index (1990) Years
Oil (1)	3,132,500	135,400,000	-	43
Bituminous coal (1)	3,038,300	521,413,000	-	172
Lignite (1)	1,342,200	519,116,000	-	387
Natural gas (1) Million m^3	2,019,576	124,000,000	-	61
Iron (2,3)	544,300	64,648,000	-	118
Aluminium (2,3)	17,878	3,488,000	-	195
Zinc (2)	7,325	144,000	295,000	20
Copper (2)	8,814	321,000	549,000	36
Nickel (2)	937	48,988	108,862	52
Manganese (2,3)	9,476	812,800	-	86
Lead (2)	3,367	70,000	120,000	21
Tin (2)	219	5,920	6,050	27
Water (2) km^3	3,240	-	-	Infinite

Figure 4.2.4: *Data for selected resources*

References:

(1) BP, 1992[21]
(2) World Resources, 1992[22].
(3) World Mineral Statistics, 1991[23]

[21] British Petroleum Company: BP Statistical Review of World Energy. British Petroleum Company p.l.c., London, 1992
[22] World Resources Institute: World Resources 1992-93. A report by the World Resources Institute in collaboration with the United Nations Programme and the United Nations Development Programme, Oxford, 1992.
[23] World Mineral Statistics 1985-1989, British Geological Survey, Keyworth, Nottingham, Derry & Sons Ltd.

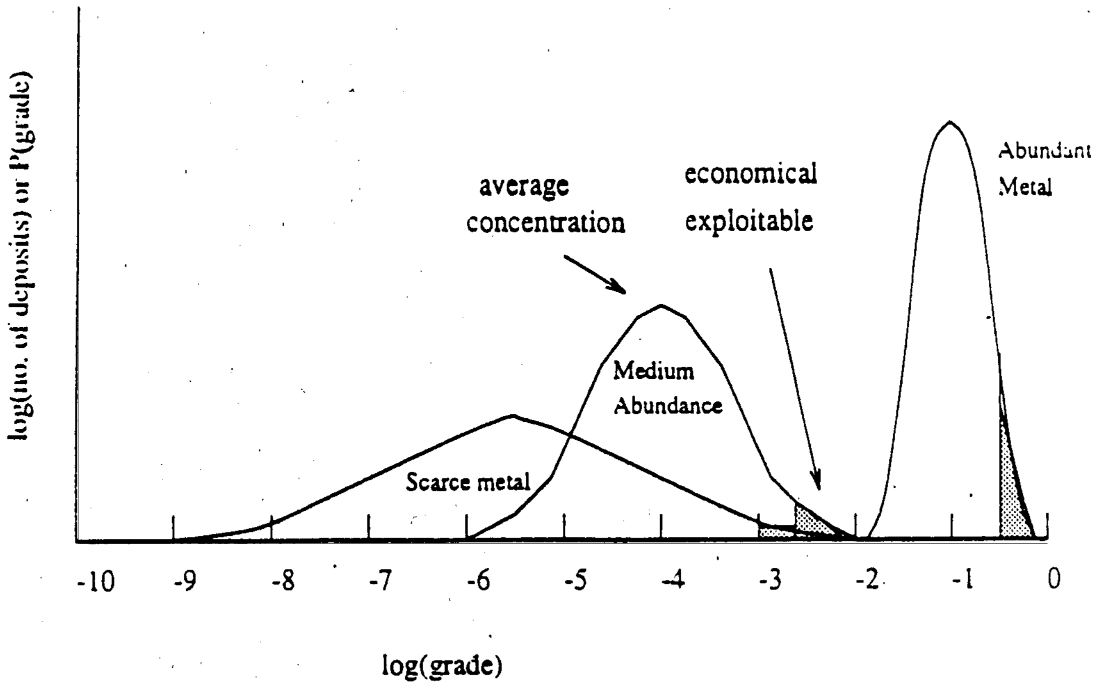


***Figure 4.2.5**: Connection between amount of ore and grade of ore for groups of metals: scarce, medium abundant and abundant (de Vries, 1989)[24].*

As a conclusion: the loss of mineral resources should be weighted according to their scarcity. The world reserves is the best base for this weighting procedure.

How easily the material can be substituted

Closely related to the world reserves life index is the dilemma of substitution. If a metal can be substituted by others it might not be relevant to look at the world reserves life index for that specific metal only. Copper for cables can in most cases be substituted by aluminium. It could therefore be argued, that for specific cases, it would be more right to look at the total reserves of copper and aluminium. This method, however, is problematic because it is not possible to state general rules for, which metals can be substituted by which without looking at specific applications. Therefore, this aspect should not be included in this context, as it would tend to limit the importance of an effort to reduce losses of valuable materials.

4.2.4 Evaluation concept

Loss of resources as an indicator

As an ideal the indicator of the mineral resources should be the *loss of resources* through the whole life cycle (representing level 2 in the CEIDOCT-concept). This approach, however, is not realistic in most cases for an individual manufacturer. The manufacturer responsible for a specific industrial process must be expected to be in control of the losses taking place by the manufacturing process itself, but only to some extent of the losses taking place during the remaining part of the life-cycle.

For the extraction stage it may be difficult to get information

Regarding the extraction and refining processes, reliable data is not likely to be easily available for the ordinary manufacturer. Usually site specific information is regarded as confidential information by the mining and refining companies. For some materials average data for the

[24] Vries, H.J.M., de: Sustainable Resource Use, optimal depletion within a geostatistical framework, Institute for Energy and the Environment (IVEM), research report no. 35, University of Groningen, the Netherlands.

branch in general will be available. Such data will, however, only allow the manufacturer of an industrial product to evaluate the consequences of substituting one material with another, and will not allow the manufacturer to choose between several suppliers of the same material for environmental reasons. Finally, one should note that the manufacturer of an industrial product can influence the activities of the extraction and refining processes only by his position as a consumer of raw materials. In many cases his real power to control the losses will be minimal. For these reasons, it is recommended that the evaluation concept should not include the losses of the extraction and refining processes, except for those cases where the industrial process in focus actually belong to these processes.

Use and disposal stages

For the use and disposal stages the manufacturer may not always know what will happen. This to some extent reflects the problem that a specific product may be used and disposed of in many different countries under different conditions. On the other hand a manufacturer of an industrial product does have a real influence on the loss of resources during these stages. This is because he is in control of the design of the product and thereby in control of, e.g. whether the materials used in the product may be separated and made available for recycling on economically sustainable terms. Actually, it should be taken as an important element of any cleaner technology effort to optimise product design with the aim to minimise the loss of resources taking place during the use and disposal stages.

For this reason it is recommended, that the evaluation concept, when possible, includes the losses occurring during the use and disposal stages.

Decision should be made at branch level

The evaluation of whether it is possible to include the losses during the use and the disposal stages should be made at the branch level. Generally, one would expect, that manufacturing companies producing final goods would always be able to include losses during the use and disposal stages, while companies dealing solely with semi-manufactured goods to be incorporated in many different industrial products may not be able to include losses during the use and disposal stages.

Not different recycling systems but recyclability

Due to the different waste management systems, no manufacturer is likely to be able to assess the actual recycling taking place in different countries. In this context the actual recycling should be taken as less important than the potential recycling, since the manufacturer should not be held responsible for the actual waste management in different countries. The manufacturer should, however, be held responsible for whether the materials incorporated in the product can be easily separated, when the product is disposed of after use.

Recommended evaluation concept

Thus, the evaluation concept to be recommended may be stated as follows:

The main indicator is the resource loss. At the most specified level which corresponds to the inventory in LCA, the resource loss of each resource is expressed by weight. Going through the normalization and weighting steps in an LCA, one ends up with the weighted values of the loss of resources (level 2). Level 2 thus represents all stages of the product life cycle. In general only non-renewable resources will have a weighting factor different from zero. Consequently the weighted values will mainly represent the non-renewable resources. An important exception, however, is water, which locally can have a consumption rate exceeding the regeneration rate. In this case water will also be among the weighted resources. For simplicity, only non-renewable resources will be represented at the levels 0 and 1. Water consumption may be regarded as a technology specific indicator (TSI), as it is illustrated in the cases in Section 6, but may also be included in the biological resources focus area, Section 4.5. In order to distinguish between materials from non-renewable resources and renewable resources, a list of materials can be consulted[18].

Resource losses

The resource losses at levels 0 and 1 can be determined as follows:

For level 0, which is the most aggregated level, only the material content of the product and the potential recycling are considered. The procedure is to determine the amount of non-renewable resources in the product by means of weight and consultancy of the list of materials. If it can be argued that parts of the product will be recycled, these contributions can be subtracted. Guidelines for estimation of recycling rates for different groups of products need to be elaborated.

In other words: In order to determine the loss of resources, the inputs and potentials of recycling must be stated. If there is no recycling on disposal, the resource loss will be equal to the inputs. Only inputs which are recycled can be subtracted from the total inputs.

For level 1 the losses of resources throughout the whole life cycle are considered.

For recycled materials a loss during recycling is expected. For aluminium the loss during recycling is expected to be 3%. The recycling loss is replaced by primary aluminium. For each 1 kg which is recycled, 30 grams of primary aluminium must be added. If the input is 1 kg aluminium, and it is recycled, the resource loss is 30 gram aluminium. Similar arguments can be carried out for all other materials. This will, however, need a thorough study of the recycling processes.

Weighting and normalisation principles

The weighting is carried out by multiplying the loss of resources with a weighting factor:

Weighted data = loss of resources x weighting factor

The weighting factor used is the same as in the EDIP method[5]; the reciprocal of the world reserves life index, defined as the reserves divided with the annual production. The reserve is the part of the total amount of a specified resource which is identified and which can be exploited economically. It can be questioned whether the world reserves life index should take into account not only the economically feasible reserves, but all of the demonstrated resources (the reserve base). It can also be questioned if the world reserves life index should be static, i.e. not correcting for an increase in the world's population and consequently an increasing demand of resources.

So far, the static index will be used. Prior to weighting, the loss of resources has been normalised, i.e. divided by the average annual production per person for the given resource. If these data are not available another procedure can be used: The amount of the reserve divided with the total population of the world can be used directly as weighting factor to the inventory data. It means that we get the amount of reserve which is available per person. The resulting value will thus be equal to the normalized and weighted data according to the EDIP method.

Summary of indicator levels

Level 0

Estimated loss of mineral/non-renewable resources for the inputs (material content of the product) and the disposal stage only. The losses are weighted according to the EDIP method and aggregated into one figure.

Level 1

Aggregation of data from the LCA of the product (level 2). Non-renewable resources, weighted and aggregated into the groups:

- metals
- minerals
- fossil raw materials

Indicator level	EPI
Level 0	EPI = Loss of mineral resources per unit (normalised) from inputs (material content) and disposal stage; aggregation of all contributions from mineral resources.
Level 1	EPI = Aggregation of normalised losses of mineral resources from the LCA in groups as: • of fossil origin • metals • other minerals

* mPR = milli Person Resources

4.3 Energy Consumption

4.3.1 Description of the focus area

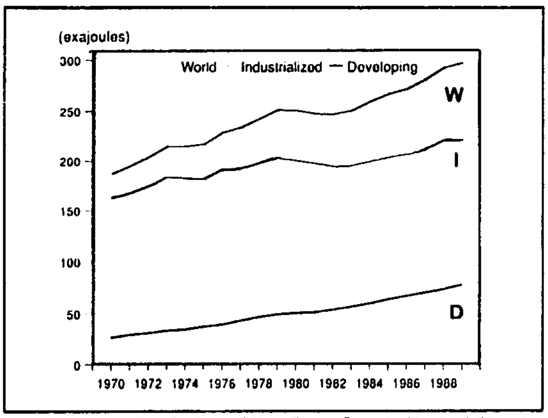
The global energy production and consumption

The World Resources Institute[22] frequently makes statistics on energy production and consumption. In this, they have kept an eye on the trends over the last two decades. From 1970 to 1989 the global, commercial energy production have increased from 205 exajoules to 311 exajoules (1 exajoule = 10^{18} joules) corresponding to a 52% increase. Typical energy sources in the developing countries, like firewood, animal and plant waste, and charcoal are *not* included in the figures, which only comprise commercial energy production.

Oil is the most important energy source, accounting for 42% of commercial energy production; secondly coal plays an important role at 31% and gas (natural gas and other petroleum gases) makes up 23% of total production. The remaining energy production is from nuclear, water, geothermal and wind and is called "primary electricity".

As an average, it is calculated that a person in the industrialised world uses about 10 times the amount of commercial energy used by a person in the developing countries. To highlight the differences, today an average US citizen consumes twice as much as a Swede, three times as much as a Greek and 295 times the energy consumed by a Tanzanian.

The Figure below[25] shows the increase in global commercial energy consumption, from 1970 to 1989:



Source: United Nations Statistical Office, *Energy Statistics Yearbook* (United Nations, New York, 1991), and previous volumes.

Figure 4.3.1: *Increase in global commercial energy consumption 1970-1989*

[25] United Nations Statistical Office, Energy Statistics Yearbook (UN, New York, 1991) and previous volumes.

Energy and related environmental effects

All modern production is based on the possibility of having a continuous supply of energy. Different productions use different types of energy, but most production needs an electrical power supply.

Energy is used for obtaining and refining raw materials, for industrial production, for transportation and for heating purposes, whether it is as heat required for industrial processes or for comfort. Energy for these purposes is used as primary energy or as secondary energy (electricity) produced from primary energy sources.

The primary energy sources

The primary energy sources are divided into three main categories:

Primary sources, non-renewable

a) Non-renewable sources:	**Possible Environmental Effects**
- Natural gas - Oil - Coal - Brown coal	* Global warming * Photo chemical ozone formation * Acidification * Eutrophication * Bulk waste * Slag and ashes
- Nuclear materials	* Nuclear waste, risks of dispersion

Primary sources, renewable

b) Renewable (biological) sources:	**Possible Environmental Effects**
- Wood - Plants - Biological gas	* Acidification (NO_x) * Eutrophication (NO_x) * Slag and ashes * Global warming (methane from biological gas production) Biological material is to be considered as CO_2-neutral.

Primary sources, lasting energy

c) Lasting sources:	**Possible Environmental Effects**
- wind - water - sun - geothermal	* Landscape destruction * Loss of biodiversity (hydro power plants)

Figure 4.3.2: *Categories of primary energy sources*

The secondary energy

Secondary energy conversion loss

Secondary energy can be described as an energy type developed from a primary energy source. The production of secondary energy - mostly electrical power - results in a conversion loss. In a power plant - only making electrical power from fossil or biological sources - there is a typical conversion loss of about 60%. In a combined power and heating plant, there is a conversion loss of only 15%, because the heat loss is utilised directly for heating purposes, and this does not fully represent a loss.

Environmental impacts

The environmental impacts caused by the use of secondary energy are directly dependent on the primary energy source and the related emissions. So, in cases where the secondary energy is produced from fossil materials, there is a relatively larger environmental problem than if the fossil materials were (could be) used directly in the actual process, because of the conversion loss.

4.3.2 Description of the system

Design of products, management

The design of the products, the design of the production equipment and the management in connection with the production; all have a considerable influence on the total energy consumption. A policy on the choice of sub-contractors, based on environmental assessment, may have great influence on the total energy consumption, the total environmental impact and the total consumption of mineral resources, and thereby on the energy consumption related to the production of raw materials.

All stages of a life cycle can be energy consuming

The life cycle stages: materials stage, manufacturing stage, user stage and disposal stage, are all linked in a network of transportation. Depending on the type of product, all life cycle stages are energy consuming - more or less. Energy consuming products like electronics or motors can have a very high consumption of energy in the user stage compared to other stages in their life cycle. Other products or parts of products <u>not</u> consuming energy in the user stage, very often have their largest consumption of energy in the materials stage.

It should be noticed that a deliberate change of product design in the effort of creating a less energy-consuming product in the user stage, *can* be a very good cleaner technology initiative, even though this design change may result in a *higher* energy consumption in the manufacturing stage. This underlines the importance of making life cycle assessments in product development.

In some cases the energy consumption in connection with transport plays a major role viewed over the entire life cycle (soy beans for food oils, is an example).

The disposal stage can be energy consuming, almost neutral or it can be energy producing. An example of the latter, is the incineration of household waste in plants connected to the public heating system.

4.3.3 Evaluation concept

The headlines in an environmental assessment of the energy consumption in connection with a “cleaner technology initiative” are:

1) *Minimise the energy use*

and

2) *Promote the use of lasting energy and renewable energy in preference to non-renewable energy.*

An evaluation of the energy consumption and the related environmental impacts before and after the introduction of cleaner technology may therefore have to include an investigation of the primary energy sources "behind" the MJ or kWh. The three groups of energy sources are:

a) Energy from non-renewable resources, (fossil materials, nuclear energy).

b) Energy from renewable resources, (biological resources).

c) Energy from lasting sources (wind, water, sun).

Electric power from the European electrical network is based on a mixture of the three primary energy sources as mentioned.

a) Energy from non-renewable resources, (fossil materials, nuclear energy)

The non-renewable resources consist of two types:

- the fossil materials.
- the radioactive materials.

Fossil materials

The fossil materials are:

Natural gas
Oil
Coal
Brown coal

Consuming these resources for energy production at a rate as we do today is considered a problem. First of all, the world lifetime reserve index[22], for these resources is estimated to be about 40 years for oil, 60 years for natural gas and 390 years for coal estimated in 1989. This means that coal will be the most important fossil energy resource within a relatively short period of time.

Secondly, the combustion of fossil materials results in an increased CO_2 content in the atmosphere and thereby an unwanted potential for global warming. Natural gas is creating less CO_2 than oil and coal. Fossil materials contain different components that contribute to different environmental effects when combusted. The major effects in addition to global warming are acidification, eutrophication and slag and ashes containing heavy metals.

Radioactive materials

Radioactive materials for nuclear power production are widely used today. The interesting radioactive energy source in this connection is Uranium-isotopes. Winning uranium implies heavy processes and creates environmental effects similar to those created by winning precious metals. Several nuclear power plants around the world have constituted a serious risk either because of missing maintenance, lack of attention to (or missing) safety precautions, bad materials or less appropriate layouts. In a well organised and well operated modern nuclear power plant the major environmental problem is radioactive waste, which must be deposited. The transport and deposition of nuclear waste presents a serious risk to the surroundings.

b) Energy from renewable resources. (biological resources)

Energy from biological resources is considered to be renewable. The biological resources in this connection embrace trees, plants and derived products. Biological resources are only considered to be renewable if they are renewed concurrently with the utilisation. Renewability is not necessarily equal to sustainability in this connection even though it might be a step in this direction. Overconsumption of biological resources is considered in Section 4.5.

On the other hand a natural and balanced utilisation of surplus biological material for energy production is at present considered a good idea in order to save non-renewable resources. Biological material is CO_2-neutral to the environment, but depending on the combustion process and its control, several types of emissions will contribute more or less to environmental effects as mentioned above.

c) Energy from lasting sources (wind, water, sun)

Much research and development has been carried out in order to find an energy source that was unlimited and not harmful to the surroundings. The three lasting primary energy sources:

wind, water and sun can be used unlimited whenever they are available. It is not, however, always possible to generate secondary energy from these three primary sources. Availability is widely dependent on the geographical location and the weather conditions.

Even though there are no direct emissions from these energy sources, their use often leads to various environmental effects. As an example, large hydro power plants and related damming can be harmful to the wildlife in the actual water system and result in a loss of biodiversity. The flooding of large areas may also imply serious habitat extinction.

Windmills make noise and if they are installed in e.g. a residential neighbourhood they can be inconvenient both with regard to noise and to visual impression. If they are placed in an attractive natural landscape the same inconveniences will apply.

In spite of this, lasting energy sources are considered to be the most environment friendly energy sources compared with non-renewable and renewable sources.

Today, the predominant part of the world's energy supply comes from non-renewable (fossil) sources and it is a general wish to reduce the consumption of these resources and instead use the renewable and lasting sources.

In the following it is therefore decided only to distinguish between:

- non-renewable resources

and

- renewable and lasting sources.

4.3.4 Four scenarios describing the complexity in aggregation

In the following section four scenarios are presented to highlight the use of indicators at levels 0 and 1. The scenarios also illustrate the difficulties in using one EPI as a top-down approach to evaluate a cleaner technology initiative with respect to electric power consumption.

Scenario no. 1

A paper machine manufacturer has developed a new production line for paper manufacturing in four operations. He wants to sell the machine on the European market. The last operation in the production line is drying of the paper product. The drying of paper is carried out by heating some rolls on which the paper is transported. It is now considered which of the following alternatives for heating of the rolls that is the most environmentally friendly.

Heating by steam condensation. Steam is normally produced on the factory's own steam plant, which typically uses natural gas or gas oil as the primary energy source, but coal can be used in some cases.

Heating by oil or gas burners directly in the rolls.

Electrical heating using the electricity from the public power supply (EU average electrical power).

a)

In the first alternative, natural gas is used to fire the steam boilers. There is an energy loss in the evaporation of water to steam, a loss in the pipe line from the steam plant to the heated rolls, and maybe a minor loss in the condensation of steam in the rolls.

b)

In the second alternative, natural gas is combusted through burners mounted inside the rolls and there is only a minor loss, because the gas supply to the burners is controlled by the temperature on the surface of the rolls.

c)

In the third alternative, electrical energy is used to heat the rolls. The electrical power comes from the public power supply (EU average electrical power). Even though the efficiency in generating heat using electricity is almost 100%, there is a conversion loss of approx. 60% in making the electricity.

In order to determine the different efficiencies and the different related environmental impacts an upper-level EPI is not enough. It will be necessary to perform a closer analysis, since all changes are based on non-renewable resources.

Scenario no. 2
A factory producing paper asks the Danish EPA for financial support to convert to a new energy system. Their present energy system, which is a combination of a natural gas fired heating system and the use of the public, electrical power system (h = 0.4) (EU average electricity), is proposed changed to a natural gas fired power/heat plant with possibility of firing with wooden chips later.

The environmental consequences must be analysed and a proper EPI suggested which reflects the consequences of the change.

In a co-generation power plant both heat and electrical power is produced. It is normally not a problem to use the electrical power or “export” it to the public electrical network, but it should be considered if the generated heat can be used. Otherwise there will be a loss in this system.

In the proposed new system, the total efficiency of a power/heat plant based on natural gas or wooden chips, has a relatively high efficiency of approx. 85%. The environmental impact from this system before and after conversion to wooden chips should be compared with the total impact from the existing energy system.

Scenario no. 3
A Danish newspaper group is looking abroad for a supplier of paper. Two interesting suppliers were found, who produced a good quality, which at the same time was cheaper than the previous supplier’s. Seen from an economic point of view the two alternatives were even.

The first alternative was a Polish supplier, who used electricity produced at a brown coal fired power plant and steam for heating purposes, also from a brown coal fired plant.

The second alternative was a Norwegian supplier, who based all his production on Norwegian electricity, which is more than 95% based on hydro power.

Which supplier should the Danish newspaper syndicate choose, from an environmental point of view? An EPI should be chosen which reflects the energy related consequences of the choice.

The immediate answer to the question is: the Norwegian supplier.

An EPI which reflects the differences in environmental impact between use of renewable/lasting resources and non-renewable resources would serve in this case.

However, due to the different primary energy resources to supply electricity to the European power network, the case is not absolutely clear-cut. The export of coal-based electricity from Denmark to Norway on the European net presents an uncertainty for calculation of environmental impacts, which at this stage cannot be included in the concept.

On the other hand the choice of the Norwegian supplier could make the Polish producer reflect on his energy source and on a longer term force him to convert his energy system to an environmentally friendlier system.

Scenario no. 4
A factory producing screws, nuts and round-headed nails uses a larger number of old turning lathes that have a very large consumption of electrical power. The government in the specific country decides to make a regulation on electrical power. A 25% tax is introduced on electrical power. The manager of the factory makes a quick decision and changes the old turning lathes to new high efficiency turning lathes.

The result is that he is able to produce 1.3 of the old production and lower his consumption of electrical power to a total of 80% of the old consumption, for the operation of the turning lathes.

In this scenario the cleaner technology initiative is easy to point out and the key indicator could simply be the number of MJ per produced unit ‘before’ compared to the ‘after’ situation.

The four scenarios are reviewed in the matrix Figure 4.3.3 to illustrate the necessity of at least two levels in an indicator model.

Scenario **Indicator level**		*No 1. Drying paper:* a) Using steam from own plant, typically heated with coal, oil or gas. b) Using oil or gas directly. c) Using electrical power from public supply.	*No 2. Energy system:* a) Combination of public, electrical power (h=0.4), and natural gas for heating. b) Natural gas fired power/heat plant with possibility of changing to wooden chips firing (h=0.85)	*No 3. Subcontractor:* a) Polish supplier using electricity from brown coal fired power plant and steam produced from brown coal for heating. b) Norwegian supplier using only electricity from a hydro power based system.	*No 4. New machines:* a) Old turning lathes using 100 kWh for the daily production. b) New turning lathes using 80 kWh for 1.3 of the daily production.
Level 0	EPI = number MJ/h per unit (Electrical power, h=0.4) (Energy measured as primary energy)	A level 0 indicator can be used, • because the producer of the new paper machine does not know where the machine is to be used. • because the choice will not affect the composition of the primary energy sources. Condition 3)			A level 0 indicator should be used. Only one energy form is involved in the decision, and the choice therefore does not affect the use and composition of primary energy sources.
Level 1	EPI = the aggregation of energy types in: Ø Non-renewable resources (% of total, MJs) Ø Biological resources (% of total, MJs) and/or lasting resources (% of total, MJs)		A level 1 indicator should be used for decision, because the choice affects the use and composition of primary energy sources.	A level 1 indicator should be used for decision in this case. It should be considered, if the capacity of the Norwegian hydro power plants will be fully utilised irrespectively of the production volume at the paper factory, because of flexible electricity import/export between Norway and Denmark. If so, Danish coal based electricity will be the real source of electricity for the Norwegian supplies.	

Figure 4.3.3: *Environmental Performance Indicator (EPI) model for energy consumption in a Cleaner Technology Assessment*

4.3.5 Suggestion for indicators at aggregated levels

In the following a two-level indicator model is introduced for evaluation of the energy parameter in a cleaner technology context.

Level 0

Level 0 is the highest aggregated level which may also be used for a top-down approach. An obvious indicator at this level is the *primary MJ*, i.e. the energy consumption in MJ and corrected by the efficiency with which the energy is produced, including any conversion loss, from primary to secondary energy.

The main difficulties in the use of the model at level 0 is the fact that secondary energy types (e.g. electricity or steam) are produced from widely different primary energy sources contributing to widely different environmental impacts. The scenario no. 3 illustrates a situation where it is necessary to take this into consideration-

On the other hand level 0 can be used in many cases, if the following conditions are met:

1) only *one* form of primary energy or just one mixture of primary energy sources is involved in the decision on choice of technology
2) the energy derives from primary electricity (lasting energy sources (wind, water, sun)), for all alternatives comprised by the decision
3) when the actual composition of primary energy sources is unknown or considered to represent a broad average, e.g. "Average European electricity".

Level 1

In cases where the choice between alternatives will actually affect the extent to which non-renewable energy sources are used compared to renewable or lasting sources it may be necessary to evaluate the decision at level 1. Level 1 is an aggregation of different energy types into two categories:

- Energy from non-renewable resources
- Energy from biological resources (renewable) and lasting sources (wind, water, sun)

where the energy is measured in efficiency corrected MJs.

The recommendation is always:

- try to achieve an alternative with the lowest possible total, primary energy consumption.

Primary electricity (from wind, water or sun) is considered primary energy, i.e. the energy efficiency is in this context set to 1. If the total energy is approximately the same for the alternatives:

- choose the system consuming the least amount of energy from the non-renewable sources
- if several of the alternatives consume the same amount of non-renewable sources, choose (among these) the system consuming the least amount of energy from the renewable and/or the lasting sources.

Level 1 is to be used when the primary energy sources are foreseeable and when the decision in question will affect the use of primary sources in a foreseeable way.

Choices may also be assessed at a more detailed level, i.e. using a life cycle assessment (level 2). Today such analyses are relatively unproblematic, as computerised models, tools and databases are already developed in this field. It should be mentioned that a life cycle assessment comprises other types of resources than just the energy sources and in this, it is not meaningful to make an LCA on the energy system alone. LCAs will end up with a total picture of the environmental impacts from the product in question and the related cleaner technology initiatives.

4.4 Chemicals

4.4.1 Description of the focus area

Definition

In this project chemicals are defined as "substances" and "preparations". These terms are defined in Danish legislation (order no. 829 of 15.10.93, last amendment 7.2.1996) as well as in the EEC directive nr. 67/548/EEC with later amendments. The definitions are:

"Substances" mean chemical elements and their compounds in the natural state or obtained by any production process, including any additive necessary to preserve the stability of the products and any impurity deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its compositions;"

"Preparations" mean mixtures or solutions composed of two or more substances;"

Use of chemicals

Chemicals are being used in industry for different purposes. In this project we distinguish between raw materials (reactants, substances providing the product with wanted properties), additives (stabilizing agents, colours etc.) and ancillary materials (i.e. cleaning agents, catalysts, filter materials etc.).

Chemicals used as raw materials or additives in a process will by definition be included in the product.

Chemicals used as ancillary materials in a process will not be included in the final product.

Environmental pressures resulting from the use and emissions of chemicals

The atmosphere is the primary recipient for airborne emissions, the secondary recipient for fugitive emissions (such as methane from landfills, ammonia from manure applied as fertiliser) and for evaporation of volatile compounds emitted to the other compartments.

The soil is primary recipient for wastes (including sewage sludge) being deposited or spillage's etc. leading to pollution of soil, it is secondary recipient for exchange between compartments in the form of deposition of airborne pollutants, adherence of certain substances, (e.g. heavy metals) to the sediment etc. Examples of chemical compounds, which end up in sediments/sludge, are heavy metals, persistent large-molecule hydrocarbons e.g. many aromatic hydrocarbons, molecules characterised by low vapour pressure, low mobility in soil e.g. because of high affinity to humus (organic matter in soil). Pesticides are an example of chemicals regularly sprayed directly on plants (and on soil).

Water is the primary recipient for emissions with waste water, surface flow and secondary recipient for exchange between compartments e.g. deposition in sea of airborne pollutants, groundwater being polluted by substances penetrating the soil etc.

Chemicals are wasted either directly as hazardous waste, resulting in controlled ambient emissions, or with municipal waste. Depending on the end treatment it is converted (e.g. by incineration) to other (not always) less harmful compounds or slowly released (e.g. heavy metals) from a landfill or a dump. When chemical compounds are treated as waste this generally means that release is controlled, and often that emissions are shifted between media, e.g. from air and water to water and soil.

Over the last decade awareness of the environmental problems resulting from emission of chemicals has raised. This situation and regulation of emissions both to air and water has reduced industry's emissions. Figure 4.4.1 shows that reductions have been achieved, but it does not show if reductions are due to application of cleaner technologies or end-of-pipe solutions.

Figure 4.4.1: *Examples of chemicals released from industrial processes are taken from Miljøstyrelsen, 1994*[26].

tonnes	1985	1988/1989
Heavy metals	20	12
Oils	90	approx. 30
Phenolic compounds	approx. 530	100
Adsorbable organic halogen (AOX)	14000	4000
Non-chlorinated aliphatic compounds	6300	4000
Non-chlorinated aromatic compounds	380	300
Chlorinated aliphatic compounds	27000	18000
Chlorinated aromatic compounds	52000	approx. 11000

Figures are approximate, but it can be seen that decreases are significant.

Fate and ultimate exposure

The amount and the properties of the chemical compounds emitted, the physical conditions at the place of emission and the possibility for chemical reactions to take place, decide for each compartment both the exchange between compartments and the fate of the particular chemical compound within the compartment. Examples are shown in the Figure 4.4.2.

Degradation

The degradation of a chemical compound in the environment, through the action of micro-organisms or through chemical reactions, determines the lifespan of the chemical compound in the environment and thus the possibility of dispersion over large areas and the possibility for bioaccumulation.

Biodegradation

Biodegradation is degradation of chemical compounds in biological systems, mostly by micro-organisms (and invertebrates) in a waste water treatment plant or in the water, soil or sediment.

Bioaccumulation

Bioaccumulation is the common term for chemical compounds being concentrated in living organisms (bioconcentration) or possibly accumulated to higher concentration levels through the food-chain (biomagnification) due to a combination of lipophilicity and persistence (non-biodegradability). The latter may lead to levels where toxic effects become evident. Very few data are available, but since accumulation mostly is connected to fatty tissues, very often the chemical compound's distribution between the water phase and n-octanol (representing body lipids), K_{ow} is used to estimate the potential for bioaccumulation. The indicator used is log K_{ow}. (= P_{ow}, but log P_{ow} is increasingly used).

Dispersion

Dispersion means spreading of the chemical compound by physical transport. Dispersion in water and soil ecosystems depends on its water solubility, its mobility in soil, its volatility etc.

Effects on humans

Exposure to chemicals may lead to a variety of toxic effects on humans. Toxicological effects are most often divided into:

- Acute toxicity, covering the effects caused by a single (or a few) exposures generally in large doses. May be fatal and irreversible or reversible, e.g. gastro-intestinal inflammation.

[26] Miljøstyrelsen, 1994, Skov- og Naturstyrelsen, Danmarks Statistik, Tal om Natur og Miljø 1994.

Example of an acute reversible effect is the narcotic effect of some solvents, whereas hydrogencyanide can be fatal even in low concentrations (down to app. 100 ppm).

- Skin and eye irritation are due to local effects in the tissues exposed. Especially inorganic acids and alkalis are very potent irritants.
- Allergic reactions, that is immunological reactions to the substance. Bisphenol A used in epoxy resins is an example of a very potent allergen.
- Systemic toxicity, are due to toxic effects to the biological functions encountered most often after long term exposure
- Organ toxicity may occur when a specific organ is more susceptible due to accumulation, different metabolism, or specific binding sites for the substance. An example of specific organ toxicity is the pain reliever Acetaminophen which induce toxic effects in the liver.
- Carcinogenicity, which is the potential to cause malign tumours or other forms of cancer.
- Mutagenicity, which is the potential to induce damages or changes into the DNA
- Reproductive toxicity, which consists of at least two different types of effects: Specific effects to the reproductive organs and teratogenicity which is the substance ability to pass the placenta and cause damages to the evolving fetus. Probably the best publicly known teratogen is Thalidomide, a sedative given to pregnant women in the early 60s, causing malformations in foetuses. An issue for the time being is the environmental dispersion of estrogenic active substances, e.g. nonylphenol, causing reproductive defects in males (decreasing viable semen production, causing testicular cancer).

Ecotoxicity

Depending on the type of assessment to be carried out, ecotoxicological effects may be classified in a number of ways such as the following:

- According to duration of exposure, i.e. either as acute or chronic effects. Whether e.g. a 96 hours test is to be considered an acute or a chronic test depends on the generation time of the test species. The vast majority of experimental ecotoxicological effect data are on acute effects. Among the standard tests only the algae growth inhibition test (72 hours) can be considered a chronic test due to the short generation time of algae populations.
- According to trophic levels, i.e. do the effects occur among the primary producers or among primary, secondary and tertiary (etc.) consumers? The trophic level approach can be exemplified by the food chain: Algae, zooplankton, fish and marine mammals.
- According to hierarchical levels, i.e. are the effects observed at the community, population, individual or cell level. Most standard tests are at the individual level, the algae test, however, being a population level test. Most often seen are the terms LC_{50} (lethal concentration, 50% mortality among test organisms) or, more rarely, LD_{50} (lethal dosis, 50% mortality among test organisms). In cases where more sensitive test end points than mortality are requested, the common term EC_{50} (effect concentration, 50% of test organisms affected) is used.

Relevant exposure and effect data are shown in the following table (Figure 4.4.2) represented by simple testdata, which normally can be found in databases like those presented in Section 4.4.5.

Figure 4.4.2: Examples of relevant exposure and effect data and their representation by simple testdata. (Modified from Kjølholt et al.,1994)[27]

	Exposure		Potential Effects	
	Property	**Representation**	**Property**	**Representation**
Atmosphere	Degradation Volatility Solubility	$T_{½}$ (Photo), atm. lifetime Vapour pressure (vp) Solubility in water (sol.)	Ozone depletion Global warming Photochemical ozone formation Toxicity by inhalation	ODP GWP POCP LC_{50} inh., rat
Soil	Degradation Bioaccumulation potential Mobility in soil Volatility	$T_{½}$, (soil) log K_{ow} K_{oc}/K_d Vapour pressure (vp)	Acidification Eutrophication Toxicity to invertebrates Toxicity to birds	Acidification pot. N- or P-content LC_{50} earthworm LC_{50} or LD_{50}, bird
Surface water	Degradation Diffusion in water Volatility Bioaccumulation potential	$T_{½}$, water Solubility in water (sol.) Vapour pressure (vp) BCF or log K_{ow}	Eutrophication Toxicity to fish Toxicity to invertebrates Toxicity to algae	N- or P-content LC_{50}, (fish) LC_{50} (daphnia or other invertebrate) EC_{50} (algae)
Ground-water	Degradation Transport to groundwater Diffusion Bioaccumulation potential	$T_{½}$ (groundwater) $T_{½}$ (soil), log K_{ow} Solubility in water (sol) log K_{ow}	Toxicity to mammals	LD_{50} oral,rat
Sediment	Degradation Bioaccumulation potential	$T_{½}$ (sediment) BCF or log K_{ow}	Toxicity to fish Toxicity to invertebrates Toxicity to algae	LC_{50} (fish) LC_{50} daphnia or other invertebrate) EC_{50} (algae)

4.4.2 Description of the system

Emission of chemicals

Based on the definitions stated in section 4.4.1, emissions of chemicals can be expressed as either 'process related' or 'product related' emissions. Process related emissions can be connected to all the three groups of chemicals (raw materials, additives and ancilliary materials). Product related chemicals can only be connected to raw materials and additives but the emissions can occur during the entire life cycle of the product ending up as waste.

The interrelation between the emission of chemical compounds and the effect on the environment is complex and involves dispersion, exchange between compartments, physical, chemical and biological alteration. LCA methods, such as the EDIP model, take the exchanges and alterations into account through simplified assumptions and possible effects are estimated.

Material stage

For raw materials most manufacturers will like to have a freedom of choice, meaning that often a large number of suppliers are kept for each chemical used. It is thus very difficult, nearly impossible, to get detailed information about manufacturing and emissions, environmental permits etc. from each individual manufacturer of raw materials. This is also in some cases due to the fact that individual chemical industries are unwilling to provide detailed information about their production. Knowledge should be obtained of significant types of emissions for each chemical, if at all possible. This goes particularly for persistent, very toxic chemicals and heavy metals. In this stage only significant emissions and wastes should be included as described in the following sections.

[27] Kjølholt et al.: Miljøbelastende stoffer i restprodukter og emissioner fra affaldsbehandlingsanlæg (Summary in English). Miljøstyrelsen, 1994

Use stage

It may not be clear to the manufacturer what the exact use of his product is; it may be applied in minute amounts and the end-disposal may be unknown. This applies for example to manufacturers of paint for metal coating used for a variety of end-purposes.

Another characteristic, however, of this type of paint is that it is solvent based. The solvents are released in the use stage and potential effects are human toxicity and POCP. Here, it is important to look at emissions in the use stage but it may often be possible to include potential effects in the disposal stage only.

Disposal stage

As a result of an uncertain end disposal method, the ultimate fate of a chemical compound is estimated by evaluation of its physical and chemical properties. For persistent chemicals and heavy metals it must be expected that the full amount ends up in the ambient media; it is a matter of time - and of concentrations. Thus impact in the disposal stage must, in case of uncertain information on the end-disposal, be calculated as emission of the full amount left after the use stage.

Either the raw material stage or the disposal stage may be excluded from the calculation of impact from the life-cycle. However, such a decision must be based on sector-specific arguments and only on a sector-specific basis. It can not in general be concluded that the raw material or disposal stages could be left out.

4.4.3 Evaluation concept

In dealing with the use of chemicals in the present project the focus is not on resource depletion; this is taken care of in the focus areas; materials (M) and energy (E). Evaluation of use of chemicals focus on the effects from emission of chemical compounds and from deposition of waste.

Environmental effects from the use of energy are assessed in focus area 4.3. It is only in very special situations that gaseous emissions from combustion of energy can be mixed with emission of chemical compounds from the production process itself. Examples are production of mineral wool or virgin steel in cupol ovens or production of cement etc. Here, it will be difficult to determine exactly which effects originate from fuel combustion and which from release of chemical compounds. In these cases the consumption of primary energy in the production process should be calculated as described in 4.3 and potential effects from known chemicals calculated as described in this section.

It is possible, though, to state which effects are *mostly* from combustion of fossil fuels and which are *mostly* from emission of chemicals. Those that can be attributed solely to the use of chemicals are toxic effects, so aggregation of toxic effects is used at level 0. In the case of suspected additional effects, however, these effects should be included at level 1. In many cases this means that it is necessary to proceed directly to level 1 for further evaluation.

Level 0 indicators for screening purposes

The level 0 indicators for screening purposes are tools to be seen as a “process-filter” permitting processes or parts of the technologies’ life-cycles to pass through, retaining only those that give important contributions to chemical-related environmental impacts. Exposure data like persistent toxicity and bioaccumulation giving rise to possible distribution over large areas and possibility for effects to coming generations is rated equal with acute effects.

It is considered important that level 0 indicators for screening purposes should be few, and based on easily accessible data.

Scoring system

The level 0 indicators for environmental effects related mainly to the emission of chemicals for technology alternatives are:

- Persistency and/or bioconcentration, assessed and categorised with the use of scores.
- Ecotoxicity and human toxicity: A combination of released amount and classification ac-

cording to hazards (through the use of classification for labelling) categorised with the use of scores.

Potential toxicity is then grouped according to problem level using scores (S) and a formula of the form:

$S_{\text{Potential toxicity}} = S_{\text{amount}} * (S_{\text{persistency}} + S_{\text{bioaccumulation}} + S_{\text{human tox}}. + S_{\text{ecotox}}.)$

Methods for calculation of level 0 indicators are shown in the matrix, Figure 4.4.5, page 59.

The method is one among other methods based on similar principles, which are:

Environmental impacts from an emission depends on the amount, the dispersion in the environment and the effect(s).

In the formula above persistence and bioaccumulation represent dispersion and toxicity represents effects. The method uses scores for selected properties. For each of the parameters; amount, dispersion and effect a score from 0 to 3 is assigned. By combination of the three parameters an assessment score is calculated. The assessment score gives 12 possible levels (0, 1, 2, 3, 4, 6, 8, 9,10, 12, 15 and 18). These levels can indicate whether a given emission is non-problematic, potentially problematic or problematic.

The method does not pretend to establish an exact or scientific assessment, it merely points out the seriousness or "problem level" of the potential health and environmental impacts. The purpose of the method is to illustrate: how serious is the environmental impact and thereby to assist decision makers in the process of environmental management, product development, etc.

To meet the requirements on data availability and simplicity of use, it is considered appropriate that the choice and definition of level 0 indicators should be made separately for the different industrial branches. They should be based on the knowledge of specific chemical-related impacts that are relevant within each branch, regarding also estimates of the emitted quantities. This way indicators may be limited to potential toxicity for the majority of industrial sectors.

Use of classification for labelling

Use of classification for labelling in the form of R-sentences means that it is only possible at level 0 to include the chemicals that are classified, i. e. volume chemicals. In addition it must be realised that a certain amount of subjective judgement is used for a decision on classification, where a number of organisations must reach a compromise.

Analysis and suggestion for indicators at level 1

The indicators used are generally as considered in the EDIP method.

Particularly if VOCs are used, it will not be appropriate to aggregate any further than level 1, since it must always be considered if the indicators used at level 0 are representing all significant effects from chemicals.

At level 1 the toxicity indicators are shown as the categories persistency/bio-accumulation, human toxicity and ecotoxicity. The photochemical ozone formation is also included at this level.

Indicators are calculated using the critical volume model and equivalence factors are shown in Figure 4.4.3.

Critical volume model

A procedure for calculating the ecotoxicity potentials, is given by Hauschild et al.(1996[5]). Up to four ecotoxicity potentials are calculated for each substance; for acute ecotoxicity in water, for chronic ecotoxicity in water, for chronic ecotoxicity in soil, and for ecotoxicity to microorganisms in sewage treatment plants.

The ecotoxicity potential is measured in m^3 of the compartment. It corresponds to the volume of the compartment to which the emission should be diluted in order to obtain a concentration of substance so low that no ecotoxic effects would be expected from the emission.

The Equivalence Factor EF is calculated as the product of three factors which represent the substance's dispersion in the environment, its ecotoxicological characteristics and its biodegradability. The equivalence factors for ecotoxicity depend exclusively on the characteristics of the substance. A more detailed description of the procedure can be found in Hauschild et al. (1996[5]).

When using the 'critical volume' model much of the work of the redistribution calculations and the calculation of equivalency factors consists of finding the necessary data for the substance's chemical and ecotoxicological characteristics.

Calculation of the *redistribution factors* requires a knowledge of the substance's

- Henry's Law constant
- atmospheric half-life
- P_{ow}

Calculation of *ecotoxicity factors* requires information on its

- Ecotoxicity
- Possibly P_{ow} and K_d

Calculation of the *biodegradability factor* requires a knowledge of the substance's

- biodegradability

These data can be found in the literature or more readily in various databases in books or electronic data media. A list of databases can be found in Section 4.4.5.

Suggestion for indicators at level 2

Evaluation Parameters and Criteria

Within each of the impact categories outlined in Figure 4.4.3 a method is proposed to aggregate all the emissions contributing to this impact category into a single parameter, the indicator. This indicator represents the potential contribution to that environmental impact category from the process or the chain of processes subject to evaluation. At level 2 LCAs are used, in this report exemplified by the methodology, which has been developed in the EDIP-program (Wenzel et al., 1996[5]):

Issues	Equivalence factor	Information source
Global warming	g CO_2-equivalents	IPCC (Albritton et al., 1995) [28]
Stratospheric ozone depletion	g CFC11-equivalents	World Meteorological Organization (WMO) (Solomon and Wuebbles, 1994)[29]
Photochemical ozone formation	g C_2H_4-equivalents	Anderson-Skjöld et al., 1992[30], Derwent and Jenkins, 1990[31]
Acidification	g SO_2-equivalents	Hauschild et al., 1996[5]
Eutrophication	g NO_3^-equivalents	Hauschild et al., 1996[5]
Toxic contamination (toxicity and ecotoxicity)	“Critical volume”	Hauschild et al. 1996a, 1996[5]

Figure 4.4.3: The equivalence factors used for each environmental effect category

[28] Albritton, D.L., Derwent,R.G., Isaksen, I.S.A., Lal, M. and Wuebbles, D.J.: Trace gas radiative forcing indices. From Houghton, J.T., Meira Filho, L.G., Bruce, J., Lee, H., Callander, B.A., Haites, E., Harris, N. and Maskell, K.: Climate change 1994, Radiative forcing of climate change and an evaluation of the IPCC SD92 emission scenarios. Cambridge University Press, 1995.

[29] Solomon, S. and Wuebbles, D.J.: Ozone depletion potentials, global warming potentials and future chlorie/bromine loading. From Albritton, D.L., Watson, R.T. and Aucamp, P.J. (Assessment Co-chairs): Scientific Assessment of Ozone Depletion: 1994. World Meteorological Organization, Global Ozone Research and Monitoring Project - Report No. 37, World Meteorological Organization, Geneva, 1995.

[30] Anderson-Skjöld, Y., Grennfelt, P. and Pleijel, K.: Photochemical Ozone Creation Potentials: A study of different concepts. J.Air Waste Manage. Assoc. 42(9), 1152-1158, 1992.

[31] Derwent, R.G. and Jenkins, M.E.: Hydrocarbon involvement in photochemical ozone formation in Europe. AERE R 13736, AEA Environment and Energy, Harwell Laboratory, Oxfordshire OS11 0RA, U.K., 1990.

Climate change as a consequence of the greenhouse effect

The total Global Warming Potential (GWP) expressed as kg CO_2-equivalents and calculated as the product of the emitted quantities of greenhouse gases and their respective global warming potentials. For the major part of industrial processes the global warming potential originates from use of energy. For this reason it is not considered a representative indicator at levels 0 and 1.

The source of data is primarily reports from the World Meteorological Organization. As for the Global Warming Potentials this data includes fate, exposure and effect considerations. They have been evaluated by an international expert panel and must be considered good quality.

Stratospheric ozone depletion

The total Ozone Depletion Potential (ODP) expressed as kg CFC11-equivalents and calculated as the product of the emitted quantities of ozone-depletion gases and their respective ozone depleting potentials.

Ozone depleting substances are heavily regulated in Europe and they are to be phased out. This process is being supervised by the national EPAs. For this reason ODP is not considered a representative indicator at levels 0 and 1.

The man-made substances contributing to the stratospheric breakdown of ozone are simple gaseous organic compounds with a substantial content of chlorine or bromine. The most important groups of ozone-depleting halocarbons are the CFCs, the HCFCs, the halons and methyl bromide.

The source of data is primarily reports from the World Meteorological Organization. As for the Global Warming Potentials this data includes fate, exposure and effect considerations. They have been evaluated by an international expert panel and must be considered good quality.

Photochemical Ozone Formation

For photochemical ozone formation (POCP) the reference substance is the gas ethylene (C_2H_4). The significance of NO_x for ozone formation is reflected in the fact that two sets of equivalency factors are used; one for emissions of VOCs occurring in areas with a low background concentration of NO_x and one for emissions occurring in areas with a high background concentration of NO_x. In the references cited, POCP values have been calculated only for the individual VOCs of greatest significance for total photochemical ozone formation in Europe. But these are not necessarily the compounds of greatest significance for a particular process. It can therefore be an advantage to be able to make an estimation of missing POCP values. Hauschild et al. (1996[5]) describe various methods of estimating POCP values.

There is no international panel of experts for the environmental impact of photochemical ozone formation such as there is for GWP and ODP. Agreement among participating countries in the UNECE on use of the POCP factor system is therefore the closest approximation to international recognition of any equivalency factor system for photochemical ozone formation. The POCP values are calculated with the aid of atmospheric chemical models and a series of assumptions must be made on climatic conditions and the magnitude of the simultaneous emissions of a number of other VOCs and of NO_x. The assumptions are discussed in the references presenting these POCP values (Andersson-Sköld *et al.*, 1992, and Derwent & Jenkin, 1990).

However, the variation between POCP values are rather small (about one order of magnitude in the most extreme cases) so even average data for VOCs may not introduce significant errors.

The majority of the NO_x, which must be present in order to get photochemical ozone formation, is a result of combustion of fossil fuels. The toxicity effects from VOCs are included at level 0, so it is only considered appropriate to include photochemical ozone formation at level 1. For these reasons photochemical ozone formation is not included at level 0.

Acidification

For a substance to be considered a contributor to *acidification:*

1. it must cause introduction or release of hydrogen ions in the environment and
2. the anions which accompany the hydrogen ions must be leached or washed out from the system.

Acidification is mainly due to combustion of fossil fuels, but in certain cases e.g. in the production of virgin steel, it may be a significant effect from the industrial production itself.

Eutrophication

For a compound to be regarded as contributing to *eutrophication*, it must contain nitrogen or phosphorus in a form, which is biologically available.

Eutrophication can be caused by emissions to air, water and soil. The main contributors are emission of sewage from households, agriculture and outlets from wastewater treatment plants and for industries emitting compounds that contain N or P. This is the case for food-production (dairies, slaughterhouses, fish-processing etc.), ammonia emissions from livestock and for the production of certain pesticides as examples.

Both acidification and eutrophication are significant problems only in certain geographical areas. For this reason they are considered local problems, which are included at level 2 only.

Human toxicity

Toxicity can be attributed to many different types of poisonous impacts, and a list of substances which can cause human toxicity in the environment may include thousands of entries. Hauschild et al.[5], have developed a procedure to calculate toxicity potentials for substances, which is shortly explained below. Up to four toxicity potentials are calculated for each substance; for toxicity to humans via air, for toxicity to humans via surface water, for toxicity to humans via soil, and for toxicity to humans via groundwater.

The toxicity potential is determined as the product of the quantity of substance Q emitted and the substance's Equivalence Factor EF for exposure through the compartment in question.

The *toxicity potential* is expressed in m^3 of the compartment and corresponds to the volume of the compartment into which the emission should be diluted for its concentration to be so low that no toxicological effects could be expected from the emission.

The equivalence factor is calculated as the product of four factors which represent the substance's dispersion in the environment, the efficiency of intake for the actual exposure route, the substance's toxic characteristics, and its biodegradability. The toxicity potential depends exclusively on the characteristics of the substance. A more detailed description of the procedure can be found in Hauschild et al.[5]. Toxicity effects are in the majority of industrial cases related to emission of chemicals only and are therefore used at levels 0 and 1.

Ecotoxicity

Ecotoxicological impacts can involve many different mechanisms, with the common feature that they all result in direct toxic impacts at one or more hierarchical levels in an ecosystem. Ecotoxicity, like human toxicity, has the character of a composite category including all substances, which can have a direct effect on the health of the ecosystems. The list of substances classified as contributing to ecotoxicity will therefore be much more comprehensive than the corresponding lists of the other environmental impacts, and it will include many different types of substances with widely differing chemical characteristics and effect categories.

Ecotoxicity is mostly connected with chemicals and is therefore used at levels 0 and 1.

A procedure for calculation of the ecotoxicity potential is described with level 1 and in Hauschild et al.[5]. The procedure used in EDIP is used for this concept.

4.4.4 Discussion

It is recommended at level 0 to use persistency and/or bioaccumulation for assessment of chemicals used, since these factors determine the long term environmental risk from use of chemicals. As can be seen from the source below[32], very little data exist on persistency (it was inferred that data were not available). For bioaccumulation log K_{ow} (also log P_{ow}) is used and virtually no data exist on actual experiments with bioaccumulation.

Figure 4.4.4: *Available data concerning the toxic effects of High Production Volume chemicals (2000 - 2500 chemicals) estimated by the ECB, ISPRA, 1996*[32]

[32] Bro-Rasmussen et al., 1996: Non-evaluated chemical substances. Teknologirådets rapporter 1996/2)

Effect	Estimated data availability
Acute toxicity	90%
Sub-acute toxicity	53%
Carcinogenicity	10% (1992 estimate)
Mutagenicity	62%
Fertility	20%
Teratogenicity	30%
Acute ecotoxicity (fish or Daphnia)	55%
Short term ecotoxicity (algae)	20-30%
Toxicity to terrestrial organisms	5%

It is remarkable that so little data exist on long term environmental risk; in addition to exposure (expressed as persistency and bioaccumulation) this includes chronic toxicity.

The fact that data are not available for parameters, which are considered key indicators for chemicals may influence the use of the CEIDOCT concept for the moment. It is a general tendency in evaluation of chemicals that these parameters are considered of major importance, so more data are obviously needed.

At present only a few chemicals have been considered for classification of ecotoxicity. This fact will probably hamper use of the concept using a top-down indicator at level 0 at the moment. In these cases, it will be necessary to go directly to level 1.

Emission of VOCs as representing photochemical ozone formation is relevant for emission of chemical substances, but smog is not formed without the presence of NO_x, which originates from combustion of fossil fuels. Also the toxicity of VOCs is included in calculation of the potential toxicity at level 0. For these reasons it has been decided *not* to include photochemical ozone formation in the calculation of the aggregated indicator at level 0. If VOC emissions from the industry are significant it will be necessary to go directly to level 1.

4.4.5 Databases

Below is a brief description of the databases to be used for evaluation of chemicals' toxicity and ecotoxicity.

Aquire:

Aquatic Information Retrieval Toxicity Database. Database with ecotoxicological substance characteristics developed for the US EPA. The latest version contains more than 100,000 test results for 5,600 chemicals collected from over 7,000 scientific publications. All test data are assessed and classified by the US EPA. Available in PC version.

Blum & Speece, 1991:

Study of toxicity of 52 different organic chemicals to nitrogen-fixing and heterotrophic bacteria.

Howard, 1990:

Database of various environmental chemical data relevant to assessment of the fates of organic substances in the environment. Data for 151 organic compounds in volumes 1 and 2.

Howard et al., 1991:

Database of rates of degradation in the environment and in a sewage treatment plant. Data for 336 organic compounds.

HSDB:

Hazardous Substance Data Bank. Information on human toxicological and ecotoxicological characteristics and information relevant to assessment of a substance's fate in the environment. Contains comprehensive review of app. 4,500 chemicals. Published by the National Library of Medicine, USA. Information included in HSDB is assessed and approved by a scientific review group. Available on CD-ROM.

IRIS:

Integrated Risk Information System. Database with information on human toxicity, ecotoxicity and fate in the environment. Prepared by the US EPA for over 300 environmentally toxic chemicals. Contains evaluated data. Available on CD-ROM.

IUCLID:

International Uniform Chemical Information Database. Database presenting the environmental data supplied to the European Chemicals Bureau (ECB) on more than 1400 chemicals that are produced or marketed within the EU in annual quantities larger than 1000 tonnes. The information is not evaluated. Available on CD-ROM.

SRC-software:

Software developed by Syracuse Research Corporation for estimating properties like log P_{ow}, atmospheric half-lives and Henry's law constant based on the molecular structure of the substance.

Verschueren, 1996:

Contains information on environmental characteristics for about 2,400 organic compounds. The information is not evaluated.

Nikunen et al., 1991:

Contains information on environmental characteristics for more than 1,700 chemicals. The information is not evaluated.

The section on sources of data for use in the calculation of ecotoxicity potentials above presents a number of databases which can also be used for collection of the data entering into the calculation of human toxicity potentials. Apart from these databases, there is a further one which is relevant only for the calculation of human toxicity potentials because it contains human toxicological data, *viz*.

RTECS:
Registry of Toxic Effects of Chemical Substances. Information on toxicological characteristics. Published by the National Institute for Occupational Safety and Health in the USA. The information is not assessed. Available on CD-ROM.

Figure 4.4.5: *Environmental Performance Indicator (EPI) model for emission of chemicals in Cleaner Technology Assessment*

Indicator level	**Environmental Performance Indicators - CEIDOCT EPIs**					
Level 0	Potential effects from chemicals, evaluated as scores, using classification for labelling: $EPI = S_{amount} * (S_{persist.}$ or $S_{bioaccumulation} + S_{toxicity})$, where $S_{toxicity} = S_{humantox} + S_{ecotox}$					
	Unit	CRITERIA FOR APPLICATION OF SCORES IN LEVEL 0				Ref.
		0	**1**	**2**	**3**	
AMOUNT	kg/year	< 0.5	0.5 - 2	2 - 10	≥ 10	
PERSISTENCY						
Degradation in soil	T½. month	<0.1	0.1 - 1	1-3	≥ 3	/1./
Degradation, water (OECD, 28 d test)	DOC-red. %	≥ 95	70 -95	40 - 70	< 40	/1./
Degradation, water (OECD, 28 d test)	CO_2-extern. %	≥ 90	60 - 90	30 - 60	< 30	/1./
Degradation, water	BOD_5/COD	≥ 0.8	0.5 - 0.8	0.3 - 0.5	< 0.3	/1./
Degradation atm.	T½, month	< 0.1	0.1 - 1	1 - 2	≥ 12	/1./
Classified in EU legislation					R53	/2./
BIOACCUMULATION Classified in EU legislation	$P_{ow} = \log K_{ow}$	<1	1-3	3-5	≥ 5 R58	/1./
TOXICITY If substances are classified according to Council Directive 67/548/EEC on classification, packaging and labelling of dangerous substances. EEC. Amendment Dec. 1994	•		For human toxicity Xn; R 20-21-22 Xi; R 36-37-38 For ecotoxicity R 52	For human toxicity T; R 23-24-25 C; R 34-3-41 Xi; R42-43 Xn, T; R39-40 or R 48 in combination with R 20-21-22-23-24-25-33 For ecotoxicity R51	For human toxicity Tx; R 26-27-28 Tx; R 48 or R39 in combination with R 26-27-28 Xn; R 40-46-62-63 T; R 45-46-60-61 For ecotoxicity R 50-54-55-56	/2./
Level 1	Calculation of critical volumes, weighted, for the categories (as EDIP): • persistency • human toxicity • ecotoxicity • photochemical ozone formation					

/1./ List of classification, packaging, labelling, sale and storage of chemicals. Danish Ministry of the Environment (order no. 829 of 15.10.93, last amendment 7.2.1996)
/2./ EU legislation Council Directive 67/548/EEC on classification, packaging and labelling of dangerous substances. EEC. amendment Dec. 1994

4.5 Biological resources

4.5.1 Description of the focus area

General considerations

Humans depend on biological resources for food, energy, construction, medicine, recreation, inspiration etc. These biological resources are generally renewable when they are properly managed. But biological resources that are abused can become extinct or damaged in other irreversible ways.

The aim of this section is to discuss how human impact on biological resources in relation to cleaner technologies, if possible, can be assessed using a few clear indicators.

Only man-made ecological threats are taken into consideration whereas natural disturbances such as fire, flooding, volcano eruptions, deforestation caused by wind blow-downs and aforestation caused by succession etc. are viewed as background conditions and not considered here. The indicators must at the same time be applicable for assessment at industry level and express key properties for biological resources and species.

Cultivation and direct exploitation

An overall indicator may be based on productive area, related to cultivation potential or on the species pool as a target for direct exploitation. The implications of choosing either of these factors will be analysed, based on their relationship to other environmental factors, influence of quality parameters, etc. Since production from these sectors have the most well-established relations to relevant technologies, they will form the core of the analysis.

Biodiversity

For natural reserves and biodiversity the basis is probably premature for aggregation. Known assessment principles will be reviewed with a view to the actual assessment framework. In particular, traditional carrying-capacity considerations will be viewed against the sustainability concept.

Primary production, photosynthesis

Plants are the primary producers of ecosystems as they via photosynthesis produce organic matter. Photosynthesis is the main mechanism of energy input into living organisms. Primary production is dependant on four main factors:

- light
- water
- CO_2
- nutrients

A part of this primary production is lost through respiration, while another large part is consumed by the heterotrophic organisms. One study suggests that humans today annually mobilise approximately 40% of the total primary production in terrestrial ecosystems. This massive and pervasive exploitation of resources leads inevitably to significant impoverishment of the biota[33].

Biological production in terrestrial ecosystems

Primary production in terrestrial ecosystems is usually measured as tons dry matter biomass/ha/ year or in smaller scale as g/m^2/day. The primary production in agricultural systems depends on the type of crop as well as on the number of crops/year.

The primary production in natural ecosystems, and thereby the annual yield or increment is dependant on the age of the ecosystem. In managed forests the production is dependant on the tree species, the stand density (number of trees/ha), and the rotation age (years). In for-

[33] McNeely, J.A., Gadgil, M.; Leveque, C.; Padoc, C. & Redford, K. 1995. Human influences on biodiversity, pp: 711-822. In: Heywood, V.H. & Watson, R.T. 1995. Global Biodiversity Assessment. UNEP Cambridge University Press.

estry the annual increment of wood in the stand is measured as m^3/ha/year. Most organic matter in a forest is stored in wood.

The harvest yield of arable lands is usually measured as fresh weight (tons/ha). The potential stocking rate (number of livestock/ha) is sometimes used as a measure for the productivity of pastures.

Biological production in aquatic ecosystems

Biological productivity in aquatic systems, including in particular the Sea (marine ecosystems) but also a diverse range of inland water bodies (lakes and wetlands) is governed by the same basic processes as terrestrial production, though the physical and biological conditions as well as the human exploitation differ markedly in practice.

Light and nutrients are in general the limiting factors for growth, with nutrients as the most common key factor. Production in aquatic systems is in general considerably lower per unit area than for productive terrestrial systems. Wetlands dominated by emergent plants (e.g. reed or cattail) are exceptions as they range among the most productive ecosystems of all.

In particular, most of the ocean area (covering 71 % of the earth surface) are low-productive areas without practical significance in terms of biological resources. The areas of practical significance are

- coastal sea areas
- upwelling areas, i.e. areas characterised by upwelling of nutrient-rich water from deeper layers.

The occurrence of productive zones in the sea is therefore at least as patchy as on land.

Carrying capacity

Carrying capacity is discussed here as it is a well established concept in particularly terrestrial ecology, which could support the development of an evaluation concept.

In the tradition of ecologists carrying capacity of an ecosystem is defined as the maximum use or disturbance an area can support without unacceptable changes in ecosystem structure or decrease in environmental values. Usually carrying capacity is regarded as, for instance, the maximum population of consumers (e.g. grazing animals) being able to live in a specific area without resulting in detrimental effects such as overgrazing or pollution[34].

The carrying capacity is closely related to the resilience of the ecosystem, i.e. the ability of an ecosystem to absorb stresses created by external disturbances without modification of the system.

Human exploitation and carrying capacity

The human exploitation of biological resources has resulted in impact on the global environment, indicating that todays use is above the carrying capacity of the natural ecosystems and thereby insustainable[33] :

- Exploitation of wild living resources
- Intensification of agriculture, forestry, and aquaculture
- Habitat fragmentation
- Wetland drainage and reclamation
- Overgrazing, deforestation, desertification and degradation
- Detrimental effects of species introduced by humans
- Building developments
- Pollution of soil, water and atmosphere
- Global climate change

Sustainability

Sustainable development characterises a development that meets the need and aspirations of the current generation without compromising the ability to meet those of a future generation.

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[34] Heywood V.H. & Watson, R.T. 1995. Global Biodiversity Assessment. UNEP Cambridge University Press. 1140 pp.

Conservation of biological resources for sustainable development has three main objectives (modified after [35]):

- to maintain essential ecological processes and dynamic systems.
- to preserve biological diversity.
- to ensure sustainable utilisation of species and ecosystems.

Proper area management as a prerequisite

Most of the environmental considerations behind a given biological resource can be summed up as two key assumptions:

1. Whether land use on a local and regional scale is managed on a sustainable and environmentally sound basis.

   By land use management is understood the allocation of land to farming, grazing, forestry, settlement and infrastructure, and wildland.

2. Whether cultivation or management practices of specific areas are sustainable and environmentally sound.

   This point refers to the land owner's practice.

Land management and cultivation practice are complex issues, often with profound socio-economic implications on a local or regional scale. The complexity is further increased by the spatial heterogeneity of the civilised world. Environmental considerations are being applied to these issues in many countries and regions.

Commercial agriculture

In commercial agriculture and forestry the production is usually based on an input of fertilisers, pesticides and irrigation. Commercial agriculture does not only effect the area of arable land but will always have impact on adjacent natural ecosystems in terms of fragmentation, eutrophication, obstruction of migrating species etc.

Traditional resource management practices

In contrast a number of traditional resource management practices have supported the maintenance of valuable habitats and biological diversity. Low input agriculture maintain important biological resources as farmers frequently grow mixtures of different crops adapted to different localities in order to reduce the risk of loss to pests or extreme weather. Environmentally sound silvicultural systems such as selection felling can in the same way maintain local diversity and ecosystem function, as the areas are constantly covered with the stand and no clear-cuttings occur.

Environmentally sound biological production is a relevant cleaner technology concern

Therefore, it is a relevant concern whether a given biological resource, available for technological elaboration, has been produced under environmentally sound conditions. This concern applies especially to raw materials derived from remote sources. A major fault at this point could considerably affect an otherwise clean technology.

4.5.2 Evaluation Concept

Framework

Human utilization of biological resources occurs in two predominant ways:

- Direct utilisation of a wild resource e.g. fishing or hunting (exploitation)
- Utilisation of land for agriculture or forestry

It is assumed that agricultural resources and forestry can be assessed on a common basis.

[35] Green, B. 1996. Protecting European cultural landscapes. pp. 5-22. In: Primdahl, J. & Brandt, J. (eds). Nye vinkler på kulturlandskabet. Rapport fra det 5. landskabsøkologiske seminar. Center for landskabsforskning. RUC.

Characteristics of biological resources

The framework for evaluation is based on the common characteristics of biological resources:

- All biological resources are the result of photosynthetic primary production in natural or managed (eco)systems, each system having a limited yield per unit area.
- The overall annual production rate of biological resources is limited, and sustainable use must account for the global demand for food, non-food utilisation and nature protection.

In a cleaner technology framework the immediate resource input can be characterised as a certain amount and type of biomass required per produced unit.

Biological materials are normally specified by organisms

In this study the qualitative characteristics of a given biological material is referred to as "type". This term was found particularly suitable in this context because the users of biological resources generally specify their requirements in terms of the organism or range of organisms required, and the part of that organism, which is demanded. There may be other qualitative requirements for production, but they are less likely to be of any significance for environmental assessment. The assumption that the user will specify organism of origin can be used as basis for the practical assessment approach.

The potential for re-cycling of biological resources differs widely between materials and application, as materials of biological origin have an inherent, but highly variable potential for degradation. Re-cycling of paper is probably the most familiar example. Re-cycling of biological resources often leads to successively lower grade products, with combustion as the typical end-use.

Biomass and area are related

Production of a given amount of biomass again represents an area requirement, which varies depending on the type of biomass and the ecological conditions.

It should be noted that area requirement relates, not to an amount of biomass (e.g. kg), but to an annual yield or consumption rate (e.g. kg/year).

Interaction with other resources

Other resources

The availability and utilisation of biological resources have complex interactions with the other focus areas evaluated in this study. Major interactions are identified below:

Water resource

- The water resource is the overall key factor for biological production in terrestrial ecosystems. (In this context the water resource is understood as fresh water). Availability of water is directly limiting the amount produced per unit area per year over most of the Earth. Northern and Central Europe belong to the relatively few zones where this dependence is relieved due to a cool, humid climate.

Energy

- Utilisation as an energy resource. This utilisation may under some circumstances compete with area use for food production and structural compounds. However, utilisation for energy is often an incidental earning based on the low grade fraction of a crop, such as straw or "scrap" wood.

Substitution of non-renewable resources

- Utilisation as substitute for non-renewable resources. In numerous cases biological resources can substitute non-renewable resources. Examples include wood for structures, and various materials and chemicals where oil can be substituted by natural compounds as raw materials. In this way a renewable resource is introduced, but it is drawn from a limited an nual potential, which involves the global demand for food.

Pollution

- Biological production is sensitive to pollution in numerous respects, and can thereby be affected by technology.

4.5.3 Potential indicators

The indicators described below are selected environmental parameters that provide a measure of impact on a qualitative/semi-quantitative scale. In order to create a scientifically rigorous basis for their potential use, they must be well defined and possible to estimate with satisfactory precision.

The proposed indicators for assessment of impact on biological resources comprise:

- area
- biomass
- biodiversity
- freshwater resources

Area

Arable areas

World-wide there is a total of 13.15 x 10^9 ha of land, but most of it is not suitable for cultivation. About half of it is non-arable and consists of mountains, glaciers, deserts, swamps etc. About 25 % of the areas supports sufficient vegetation to provide grazing for animals but cannot be cultivated. This leaves 25% of the land with physical potential for cultivation, but only half of this potentially arable land is actually under cultivation[36]. The cultivation value of the potentially arable land can furthermore be decreased by:

- drought
- mineral stress
- shallow depth
- water excess
- extreme climatic conditions

Soil classification

Soil productivity and cultivation potential depends on soil properties such as

- topography
- natural drainage
- texture and organic matter content of the top soil
- texture of the subsoil
- field capacity
- structure and porosity

In the classification of soils also the following climatic factors are taken into account

- precipitation
- solar radiation
- temperature
- potential evapotranspiration
- actual evapotranspiration

Soil fertility depends on the amount of accessible water, which in most cases is the only limiting factor to agricultural plant production. Soil fertility in terms of plant nutrient availability plays a minor or secondary role[36].

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[36] Brady, N.C. 1984. The nature and properties of soils. MacMillan Publishing Company. New York.

Commercial agriculture has led to considerable changes in the landscapes, transforming the complex mosaic of micro habitats into a uniform unity favouring a few crop species. Small landscape elements such as hedgerows, fallow-fields, tree groves and riparian vegetation are often lost in this process.

Exploitation and nature protection

Given a limited total land area it is obvious that nature protection, and thereby biodiversity is affected by land occupation for cultivation and other exploitation of biological resources.

Though culture and nature can be seen as alternatives for land use they are not simply interchangeable, for several reasons.

- Between intensive culture and wildlands there is a wide range of practices for extensive culture and exploitation. Extensive exploitation applies to many areas which are commonly perceived as nature, and extensive exploitation is the economic basis for much of the nature protection that is practised at present.
- Extensive utilisation is often caused by a lack of suitability for intensive utilisation. This may be due to factors like soil conditions, slope or remote location. Often, however, the suitability is governed by climate, with the water balance as the key factor. Large areas in arid or semi-arid zones are managed by extensive grazing or forestry, and can only be cultured more intensively if irrigation is provided. The significance of the water balance is discussed in more detail later in this section (p. 77).

Areas of special conservation value

Areas containing special conservation values usually possess one or more of the following qualities:

- varied wildlife populations (number/area)
- natural functional plant communities (number/area)
- habitat corridors (km per type)
- recreational and amenity values (number of visitors/area)
- educational or scientific potential
- scenery

The assessment of soft values such as scenery and educational or scientific potential is extremely difficult.

The following indicators for assessing the impact of agriculture and forestry on biological resources, as well as the detrimental effects on the nature areas have been proposed (modified after proposal by The European Commission, Eurostat[9])

- area used for intensive agriculture (% of total arable land area)
- area of forest cultivated with exotic species in monoculture (% of total managed forest area)
- clearance of natural and semi-natural forested areas (ha/year)
- loss of natural and semi-natural grasslands (ha/year)
- landscape fragmentation by roads/inter-sections (km/ha per habitat type)
- loss of corridors, linear landscape elements (km/year)
- urbanisation of rural areas (ha or % of total per habitat type)

One major problem in using these indicators is that they are too difficult to relate to the amount of products derived from biological resources, e.g. how many km of dispersal corridor is lost per kg barley grain produced?

Area as an aggregated indicator?

As described above biological production can in most (80%) cases be related to a specific area of land. The production in this specific area will influence other factors depending on the area management and/or production system:

- freshwater resources
- potential biomass production

- biodiversity potential

Biomass

The term biomass is commonly used for arbitrary dry matter directly obtained from biological production. In this study it is used as a common term for the resource input, indicating that it can be characterised by its weight.

It is obvious, however, that technological use of biomass depends strictly on its composition and type. This is true for typical non-food resources like timber, vegetable oil and fibre, e.g. cotton.

High-grade and low-grade fractions of biomass

Most crops can be divided into a high-grade fraction and one or more low-grade fractions. Examples of low-grade fractions are timber refuse, straw, and molasses.

In many cases the economic interest of the land owner is based entirely on the high-grade fraction. If market conditions do not favour utilisation of the low-grade fraction it is often simply abandoned: allowed to decompose, or burned. Transport is often a key problem with resources of low value per unit weight.

When biomass is viewed as a renewable resource having a limited annual exploitation rate, however, the best resource economy would be utilising also the low-grade fractions of biomass.

In practice energy production is the most wide-spread use of low-grade fractions, but several examples exist of upgraded use due to new technologies. Use of timber refuse for chipboard is a familiar example.

From an assessment point of view it clearly makes a difference whether a resource demand relates to a high-grade resource with alternative use or an otherwise useless low-grade fraction, to mention the extreme cases. The first case would increase the demand of land use, the second would not. Many practical cases are intermediate in this sense.

Biomass as an indicator?

Data on biomass are both well documented and readily available data in most cases of utilisation. For many specific resources the demand for a given technology can be related to an annual potential resource in an operational way.

An advantage of biomass is that the effect of differences in land fertility is cancelled as long as the same resource is considered. Often, however, one biological production can replace another, depending on market conditions.

The environmental impact of different productions differ widely. This includes the impact on area demand as well as impacts on nature protection.

In situations where alternative technologies utilise the same resource, biomass is clearly the most efficient parameter, as it relates directly to the demand. The same is true for comparisons involving resources which are reasonably comparable with respect to quality and conditions for cultivation.

When a comparison involves widely different biological resources, however, biomass cannot account for the differences in impact due to cultivation or exploitation.

Biodiversity

Biodiversity can be seen as an indicator for nature protection. A major reason for concern about biodiversity is the fact that loss of a biological species is an irreversible event, where its genetic information is lost.

Loss of species is a concern at the global level, and also on a more local scale, when rare species of limited distribution are considered. On a local scale, however, biodiversity can be affected in numerous ways by human practice, as well as by local disappearance and immigration of species, and thereby reflects the local environmental conditions, and to some extent the immediate situation.

Definition

Biological diversity is defined as the variability among living organisms from all sources including terrestrial, marine and aquatic ecosystems and the complexes of which they are part; this includes diversity within species, between species, and of ecosystems[34].

The most common measure for biodiversity is the number of species per area. It is important to emphasise that the biological diversity not only constitutes in the diversity of the species. Genetic diversity and diversity of habitats are equally important.

The compositions and levels of biodiversity

Diversity can be regarded as ecological, genetic and organismal (taxonomic) diversity, which comprises the following levels:

Ecological diversity	Genetic diversity	Taxonomic diversity
biomes bioregions landscapes ecosystems habitats niches	populations individuals chromosomes genes nucleotides	families genera species subspecies varieties

Complete lists of species can be difficult to obtain, and even when they can be obtained they may not be a good measure for site value. Temporary conditions may inflate the total species list with common and widespread species[37]. Species traits may therefore be a desirable component.

Indicator species

An indicator species is a species whose status provides information on the overall biotic or abiotic conditions of the ecosystem. They reflect the quality and changes in the environmental conditions as well as aspects of community composition. The presence/absence of these particular species can be used as parameters that provide a measure of an impact, at least at some qualitative scale. Indicator species can be useful tools in estimating environmental impact.

Rare and endangered species

The number of rare or threatened species in a community is widely used as an indicator for the value of a specific site. The national “red lists” of rare, vulnerable and endangered species comprises many species which are genetically impoverished, variable in population density, or on their limit of geographical distribution[34], and may therefore be too incalculable for use as indicators.

Many rare species are slow growing, long-lived species of modest fecundity being dependent on permanent habitat conditions[38]. These rare species are usually rare because of lack of suitable habitats. This suggests that the number of habitat types in a specific landscape would be a better tool for evaluating biological diversity.

Keystone species

The best way to minimise decline in species number is to maintain the integrity of ecosystem function[39]. It is therefore important to be concerned with the species that are significant to eco-

[37] Peterken, G.F. 1974. A method for assessing woodland flora for conservation using indicator species. Biological conservation. 6:239-245.

[38] Grime J.P.; Hodgson, J.G. & Hunt, R. 1986. Comparative plant ecology. Unwin Hyman, London.

[39] Walker, B.H. 1992. Biodiversity and ecological redundancy. Conservation Biology &:18-23.

system function (the so-called keystone species), rather than the total number of species present in the ecosystem.

Keystone species are defined as species whose loss from the ecosystem would cause a greater than average change in other species populations and ecosystem processes, species which have a large effect on other species in a community[34]. Examples could be the beech trees in a forest or the krill in the Southern Arctic Ocean.

Impacts on biodiversity can be quantified in several ways :

- decline in numbers of keystone species in different habitat types (number/habitat type/year)
- decline in number of indicator species in different habitat types (number/habitat type/year)
- decline in number of natural and semi-natural habitats in a specific landscape (number/type/year)
- decline in number of landscape elements in a specific landscape (number/type/year)
- loss of genetic resources through non-utilisation of available livestock genetic pool, crop species and varieties (number of available species and varieties)
- hunting or collection of wild flora and fauna (number of specimens or individuals killed or collected/year/habitat type)
- loss of genetic or habitat integrity by anthropogenic introduction of invasive species (number of species naturalised/ ha or habitat type).

Biological diversity as an aggregated indicator?

Measures of species diversity have application in conservation assessment, it being argued that sites with high diversity are more valuable than those with low diversity[39]. Low biodiversity of an ecosystem is not always an indicator of negative changes in the ecosystem. In for instance dunes, heaths, and raised bogs a high diversity of vascular plant species can be an indication of human impact such as disturbance, eutrophication, or invasion.

Biological diversity does not consider important ecological dynamic processes such as nutrient flows, energy flows, species migration and dispersal, and succession.

In relation to assessment of technologies, however, the main problem is, that in most cases the relationship between exploitation of biological resources and impacts on biodiversity is not sufficiently well defined to establish biodiversity as an indicator parameter. In such cases the impact on biodiversity must either be handled by

- case-by-case assessment,
- reference to the general situation: that an increased resource demand leads to an increased area demand, again leading to a loss of diversity,
- or by testing the assumption of good land management practices.

If a technology does not involve mass consumption of biological resources, its impact on biodiversity may be trivial.

When specific valuable compounds, derived from particular natural species, are exploited, the existence of the affected species may soon be challenged. In such cases the relationship between technology and biodiversity is easily established by relating demand to population size and fertility. Recent examples of such challenges to biodiversity have been reviewed by Pain[40].

Fresh-water resources

The fresh-water resource is the principal limiting factor for biological production on land, when viewed on a regional or global scale. This relationship is most conspicuous in warm-temperate, subtropical and tropical climates, while in cold-temperate and arctic climates the water resource problems have a more local character and relate more to water quality than to amount.

The dependence of biological production on water has several implications:

- In situations with a demand for water, alternative uses give rise to serious and complicated conflicts. A classical example is the conflict between hydropower and irrigation demands,

[40] Pain, S. 1996. Hostages of the deep. New Scientist 14 September 1996, pp. 38-42.

which is a familiar and wide-spread problem in developing countries. This conflict also is a key example of interaction between biological resources and energy.

- Impacts of climate change will typically depend on the extent to which the water balance is affected. In this way the emissions from human activity can have a feed-back impact on resource availability.

In the global context water is generally considered the most critical limiting resource for human civilisation.

Further, the large-scale exploitation of water disturbs the natural water balance, often leading to profound impacts on nature protection and biodiversity.

The amounts of water involved in regional conflicts of interest, such as land use, are several orders of magnitude higher than any industrial demand of water.

To assess water resources as a potential indicator for biological resources, it can be noted that large-scale water balances are well studied, both on local, regional and global levels, due to the vital economic interests involved. Thus an excellent reference basis and operational methods for characterisation are available.

The relationship to a given demand of biological resources is less obvious, and a generic relationship is probably not practicable. In more specific cases, where it can be shown that increased demand of a given resource leads directly to increased demand of irrigated land, the water resource demand is a highly relevant indicator, as it is likely to be a regional key issue.

Freshwater resource as an aggregated indicator?

The water resource is certainly a key factor for biological production in the global perspective. Further it has the operational advantage that the water balance is well covered by monitoring, globally as well as regionally.

The disadvantages of the water resource are that its relationship to specific resource inputs is of an indirect nature with several intermediate steps, and that it interacts with other climatic and geographic factors in a complex way. For these reasons impact on the water resource is not found to be an operational indicator for the present purpose.

Marine resources

Exploitation of marine biological resources is predominated by food production. In general only high-grade products like fish meat are relevant in view of the cost and energy consumption for retrieval.

Regulation of marine exploitation is a highly complex and sensitive political issue for numerous reasons.

In this context the possible utilisation of a marine resource for non-food technology on a large scale, and the impact of the new demand created, would most likely be governed by considerations which cannot be expressed on a common basis.

For these reasons the utilisation of marine resources is not seen as comparable with land-based biological resources, and it is not attempted to identify common indicators. Utilisation of marine resources should in general be a matter of concern, and reservations about sustainable practices should be made.

4.5.4 Discussion

General

The assessment of biological resource utilisation can be viewed as indicated on fig. 4.5.1. First the biological resource input has to be characterised with respect to amount and type. Then the method of procurement has to be identified and characterised, focusing on the question whether it can be characterised as cultivation or exploitation.

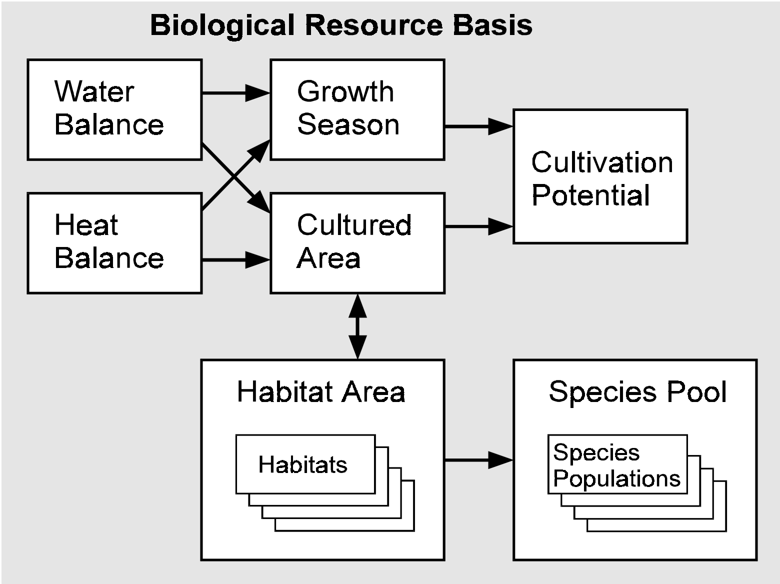

Figure 4.5.1: *Schematic model of interactions between heat- and waterbalance creating the basis for species pool and cultivation potential in terrestrial ecosystems*

Cultivation - area occupation as an indicator

When cultivation is considered, the area requirement for the required resource input is estimated. To assess the environmental impact the area occupation should then be related to a relevant measure of the global cultivation potential. This complex issue is discussed shortly below.

Exploitation - biodiversity as an indicator

When exploitation is considered, the identification of biological species or range of species is a key to assessment, and an evaluation of exploitation rate in relation to population yield (global and/or local, depending on circumstances) should always be performed, to assess whether there is a potential for over-exploitation. In general, over-exploitation cannot be converted to area occupation, but must be viewed as an independent dimension of impact, affecting biodiversity through the gene pool.

Many cases of exploitation, however, are intensive enough to affect the habitat area or interfere with potentially cultivable areas. Indeed a range of intermediate practices between cultivation and exploitation exist. When an impact on area occupation can be clearly defined, it should be analysed and utilised for assessment.

The biological resource basis

The complexity of the biological resource basis is clearly a problem for establishing an operational assessment basis for terrestrial ecosystems, i.e. a "scale" to compare indicators with. In Fig. 4.5.2 the resource basis is simplified as a box where "cultivation potential" and "species pool" are identified as immediate reference frames for area occupation and exploitation, respectively.

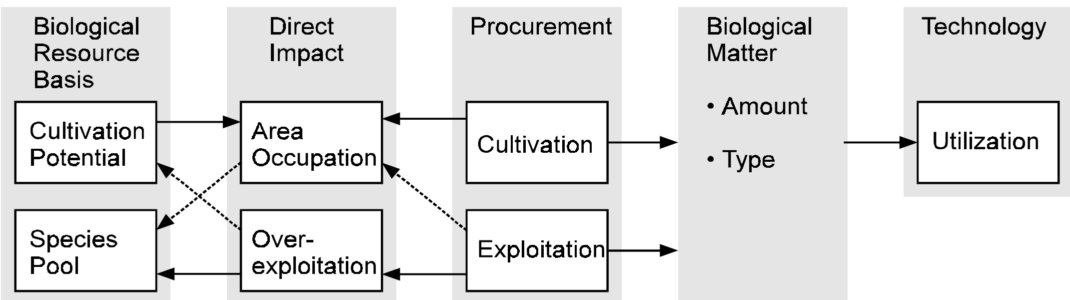

Figure 4.5.2: *Conceptual view of factors affecting the biological resource basis*

The water resource is represented in Fig. 4.5.2 to indicate the complexity of its interaction with the primary biological resource.

Cultivation potential

The cultivation potential can ideally be viewed as a sum of normalised areas, accounting for length of growth season, soil quality, sustainability of cultivation practices etc. To define a basis for normalisation and obtain a reasonable degree of international consensus about it is, however, a complex task.

Normalisation of area

As a provisional basis for assessment of cleaner technologies a simple estimate of global cultivated area, related to the world population could be used (area per citizen). If the resource impact of a technology is expressed as area occupation per consumer, it can at least be assessed whether or not the resource consumption is significant. An assessment on this basis would be satisfactory as background for comparison of related technologies, as long as the impacts do not include massive or complex changes of key biological resources.

Species pool

Biodiversity is here represented by the species pool, indicating that direct impacts of exploitation can be assessed only when the target species or range of species is identified. Further, it must be possible to estimate the sustainable exploitation rate for the target species in terms of amount per year, i.e. the maximum exploitation which permits the population to maintain itself over extended time spans. If the population is exploited for other purposes than the technology considered, this exploitation should be deducted (allocation principle).

Biodiversity is affected by area reclamation as well. This impact, however, is generally not population specific, but based on the relationship between biodiversity and availability of habitat. It has not been found operational to represent this relationship directly in the assessment framework. Rather, any extension of area demand must be viewed in the perspective of general reduction of habitat for wild organisms.

4.5.5 Practical implementation

Annual sustainable yield as reference basis

For assessment of biological resources it is essential to notice that all assessments must be based on annual *rates* of production, exploitation etc., because annual sustainable yield is the only valid reference basis for a renewable resource.

Making up the amounts and identifying the type of biological material required for a production is simple, since the information should be available for any large-scale production.

In cases where the comparison is focused on different amounts of one familiar resource, it is attractive to maintain the amount itself as an indicator. In more complicated cases, e.g. where alternative resources have to be compared, the area requirement has to be estimated in order to obtain a comparable basis for cultivated resources. Area requirement should be normalised with respect to e.g. soil conditions and length of growth season, at least as far as the ad hoc comparability requires.

When resources obtained by exploitation are considered, comparison becomes difficult, when resources of different types must be compared. The comparison has to be based on actual exploitation related to sustainable yield of each population. In practice the difference between alternatives will be obvious, even by a simple estimate.

In more elaborate cases the question of the value of each species may arise. A priori, it may be assumed that any species may be worth preserving. For some species, however, there may be considerations of a key ecological function, meaning that disturbing this population will have wide-spread effects on other species. Further, there may be national or international regulations applying to particular species, which have to be respected.

The framework outlined here certainly needs further elaboration to account for the complexity of biological resources. However, already in its present form it provides a basis for provisional assessment which will be satisfactory for many cases of cleaner technology.

4.5.6 Conclusions

Summing up, the following conclusions can be drawn:

- Environmental assessments of biological resources consumption should be based on two evaluation areas in CEIDOCT:
  - cultivation
  - exploitation
- At level 0 the indicator proposed is normalised and aggregated area requirement, including effects of exploitation, supplemented by a logical parameter indicating risk of extinction or system collapse.
- At level 1 the indicators proposed are for:
  - *Cultivation*: normalised area requirement, aggregated to account for fertility, water availability, length of growth season etc.
  - *Exploitation:* integrated measure expressing degree of exploitation of sensitive species, accounting for risk of extinction and collapse of ecosystem structure.
- At level 2, which is the LCA-level for the other focus areas, the indicators proposed are amounts and types of utilised resources; area requirements, supplemented by indicators of land use and cultivation conditions (e.g. water consumption, nutrients) for the case of cultivation. For exploitation is suggested to use degree of exploitation for individual species.

The proposed indicators still need some elaboration, so at this stage it has not been possible to finish formalisation of a CEIDOCT/EPI concept for the biological resources consumption. However, the issue has been analysed and structured in an appropriate manner and it will be possible on this basis to finish the development of the CEIDOCT concept for the biological resources to the same level as for the other focus areas.

The stage to which this discussion has been brought is also seen as a good basis for development of the biological resources as an integrated and operational element of existing LCA-methodologies. Such initiatives are recommended.

5. CONCEPT FOR DEVELOPMENT AND USE OF EPIs WITHIN SPECIFIC TRADES

Below is a brief description of the working process in a given branch of trade to develop trade-specific EPIs for cleaner technology assessment, development and other purposes. It is assumed that an operational detailed tool for environmental assessments including LCAs is available. The description is necessarily rather general and important elements are therefore exemplified via the three cases in Chapter 6.

5.1 Preparatory assessments

When a trade association considers to develop and use common trade EPIs on a detailed level, some basic conditions should be reviewed and assessed:

Environmental similarity?

- Does a significant number of enterprises within the trade show environmental similarities? Or may the trade be divided into subsectors each giving similar environmental pressures? Alternatively into a limited number of typical production and work processes?

  Important conditions for environmental similarities are

  - similar main categories of raw materials and compounds for the typical production processes and products
  - specific production processes characterising the trade, including specific impacts and emissions from these processes important product types,

    including main characteristics for the use and life time of these products.

  Environmental similarities are of importance for the value of developing common detailed EPIs for branches of trade.

Sector traditions

- Has the branch of trade a common organisation and the necessary resources regarding staff and economy for the task, and does a tradition exist in the trade for this organisation to handle such tasks?

  This is of importance as the process of developing common detailed EPIs is a challenging project and demands considerable experience in project management and communication.

Cooperation with other sectors?

- Do other sectors or other groups of industries exist with environmental impacts and pressures of a similar nature?

  The potential for cooperation with other sectors or organisations may be of great importance for success and save resources of staff and money.

After having been through the above considerations, a solid basis exists to decide whether to continue the project or to identify other options for solutions.

5.2 Project organisation

A project organisation should be established to perform the necessary development work. Normal principles of project management should be applied.

Project team and qualifications

The project team must consist of professionals with extensive networks as well inside as outside the specific sector. The team must be dominated by experienced people from the trade with extensive knowledge of the technologies and environmental and occupational health and safety aspects of the trade industries. The trade association should also be represented and a qualified consultant might be advantageous.

Apart from the experience and professional qualifications of the team members, also abilities to cooperate in an interdisciplinary fashion and produce a common knowledge platform and operational results are important.

Project manager

A most competent member of the project team should be assigned as project manager.

Consensus and stakeholder dialogue

In the working process, consensus should be established regarding the key environmental issues of the individual technologies and the sector as a whole. This will imply involvement of parties external to the industry sector in question, e.g. authorities, important raw material suppliers, important customer group representatives, relevant NGOs, etc.

5.3 Reference technologies, process and product dimensions

Technology overview and reference technologies

An overview of the typical technologies of the trade must be established by the project team and a set of reference technologies identified. The reference technologies must then be described in unit operations and also in one or more typical product life cycle contexts.

Life cycle perspective

The reference technologies must be documented in a life cycle perspective regarding environmental impacts, e.g. via an available LCA-assessment tool based on internationally recognised principles of LCA methodology.

Process and product dimensions

Using a life cycle approach to assess environmental impacts from cleaner technologies makes it necessary to identify links between the process dimension and the product dimension. If these links are not known, the effects on the product life cycle from a given new process technology cannot be managed in a well-defined manner, and a cleaner technology implementation can consequently not be effectively performed.

Key product properties link process and product dimensions

These links between process and product dimensions are key product quality parameters reflecting life cycle environmental impacts and are often associated with product life time. A change in technology, which affects these “key product properties” or “technology specific indicators on product level”, may significantly change the environmental impacts over the product life cycle. In such cases, a “cleaner” process technology may prove to be neutral or even “dirtier” in a life cycle perspective than the existing technology.

The key product properties are of major importance in cleaner technology projects: The reference technologies and corresponding LCAs provide the necessary information and data to identify the reference environmental impacts in all stages of the life cycle. The key product properties make it possible to identify, in an operational manner, in which life cycle stages environmental changes occur and assess and manage the environmental impacts of these changes.

Δ-LCA

This type of life cycle evaluation is termed a Δ-LCA (delta-LCA) and constitutes a comparison of a new technology to a reference technology, but a comparison where only the environmentally different parts of the new technology are involved. For an individual industry the reference technology may be the existing technology. When Δ-LCA is known, also the total LCA of the new technology in question can be calculated via the LCA of the reference technology.

5.4 Use of EPIS on various levels

The Δ-LCA may provide detailed EPIs for practical application on company and industry sector level. The full LCA is necessary, however, to document the EPIs on levels 0 or 1 for reporting and evaluation on national or regional authority level. The EPIs at lower levels may of course also be based on the full LCA if preferred.

Technology Specific Environmental Indicators (TSIs)

The detailed EPIs at trade level will represent environmental issues considered to be of significant concern to the trade. These EPIs may further be transformed into "technology specific (environmental) indicators" (TSIs) on trade or company level. These may be very specific and developed into very decentralised process indicators. They may have any form as long as they are clearly related to one or more of the priority EPIs of the company or trade in a well-defined manner. As an example, the EPIs "specific energy consumption" and "specific consumption of chemicals X and Y" may be heavily dependent on "process temperature" and "uniformity of quality and supply of key compound Z", which then constitute Technology Specific Indicators. Several of these indicators in various processes may thus contribute in different ways to one or more EPIs for the production as a whole.

Thus, the detailed EPIs represent the environmental priorities of the company or trade, while the Technology Specific Indicators represent the parameters by which to manage the environmental priorities during process operation. Examples of this are shown in the case-stories in Chapter 6.

5.5 Use of EPIS and TSIS in Cleaner Technology Development

EPIs and TSIs on the various levels may be used in various ways depending on the actual task to be performed. When the task is Cleaner Technology development, the working process includes the following steps:

- Define a reference technology and calculate the corresponding LCA and EPIs on levels 0 and 1.
- A preliminary assessment of the EPIs on levels 0 or 1 for the new technology to be evaluated is made. At this stage is used a fast assessment approach for each aggregated indicator. These EPIs are compared to the corresponding EPIs of the reference technology. If no significant net improvements of the upper-level EPIs can be seen, a decision to proceed with the development of the new technology should be based on important lower level EPIs or a further - more detailed - evaluation should be made. If a clearly significant improvement in the upper-level EPIs can be seen, a further development process of the new technology can be planned with a view to the expected improvements in the upper-level EPIs.
- The relevant key product properties (TSIs) for the technologies in question are identified to form the technological link between the process dimension and the product dimension.
- The lower level EPIs for the new technology in the product dimension represented by Δ-LCA and the full LCA are calculated. By using the CEIDOCT methods of indicator aggregation, the EPIs on levels 0 or 1 for the new technology are computed. These are compared to the preliminary assessment values and the result is used in the further development process.
- In later stages of the technology development process it is necessary to identify relevant Technology Specific Indicators for management on process level. When the new technology is finally in operation, the environmental management of this operation will be taken care of by monitoring of the TSIs, while the environmental performance will be measured by the relevant EPIs on company and industry sector levels.

When the assessment methodology stated above is repeated regularly all through the development and testing of the new technology, it can be efficiently assured that the environmental objectives and targets for the new technology are continuously observed and adhered to, and the development process can be continuously adjusted as necessary. The same will be true in the case of product development at any level, i.e. all technological development processes may be managed efficiently from an

environmental viewpoint via the proposed concept and methodology.

The concept may also be used if authorities are involved in the process, e.g. to provide financial support or other types of cooperation. In such cases the concept will constitute a systematic framework for the communication between the company/industry sector and the governmental authority in order to make sure that previously assessed environmental objectives and targets are reached, or to verify if this is not the case.

Illustrated in Figure 5.1.

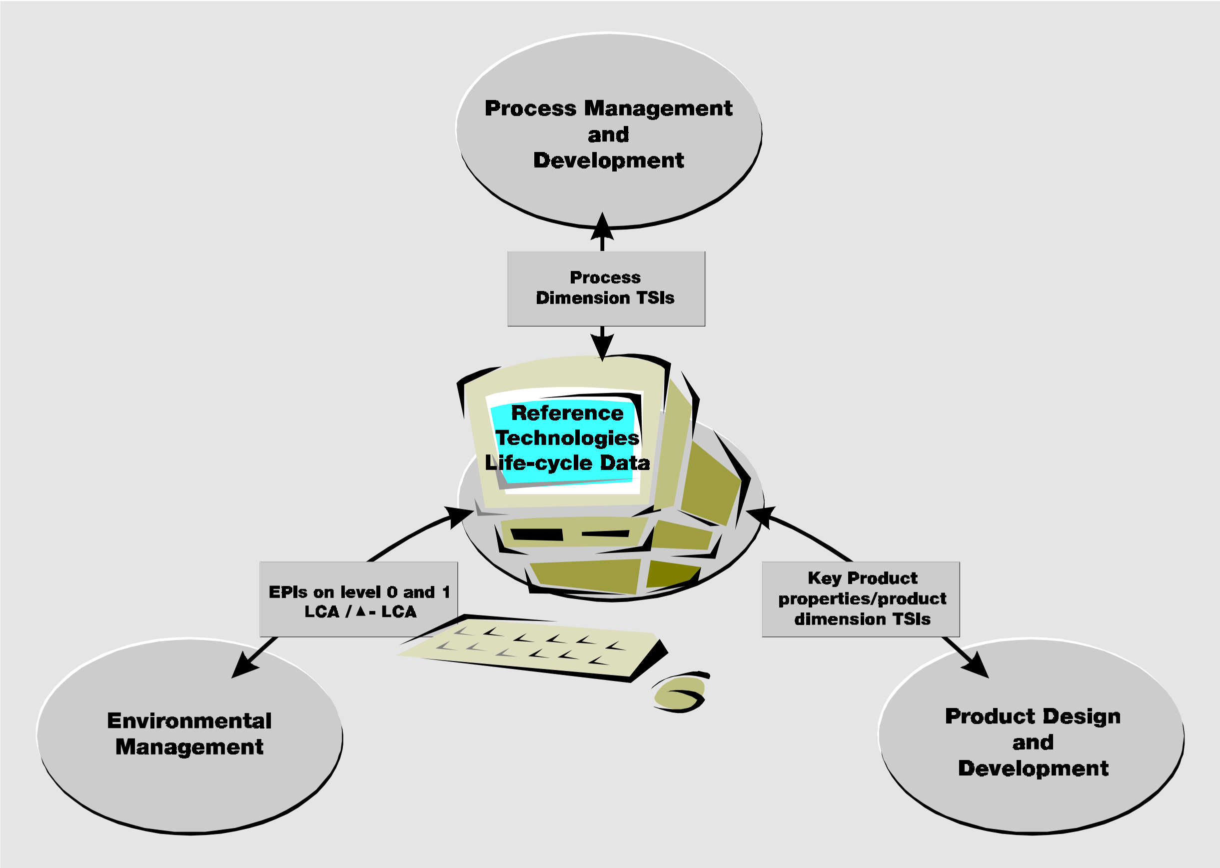

Figure 5.1: *Illustration of the role of reference technologies in cleaner technology approaches in specific branches of industry*

6. TESTING THE CONCEPTS - EXAMPLES FROM THE PAPER, TEXTILE AND SURFACE TREATMENT INDUSTRY

The following work is based on information from the EDIP unit process database and cleaner technology projects performed by the Institute for Product Development. The relevant data have been collected and hand-led following the principles in the EDIP method and in Chapter 4 of this report.

Due to the purpose of these case studies, information regarding the various stages of the product life cycle has been omitted. The final step of the valuation, weighting, will be shown, and the indicators at the life cycle assessment level are discussed.

The purpose of the cases is to document and illustrate:

- That a cleaner technology should always be assessed both in the process dimension and the product dimension.
- That the product dimension, i.e. the life cycle of the product, can be influenced by the technology and that this influence is often environmentally decisive.
- How important the product dimension is, compared to the process dimension.
- That environmental performance can be controlled by "technology specific indicators", which are the *process parameters* respectively the *product parameters* that are decisive to the environmental performance.
- That such process parameters and product properties are easy to identify on the basis of sufficient technological and environmental knowledge of the technology, and that they are easy to use in the control of environmental performance.

The cases thus illustrate the working principles described in Section 5.5 and illustrated in Figure 5.1, and demonstrate that these working principles can be applied in practice.

The EPIs used in the work with the cases are the EPIs of the EDIP method. These are not transformed to the level 0 and level 1 EPIs of the CEIDOCT concept. However, for the indicators of the focus areas M, E and C, the information to perform this transformation is present in the EDIP-EPIs as shown in the following diagram (ref. Figure 3.1):

Assessment parameters in the EDIP-method, related to the CEIDOCT-EPIs level 0 and 1 for focus areas M, E and C[5]

	Environmental Impacts	Resource consumption	Impacts on the working environment
Materials **Focus area M**	Bulk waste Slag and ashes	Resources used in materials Mainly reversible consumption	
Energy **Focus area E**	Global warming Photochemical ozone formation Acidification Nutrient enrichment Bulk waste Slag and ashes Nuclear waste	Energy carriers, especially fossil resources and wood. Mainly irreversible consumption.	
Chemicals **Focus area C**	Ozone depletion Photochemical ozone formation Persistent toxicity Ecotoxicity Human toxicity Hazardous waste	Resources used in the production of chemicals	Impacts related to chemical exposure: cancer, damage to the reproductive system, allergy and damage to the nervous system
Others			Monotonous repetitive work, noise, work accidents

Thus, direct relations exist between the EDIP-EPIs and the CEIDOCT focus areas M, E and C. For focus area B this is not the case as the biological resources area is not included in EDIP or any other present LCA-method. The B-indicators have not been sufficiently developed in this project to be calculated in the cases.

6.1 Paper case: Recovery process for fluting and test-liner

Process to be assessed

The process to be assessed in the present case is the production process of recycled fluting and test-liner, i.e. the recovery process for fluting and test-liner.

Superior service

The superior service of the product (fluting and test-liner) is to serve as packaging of goods.

The functional unit

The functional unit is the production of 232,500 tons of recycled fluting and test-liner, calculated as dry matter. The Figure chosen corresponds to a realistic annual production for a company.

6.1.1 Reference technology, process and product dimension

The reference process: Production of recycled fluting and test-liner

The production of recycled fluting and test-liner can roughly be divided into two sections: the pulping process and the paper making process as shown in Figure 6.1.1.

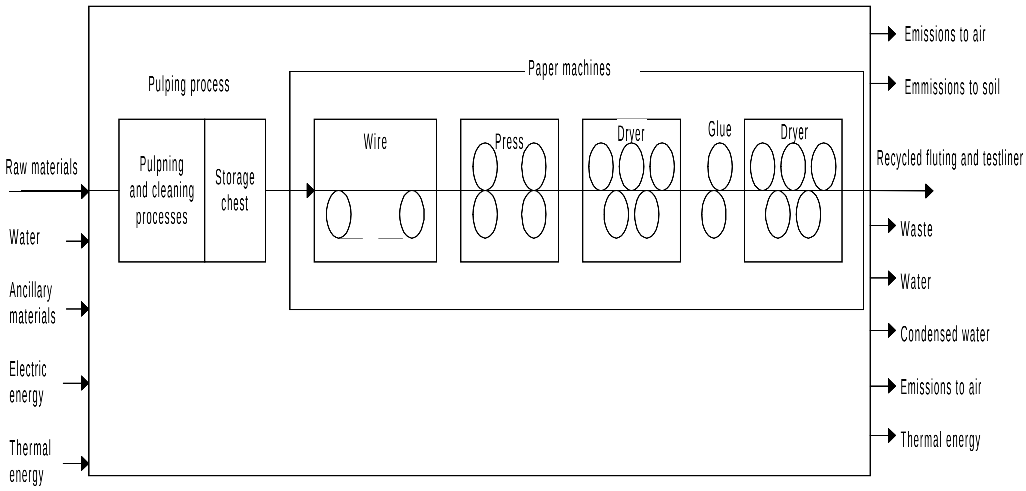

Figure 6.1.1: *Flow chart of recycled fluting and testliner*

The pulping stage

The pulping stage is the process in which the raw materials are treated physically and chemically in order to achieve the desired qualities of the paper pulp. This is done by pulping, removing contaminants (sand, metals, stickies, etc.) and screening. The final paper pulp in the storage chest has a consistency of approx. 4-5% dry matter.

Paper making

The paper making stage is subsequently divided into 5 minor stages:

- the wire, where the paper web is formed.
- the press, where the paper web is pressed to a consistency of approx. 50%.
- the drying press, where the paper web is dried to a consistency of approx. 85% dry matter.

- the glue press that glues the paper web.
- the final drying press, where the paper is dried from a consistency of 60% dry matter to a consistency of 93% dry matter.

After the final drying process the paper web is rolled onto reels and stored for sale.

The reference product: Corrugated cardboard

A simplified life-cycle for recycled corrugated cardboard is shown in Figure 6.1.2.

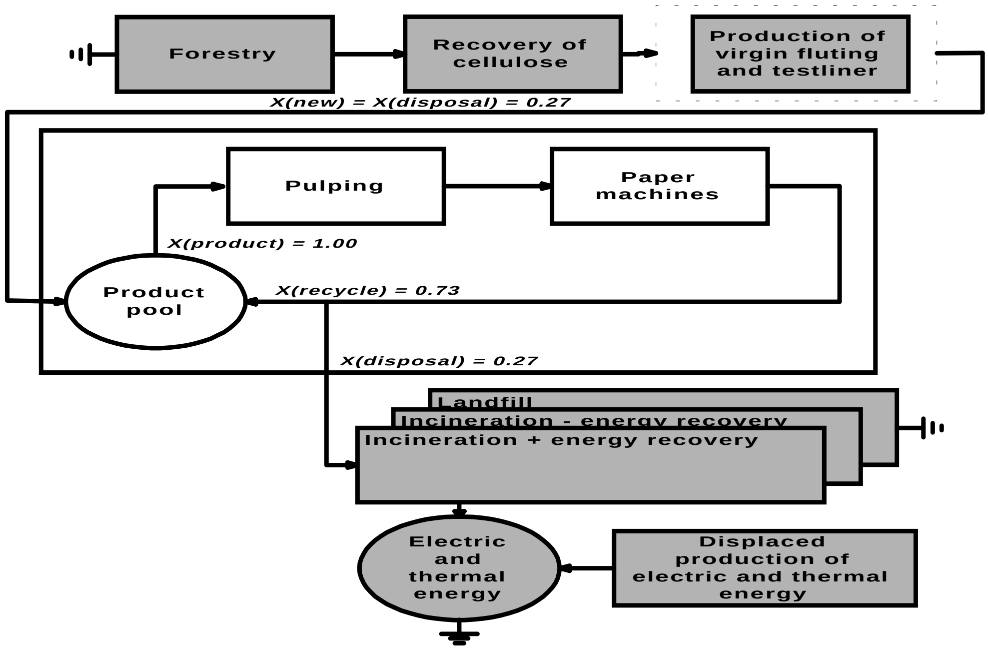

***Figure 6.1.2**: Life cycle for recycled corrugated cardboard*

The dotted box around the production of virgin fluting and test-liner implies that this process is not included in the inventory. This is due to the allocation model used in this LCA. This model will not be described further. The *X* values serve as an illustration of the utilized recycling fraction. For every unit produced fluting and test-liner 27% is disposed of. In order to obtain a constant mass in the closed recycling loop an equal amount of new fibres have to be admitted into the loop so *X(recycle) + X(new)* always equals 1. The paper removed from the recycling loop is subsequently disposed by sending to landfill, incinerating without energy recovery or incinerated with energy recovery. If the paper is incinerated with recovery of energy, the energy produced, electric and thermal will displace other energy productions which will lead to savings in consumption of resources (coal, natural gas, etc.). Subsequently, the mass of paper taken out of the system has to re-enter as fresh fibre mass. This is done by collecting virgin corrugated cardboard. With this system an equilibrium is reached so the quality and quantity of paper fibres in the recycling loop is constant.

The environmental aspects of used cardboard recovery and sorting is not included.

Discussion of process versus product system.

From an LCA of recycled corrugated cardboard, Figures 6.1.3 and 6.1.4, it can be seen that most of the impacts actually derive from the production process itself.

Most of these are due to the energy consumption at the production facility for recycled fluting and test-liner.

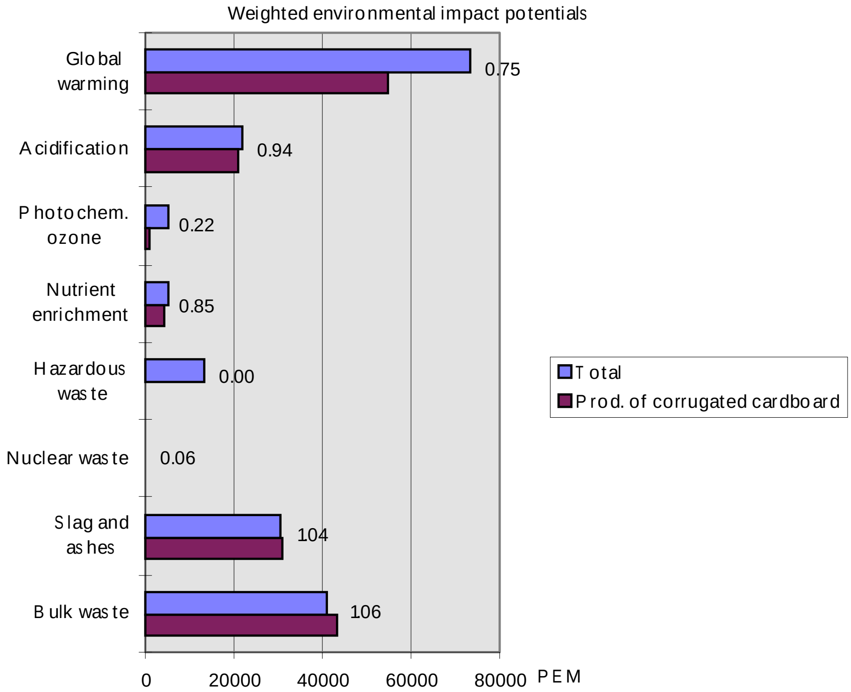

***Figure 6.1.3**: Weighted environmental impact potentials for the production of corrugated cardboard and for the total life cycle respectively*

In Figure 6.1.3 is shown weighted environmental impact potentials for global warming, acidification, slag and ashes and bulk waste and as shown, the studied process is responsible for 25-100% of the impacts from the whole life-cycle of the product. The Figures next to the columns indicate the proportion of the process as related to the whole product system. The reason why this ratio can be >1 is due to the incineration of used corrugated cardboard with energy recovery displaces alternative production of energy.

The displacement of energy also explains the ratio for coal shown in Figure 6.1.4.

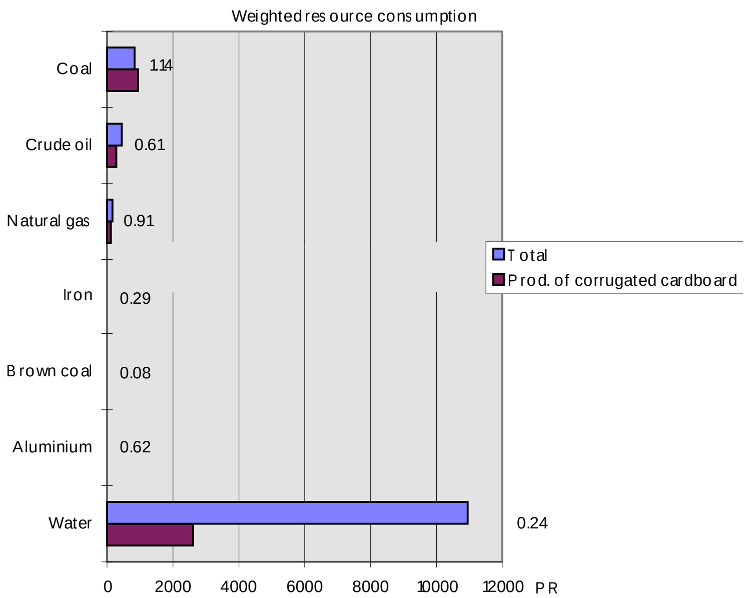

***Figure 6.1.4**: Weighted resource consumption for the production of corrugated cardboard and the total life cycle respectively*

The technology influences the products environmental performance in several ways. One of the most obvious is the pulping process, where most of the wear and tear on the paper fibres occurs. A reduction of the impacts on the fibres in this process would affect the product in a number of ways:

- the strength of the paper fibres would be increased
- the strength of the paper would be increased
- the finished product could be made thinner without influencing its strength
- reduction of raw materials consumption
- reduction of energy consumption

While improving the environmental performance of the process itself, these parameters will also influence the essential product properties and thereby improve the environmental performance of the product.

6.1.2 Cleaner technology assessment in the process dimension

Process modification

As mentioned earlier the investigated production facility has a closed water system. This means that no waste water is emitted, but treated and returned to the main process water flow. This has resulted in a number of problems arising in the production:

- reduced quality of product
- reduced efficiency of machinery
- deposits in machinery
- increased wear
- corrosion
- foul odour
- increased bacterial growth

Filtration process

In order to solve these problems in a non-chemical way it was decided to investigate the use of a filtration process (Figure 6.1.5) followed by an anaerobic reactor for the production of methane (Figure 6.1.6).

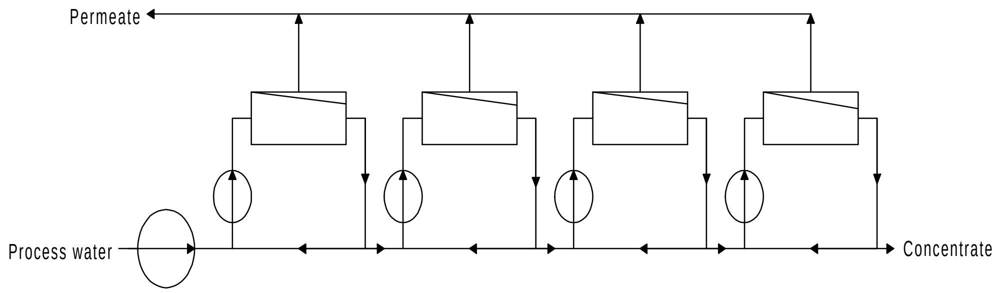

***Figure 6.1.5**: Filtration principle*

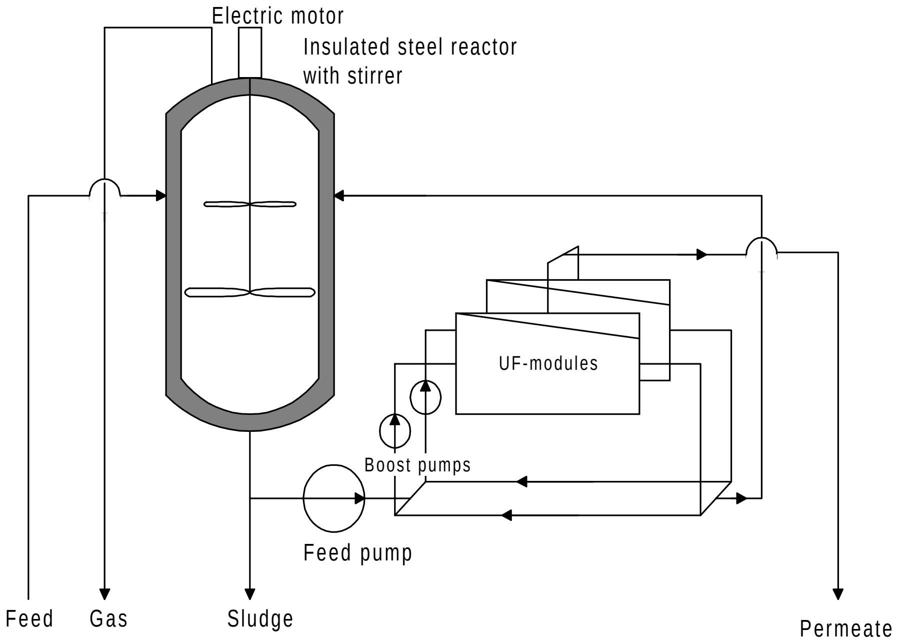

***Figure 6.1.6**: Anaerobic reactor for the production of methane*

The methane was to be utilized in a gas motor, producing electricity and the sludge was to be pressed and incinerated at a nearby incineration plant.

With the new processes the life cycle of the product system of fluting and test-liner will be as shown in Figure 6.1.7.

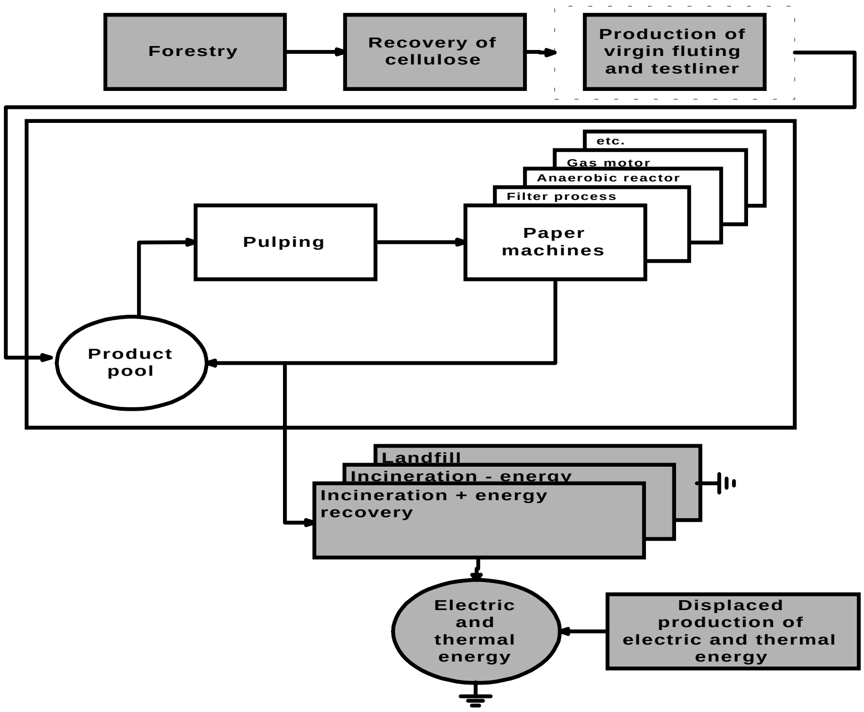

***Figure 6.1.7**: Life cycle of system with the implementation of cleaner technology*

If compared to the reference product system (Figure 6.1.2), it can be seen that the life cycles of the cleaner technologies have been included in the new model.

Environmental impacts of implementation of cleaner technology

As a result of the filtration process the final product will contain less COD. Because the COD is a main factor in the production of methane gas at landfills this emission of greenhouse gas from landfills will be reduced.

As before, it is global warming, acidification, slag and ashes, bulk waste and water consumption that characterise the environmental profiles as shown if Figure 6.1.8 and 6.1.9.

Nickel has been included as a new resource. This mainly comes from the filtration plant that, due to the highly corrosive nature of the process water, is made of stainless steel.

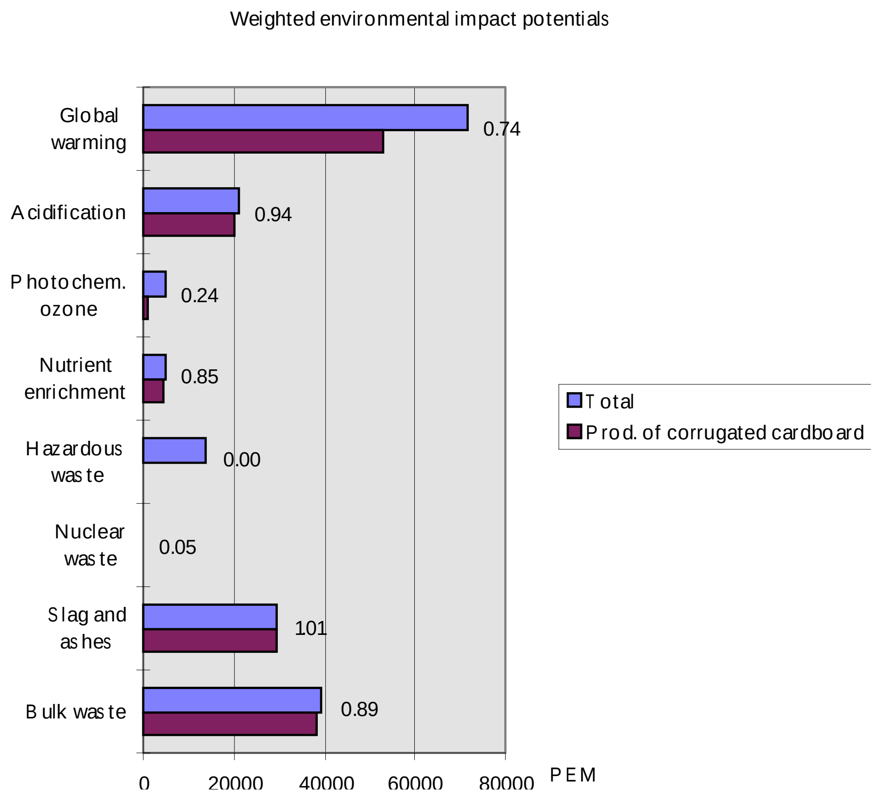

***Figure 6.1.8**: Weighted environmental impact potentials of system with the implementation of cleaner technology*

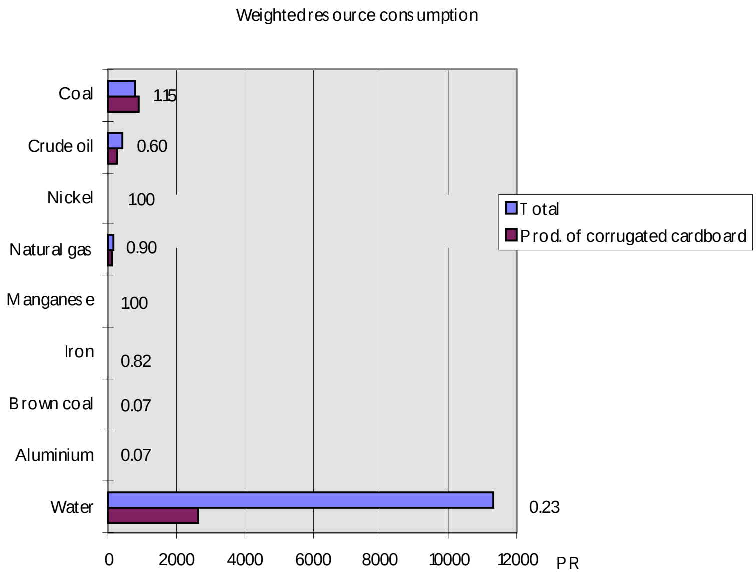

***Figure 6.1.9**: Weighted resource consumption for the system with the implementation of cleaner technology*

The new processes themselves do not have much of an effect on the profiles, but the gas motor contributes with relatively large reductions. The energy produced is larger than the consumption of the filtration process and the anaerobic reactor thereby causing a total decrease in energy consumption from the production system.

A factor not mentioned earlier is the consumption of ancillary substances (biocides, flocking agents, etc.). Introducing the mentioned cleaner technologies it should be possible to reduce the consumption of ancillary substances by approx. 30%, with some of the substances being reduced by up to 50%.

6.1.3 Cleaner technology assessment in the product dimension

Life time for paper fibres

In the reference system, 27% of the fibres are disposed of in each recycling loop. If the disposal rate could be reduced, a reduction of the amount of new fibres would be the result. According to experience from the industry a paper fibre can stand up to 6 times of use. Theoretically this means that for each recycling stage 1/6 of the paper fibres have lost so much material grade that they have to be taken out of the recycling loop in order not to reduce the overall paper quality. An illustration of this scenario, according to Figure 6.1.2 would be:

$X(recycle) = 5/6 = 0.83$

$$X(disposal) = X(new) = 1/6 = 0.17$$

The environmental profiles of this scenario can be seen in Figures 6.1.10 and 6.1.11.

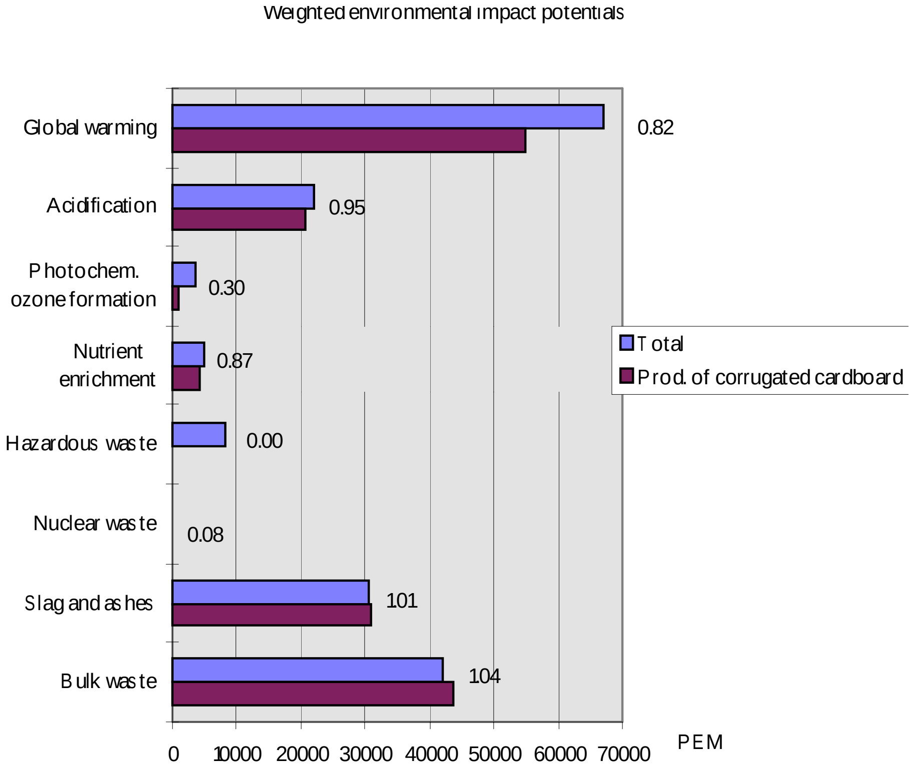

***Figure 6.1.10**: Weighted environmental impact potentials for system with altered life time of paper fibre*

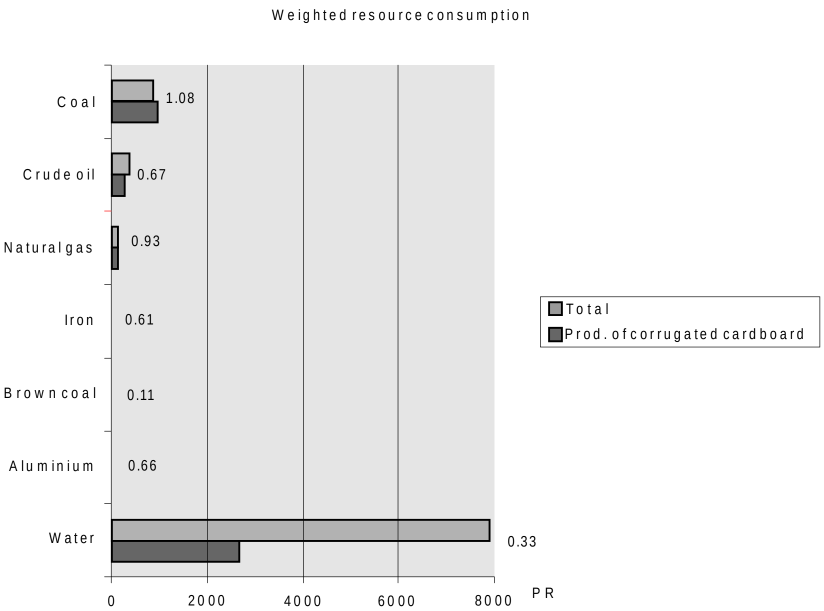

Figure 6.1.11: Weighted resource consumption for system with altered lifetime of paper fibre.

If we compare these figures to Figures 6.1.3 and 6.1.4 we will see that the ratios have become closer to 1. This can be explained by the fact that the surrounding product system contributes to a smaller part of the product system.

Recycling rate

If the recycling percentage was lowered to a mere 50%, so:

X(recycling) = 0.50 and *X(new) = X(disposal) = 0.50*,
the environmental and resource profiles would be as illustrated in Figures 6.1.12 and 6.1.13.

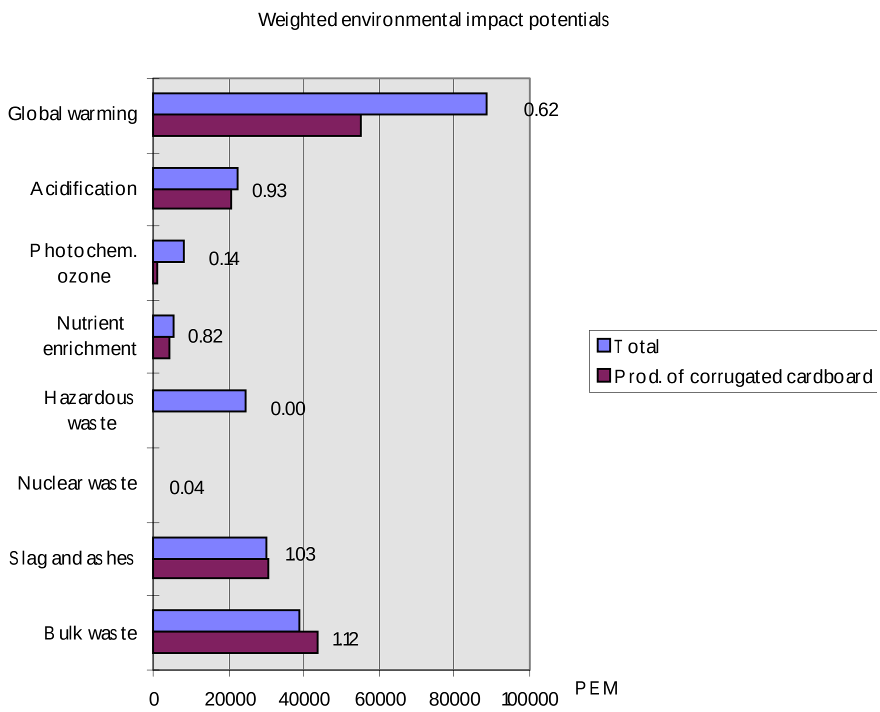

Figure 6.1.12: *Weighted environmental impact potentials for a system with recycling percentage of 50%*

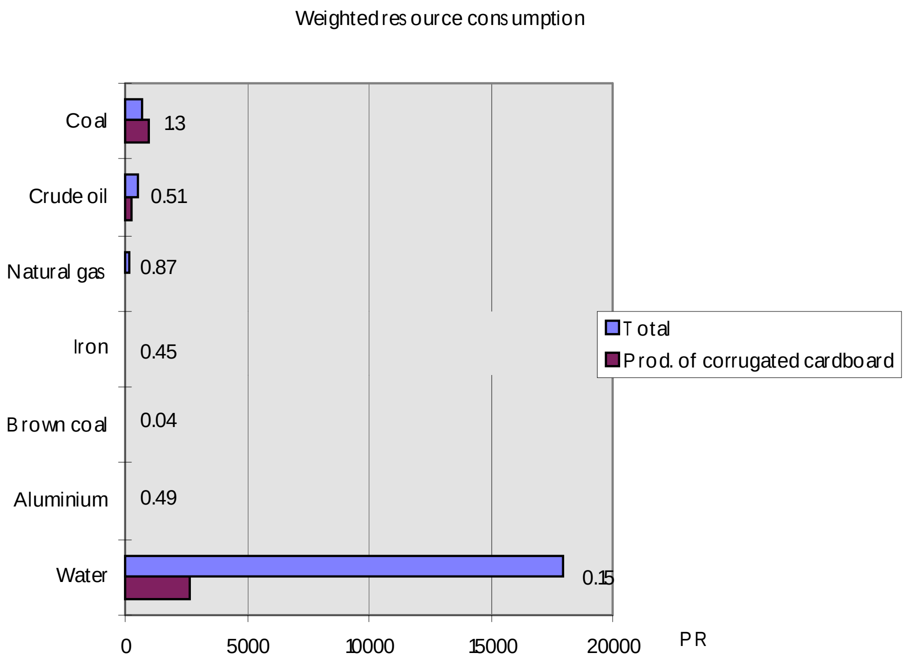

Figure 6.1.13: *Weighted resource consumption for a system with recycling percentage of 50%*

This exemplifies the exact opposite of the Figures 6.1.3 and 6.1.4. Here the ratios have moved further away from the value 1. Mathematically this can be explained as:

$$\frac{environmental\ impact_{i,\ production\ process}}{environmental\ impact_{i,\ total\ product\ system}} \rightarrow 1$$

$$for\ X(recycle) \rightarrow 1$$

So, the higher the utilised recycling potential, the less important the surrounding product system.

6.1.4 Technology specific EPIS

In order to control environmental performance, technology specific indicators which are related to the process parameters and the product properties respectively, can be defined.

The process dimension of environmental performance

There are many factors in the technology that are of environmental importance, as seen in the environmental and resource profiles. These are illustrated by the ratios. If they have a value close to 1 the main improvement potential will be located in the process, if not, the main improvement potentials for the product system are to be found in the surrounding product system. In the process, specific improvement potentials are illustrated by global warming, acidification, slag and ashes and bulk waste. Together with coal and natural gas they mainly represent consumed energy. The metals present in the cleaner technology scenario are not considered important. The resource profile for water is not representative for all manufactures of recycled paper (mentioned earlier). Many other manufactures will have a consumption that is considerably larger.

Another important property of the process is the amount of consumed ancillary substances, not mentioned earlier. It has been proven that the overall consumption of chemicals can be reduced by 30%, some up to 50%. This will have a considerable impact of toxicology, but due to deficiency of data these impacts have not been proven.

To sum up on the process dimensions that will influence the environmental performance of the product, they are:

- consumption of energy
- consumption of ancillary substances
- (consumption of water)

The product dimension of environmental performance

The product dimension of environmental performance is the technology's influence on the product's performance. The environmental performance of the product is determined by a number of its key properties. In the case of fluting and test-liner examples of essential properties are:

- fibre quality (determine the residual life time of the fibre)
- strength/weight relationship

Lifetime

Experience shows that the lifetime of a paper fibre is in practice determined by the number of recycling steps the fibre has been through. A paper fibre can according to the industry be used 6 times before the material grade is reduced to a quality too low for the production of paper (it must be noted that durability depends on many factors, and the durability of fibres in a recycling system is not a scalar but a probability distribution). With an increased amount of paper being recycled the single paper fibre is increasingly used in more products. This means that many of the paper fibres are more worn. Paper fibres that have lost “all” of their material grade qualities are called “0-fibres”, the only function these fibres have is as inert fillers that reduce the strength of the paper or pollutants in the waste water.

A major part of the wearing down of the fibres happens in the pulping process (see Figure 6.1.3) where the fibres are exposed to physical and chemical wear and in the drying stage, where the heat causes irreversible structural changes in the cell wall of the fibre (hornification).

The higher the wear on the fibre in the recovery process, the higher the environmental impact from the product. When the fibre is worn, the need for primary paper production increases and thus the impacts from the parts of the product system external to the recovery process itself.

Strength/weight

The manufacturers of fluting and test-liner have certain demands, derived from their customers, as to the strength of the cardboard. These demands are fulfilled by alternating the specific gravity, e.g. g per m^2. Increased thickness is obtained by increasing the amount of consumed raw materials (mostly recycled cardboard) per produced m^2.

The strength of the paper is a property affected by many parameters, e.g. length of paper fibre, thickness of the sheet, amount of inorganic fillers, amount of glue, etc. When producing paper with a greater amount of "used" fibres, as mentioned above, one could expect that the quality of the final paper will fall. Measurements of strength from producers of recycled fluting and test-liner show the exact opposite. Their Figures show increased strength even with lighter paper (g per m^2). This is explained by process optimizations (it has not been specified if these optimizations are technological or physical, i.e. increased amount of consumed starch per basis weight). But again, the influence of the studied process on this essential product property is highly essential to the environmental impact of the product, when providing its superior service, namely packaging of goods. If the process increases the strength/weight relationship, and the customers demands cardboard with reference to the strength of the cardboard and not only focuses on the weight, the process would cause the need for less weight for the same overall service of the product. This would again imply decreased environmental impact from the product system external to the studied process itself.

6.1.5 Conclusions

The conclusions from this case are:

- that the process dimension is the decisive parameter for the environmental performance of the corrugated cardboard. This means that environmental improvements of the process will significantly improve the environmental performance of the product.
- that increasing the recycling rate makes the process dimension even more important.
- that the environmental performance can be controlled by using the technology specific indicators.

6.2 Textile case: Reactive dyeing of cotton

Process to be assessed

The process to be assessed in the present case is reactive dyeing of cotton knitwear in batch machines.

This batch is widely known and is increasingly being used. Cotton represents approximately half of all textiles world-wide, and nearly all cotton is today dyed by reactive dyes.

The product to be assessed

The product that is to be assessed in the present case is a dyed T-shirt of 250 g 100% cotton.

A T-shirt is defined as a lightweight, weftknitted, unadorned, crew-neck, short or long sleeved garment, giving a T-shape when laid flat, designed for outerwear. T-shirts covered by these criteria must not be equipped with buttons, ribs or a collar made of other materials.

The average consumer's annual requirement for such T-shirts is defined as 75 times of use or in practice as washing 75 times and drying 45 times in a household dryer. If a given quality of a dyed T-shirt can stand washing 75 times and drying 45 times in a household dryer, before being classified as worn out, this T-shirt will have a lifetime of one year.

Superior service

The superior service of the product is to serve as clothing. The functional unit is:

The functional unit

Number of T-shirts needed to meet a consumer's demand for one year, i.e. washing 75 times and dried in a household dryer 45 times.

6.2.1 Reference technology, process and product dimension

The reference process: Reactive dyeing of cotton

The dyeing process of knitted cotton fabric can be divided into four stages: pre-treatment, dyeing, rinse and finish. In this reference case all these stages take place in the same machine shown in Figure 6.2.1:

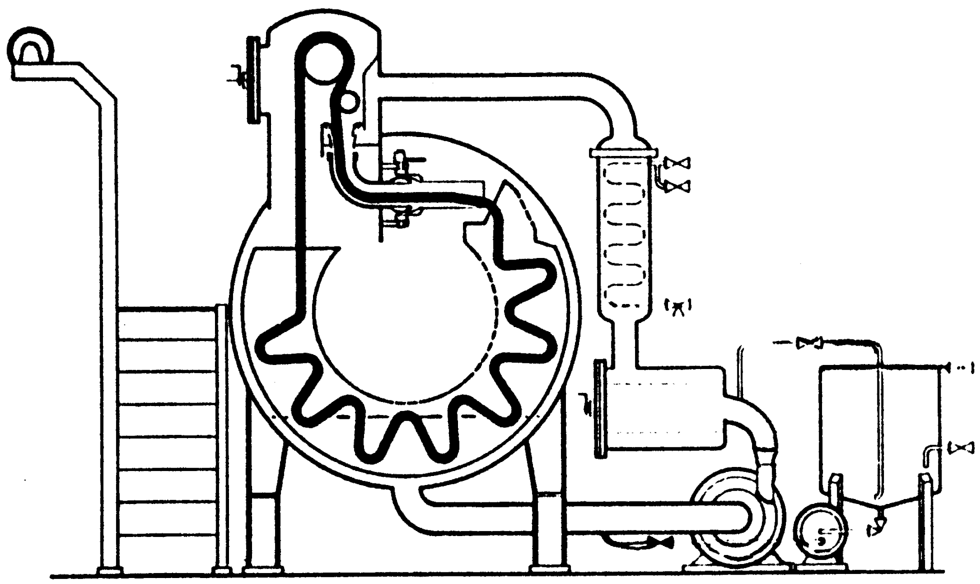

***Figure 6.2.1**: Jet dyeing machine. Vald. Henriksen A/S*

Pre-treatment

The pre-treatment prepares the fabric for further manufacturing and can be divided into two stages:

- Washing and bleaching to remove impurities such as waxes, grease and natural colour to ensure a uniform clean, white textile.
- neutralising and rinsing that ensures that the bleaching chemicals are removed from the fabric.

Dyeing

The dyeing process consists of a number of process steps, where pH, temperature and ion strength are used to ensure that the colour intensity and fastness of the product match that required by the customer.

Rinse

During rinsing the surplus dye-stuff, which is not fixed on the textile, is washed off, and the product is nearly finished.

Finish

Finishing is a process that allows the manufacturer to add one or several qualities to the final product. When talking about knitted cotton, the finish consists of treatment with antistatic and softening agents in order to decrease interfibre friction during sewing.

The reference product: A cotton T-shirt

A simplified life cycle for a cotton T-shirt is shown in Figure 6.2.2:

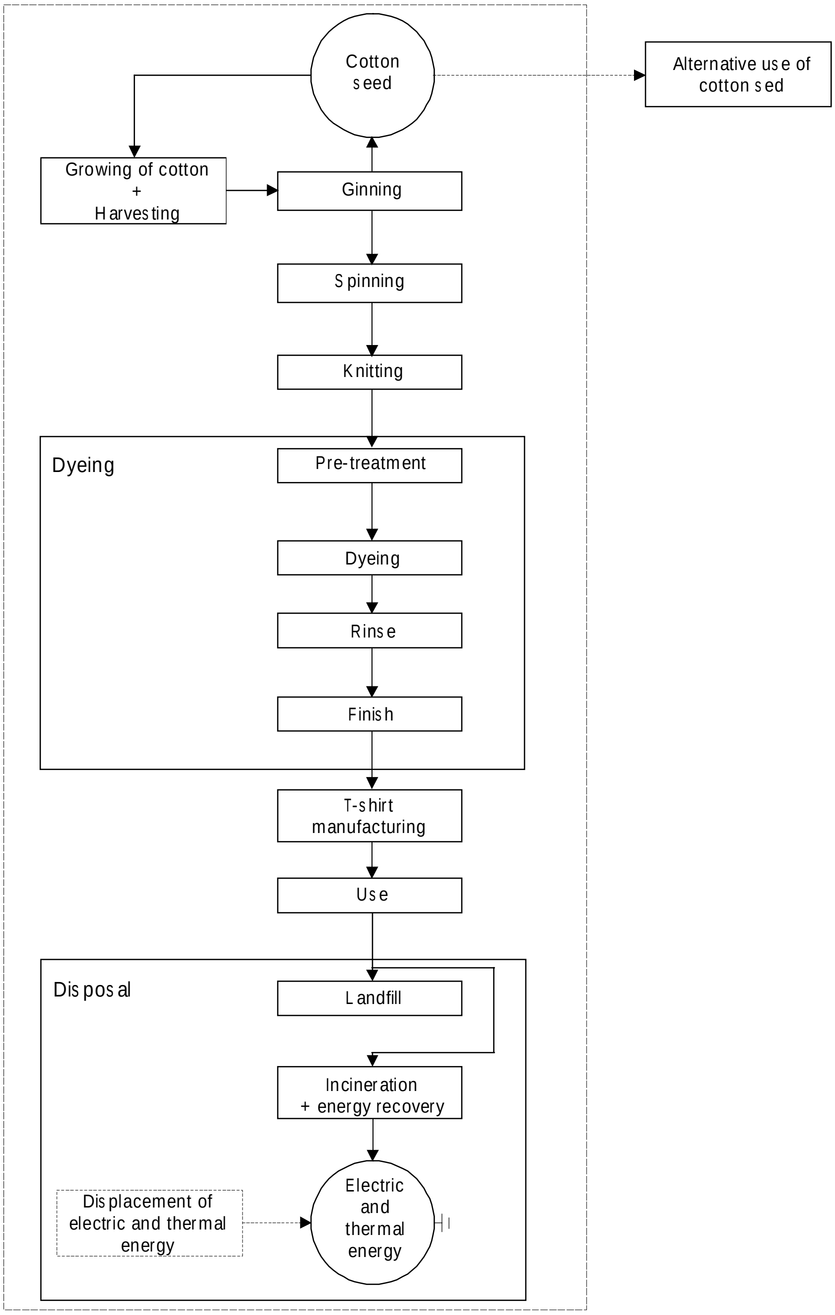

***Figure 6.2.2**: Product system. Cotton from seed to waste*

Growing and harvesting

The life cycle of cotton fibres starts with the growing and harvesting of the cotton. Harvesting is done by machines, requiring application of defoilaging agents before harvesting. The harvested cotton does not only consist of pure cotton fibres but also of cotton seeds and other impurities (soil, twigs, leaves etc.). These impurities are cleaned off, and the pure cotton fibre is baled and sent to further processing.

Seeds

The cotton seeds are utilised in different ways. A small fraction is returned to the cotton farmers for new crops. The main fraction is used for other products such as cotton oil and animal feed. This gives rise to an allocation problem. The income from the sale of cotton is higher than the income from cotton seeds, and an economical allocation model has been used.

Impurities

All other impurities are treated as terminal waste.

Cotton fabric

The cleaned and baled cotton fibres is sent to the spinner. Here the fibres are spun into cotton yarn. The cotton yarn is knitted into cotton fabric and dyed with reactive dyestuffs in a jet dyeing machine.

Manufacturing of T-shirts

The dyed fabric is cut and sewn into T-shirts with a weight of 250 g per T-shirt. Assessments of the environmental impacts from these processes have outlined the energy consumption, including the energy consumption for compressed air, as the only impact worth mentioning. The manufacturing process is not included in the following environmental assessment.

Use

The use is characterized by washing and dying processes. Regarding environmental impacts and resource consumption, these processes can be of paramount importance compared to the rest of the life cycle.

Disposal

In the disposal stage of the T-shirts, these are treated as normal household waste.

Discussion of the process versus the product system

The LCA of the T-shirt can be expressed in an environmental profile in Figure 6.2.3 and a resource profile in Figure 6.2.4. It is seen that the use stage is the most dominant. This is due to the washing and drying processes during this stage of the product life cycle. The environmental impact categories all demonstrate that this stage is very energy consuming. The water consumption in the resource profile can also be ascribed to the washing process.

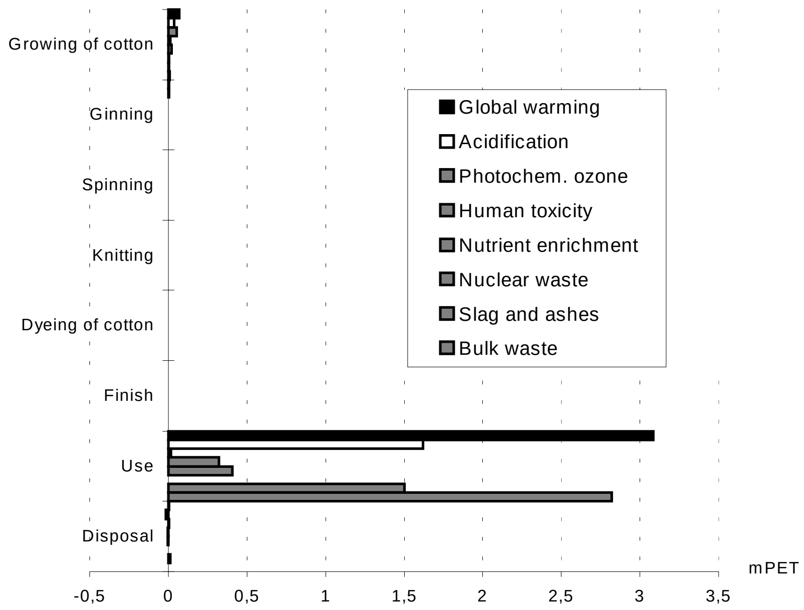

***Figure 6.2.3**: Weighted environmental impact potentials for a cotton T-shirt*

Growing and harvesting of cotton is also seen to have noticeable impacts. These are due to the burning of fossil fuels.

From a product LCA point of view the impacts from the remaining stages in the product system are negligible.

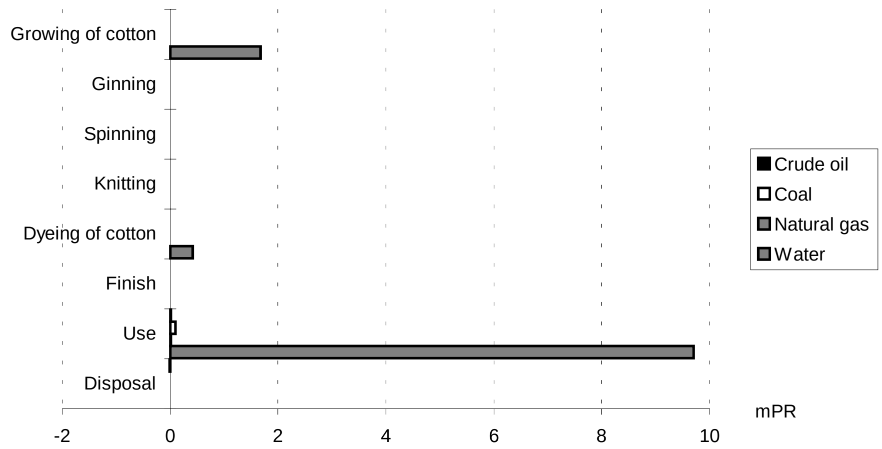

***Figure 6.2.4**: Weighted resource consumption for a cotton T-shirt*

It can be concluded, that the environmental impacts from the life cycle of a cotton T-shirt predominately is governed by its use stage and secondarily by the growing and harvesting of the cotton.

Lifetime

Figure 6.2.5 illustrates the global warming potential as a function of the number of T-shirts needed to meet the demand for a person in one year. The impact from the use stage is constant, i.e. independent of how many T-shirts the person needs. In contrast, the impact from the product life cycle excl. use is directly proportional to the number of T-shirts needed. The total global warming potential from the life cycle incl. use is obtained by adding two curves. It can be seen that from one high quality T-shirt, which can stand 75 washing cycles (one T-shirt used per year), the impacts will mainly come from the use stage. On the contrary it can be seen that from a low quality T-shirt, which can stand only 5 times washing (15 T-shirts used per year), the impacts from the rest of the product life cycle become as weighty as the rest of the use stage - and the total global warming impact from the low quality T-shirt is double that of the high quality T-shirt.

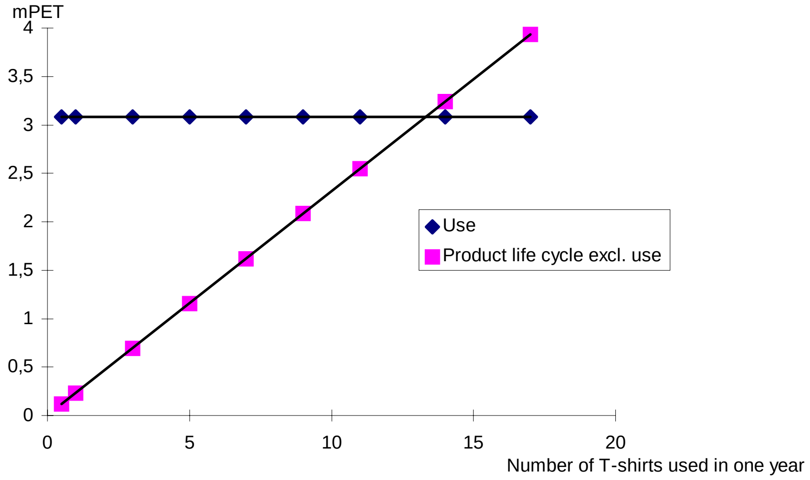

Figure 6.2.5: *Weighted global warming impact as a function of T-shirt lifetime*

6.2.2 **Cleaner technology assessment in the process dimension**

Process modifications

The investigated cleaner technology process modification is rinsing after dyeing. In the investigated system 60% of the total water consumption and 20% of the total consumption of chemicals in the dyehouse processes have been saved. This has been accomplished by introducing a new dyeing method in the dyehouse and by upgrading and reuse of rinsing water by membrane filtration. The concentrate from the membrane filtration is utilized in a biogas reactor.

DLCA

The process modification results in large improvements of the environmental impacts from the rinsing. This is illustrated by Figure 6.2.6 that compares the impacts from dyeing and rinsing.

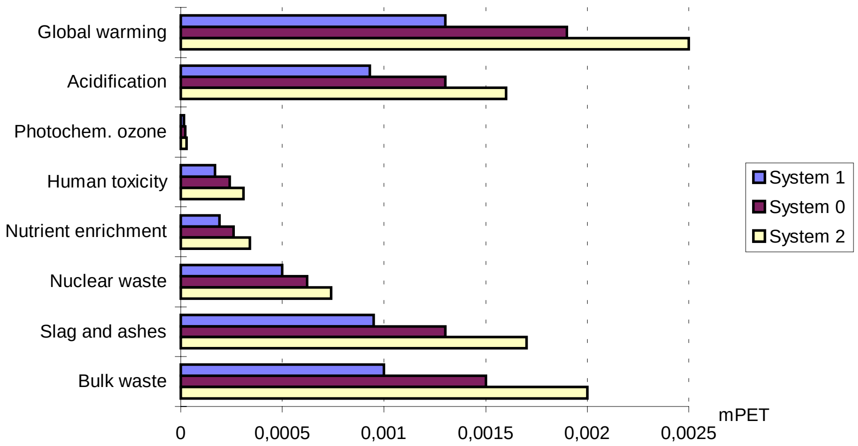

***Figure 6.2.6**: Weighted environmental impact potentials for the dyeing process*

System 1 and 2 versus the reference system, System 0

The Figure shows three alternative systems, namely system 0, the reference system earlier described, system 1, the above-mentioned improvement, and finally system 2, dyeing and rinsing in an old-fashioned machine (the winch) just for comparison.

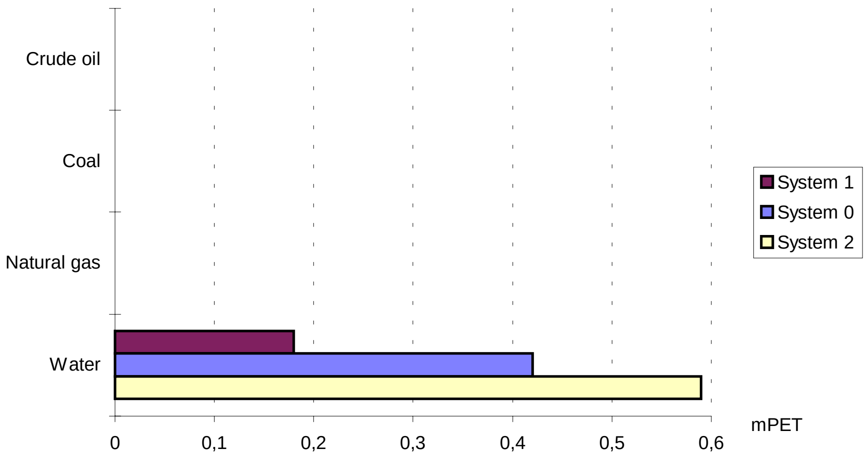

***Figure 6.2.7**: Weighted resource consumption for the dyeing process*

System 1 and 2 versus the reference system, System 0

ΔLCA

To compare with the above DLCAs the total LCAs of the environmental impact and the resource consumption are outlined in Figures 6.2.8 and 6.2.9.

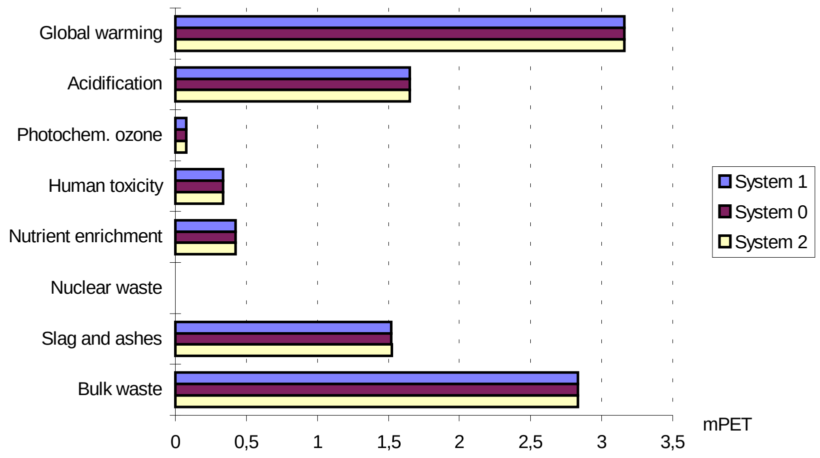

Figure 6.2.8: *Weighted environmental impact potentials for a cotton T-shirt. System 1 and 2 versus the reference system, System 0*

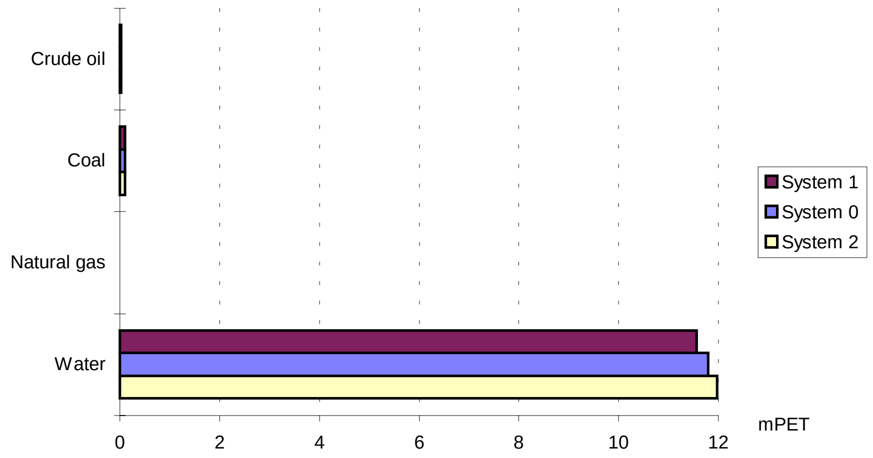

Figure 6.2.9*: Weighted resource consumption for a cotton T-shirt. System 1 and 2 versus the reference system, System 0*

The differences in the environmental impacts expressed in Figure 6.2.6 are too small to be visible in the full perspective due to other dominating processes in the life cycle.

The resource profile for the total product life cycle, Figure 6.2.9, shows, however, a significant change in the consumption of water. This is due to the rinsing stage in the dyeing process being very water consuming.

The process modifications of the assessed technology, reactive dyeing, thus have a large influence on environmental performance of the process but the positive influence of the modification is too small to be visible in the product dimension due to other dominating steps in the life cycle of the product.

6.2.3 **Cleaner technology assessment in the product dimension**

Investigated scenarios

A process modification can potentially influence the product properties and thereby its performance in other stages of its life cycle. Examples of some important ways in which this influence is seen are:

- affecting the lifetime of the product
- affecting product disposal
- affecting the performance of the product during use

To illustrate the environmental consequences of impacts that the technology potentially can have on the product and its life cycle, a number of scenarios have been analysed. These are shown in the following table.

Analysed scenarios to illustrate technology impact on product performance

Technology	**System identification**	**Technology impact**
"State of the art"	System 0	Lifetime of a T-shirt defined as one year
Change in lifetime	System 3: Improved fastness of the dyestuff	Lifetime of a T-shirt increased to 1.6 years. Use stages unchanged, remaining stages reduced by 60%.
	System 4: Reduced fastness of the dyestuff	Lifetime of a T-shirt reduced to 0.5 years. Use stages unchanged, remaining stages increased by 100%.
Change in waste management	System 5: Waste scenario A: Incineration	All waste sent to municipal waste incineration plant, including recovery of energy. Remaining product life cycle unchanged.
	System 6: Waste scenario B: Landfill	All waste sent to landfill. Remaining product life cycle unchanged.
Change in use process	System 7: New finishing process	New surface treatment to reduce attachment of dirt. Use stage processes reduced by 30%, remaining stages unchanged
	System 8: Low cost cotton fabric used	The surface of the T-shirt becomes more dirt adhering. Use stage processes increased by 30%, remaining stages unchanged.

Altered lifetime

One of the most obvious ways a technology can affect the lifetime of the T-shirt is the strength of the binding between the dyestuff and the cotton fibre. An increased dyeing quality could increase the number of withstandable washes and thereby the life span of the T-shirt. This would affect the product life cycle in a number of ways. First and foremost the number of T-shirts used per functional unit would decrease. Thus, environmental impact potentials throughout the product life cycle would decrease, i.e. consumption of raw materials and fossil fuels and related environmental impact potentials. In order to illustrate the consequences of altered lifetimes three examples have been chosen:

- System 0: 1 T-shirt per year (the reference)
- System 3: 0.6 T-shirts per year
- System 4: 2.0 T-shirts per year

From Figures 6.2.10 and 6.2.11 it can be seen that even the rather limited alterations in lifetime in the examples give considerable reflections in the contribution to the environmental effects referring to the energy consumption. In the resource profile it is the consumption of water that is the decisive factor.

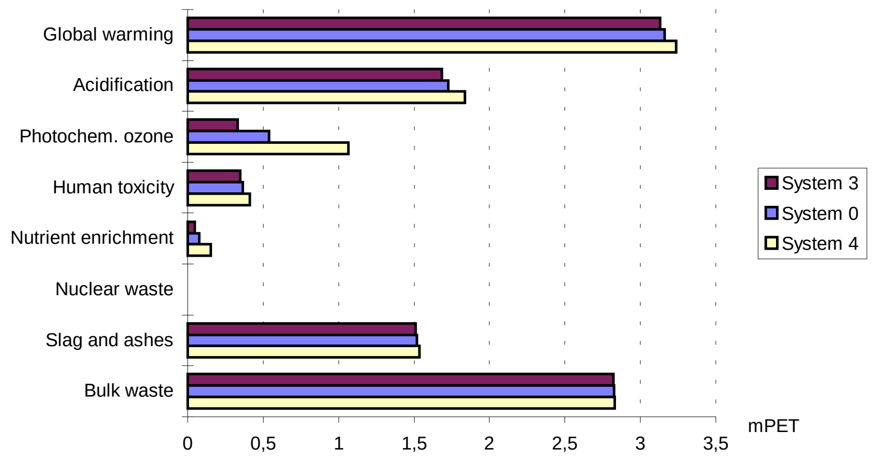

***Figure 6.2.10**: Weighted environmental impact potentials for a cotton T-shirt. System 3 and 4 versus the reference system, System 0*

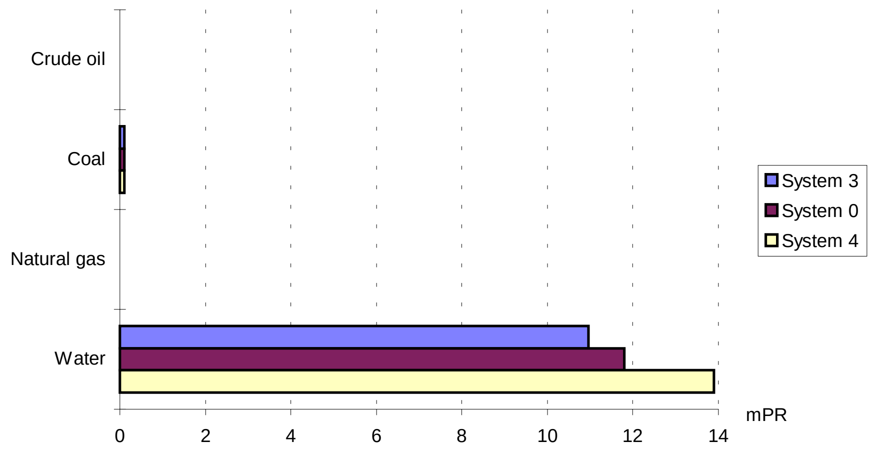

***Figure 6.2.11**: Weighted resource consumption potentials for a cotton T-shirt. System 3 and 4 versus the reference system, System 0*

Environmental benefits gained by the cleaner technology process modification outlined in Figure 6.2.6 - about 0.0006 mPET referring to global warming - can be compared to disadvantages by lifetime shortening in Figure 6.2.10 - about 0.05 mPET with a 50% lifetime reduction referring to global warming. The benefits by the process modification can in this way be quantified to only about 1.2% of a lifetime shortening. If a lifetime shortening will result from the process modifications, the total environmental account will very easily grow negative.

The same calculations concerning the water consumption in Figure 6.2.7 - 0.25 mPR benefits by process modifications - respectively Figure 6.2.11 - 2 mPR loss due to 50% reduction lifetime reduction - quantifies the benefits by the cleaner technology solutions to about 13% of a life time shortening. The water savings in the new dyeing and rinsing processes is obviously of a quantity that can be noticed in the total resource consumption of the life cycle of the T-shirt, but only limited lifetime reduction due to the cleaner technology solution would give a posi-

positive account referring to the total resource account.

The lifetime must, however, be judged as a very decisive factor for the environmental performance of the T-shirt and as a factor that has to be watched very carefully whenever alterations in the life cycle of the T-shirt come up.

Altered disposal

T-shirts can be disposed of in several ways. In this work T-shirts are assumed to be collected by the municipal waste system after use. In 1990 in Denmark 26% of this waste was sent to landfills and the remaining 74% was incinerated with recovery of energy, this is anticipated in system 0.

An optimised system (system 5) is exemplified with all the household waste being sent to municipal waste incineration plants with energy recovery. Finally these are compared with a hypothetical example (system 6) where the used product is sent to landfills. These scenarios are illustrated in Figures 6.2.12 and 6.2.13.

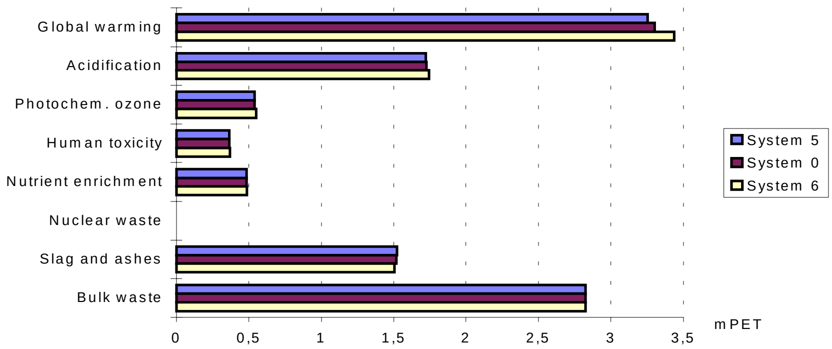

***Figure 6.2.12**: Weighted environmental impact potentials for a cotton T-shirt. System 5 and 6 versus the reference system, System 0*

The environmental profile, Figure 6.2.12 shows that the largest changes in the environmental impact potentials are seen in the global warming potentials. The large contribution from system 6 is a result of the anaerobic production of methane gas from landfills.

The resource profile, Figure 6.2.13, does not show any visible changes.

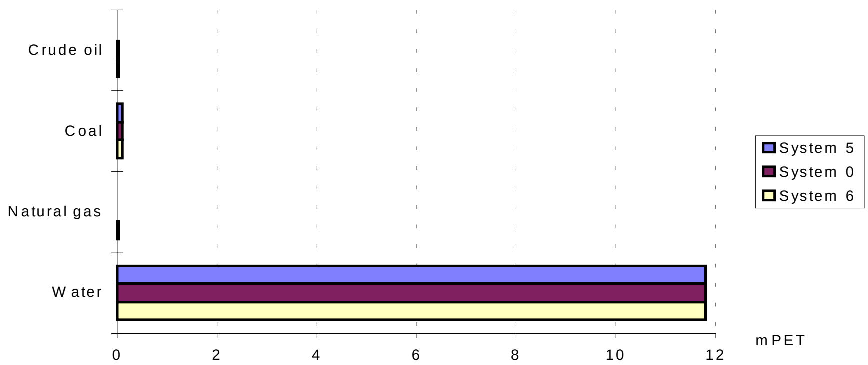

***Figure 6.2.13**: Weighted resource consumption potentials for a cotton T-shirt. System 5 and 6 versus the reference system, System 0*

Calculations to quantify the environmental benefits gained by process modifications - in Figure 6.2.6 0.0006 mPET - compared to disadvantages by alterations in disposal procedures - in Figure 6.2.12 0.15 mPET - gives approximately 0.5%. Thus, the environmental impacts from the disposal stage can also be pointed out as decisive in the life cycle of the T-shirt.

Altered use

The environmental performance of the T-shirt during use will be illustrated by the following alterations:

New surface treatment of the textile as reduces the number of annual washing and drying processes by about 30% (system 7)

- Textile products produced from short fibred cotton gives a shaggy surface as increases the number of washing and drying processes by about 30% (system 8)

The alterations in the environmental performance of the two examples can be outlined with the help of Figure 6.2.5. The new surface treatment will result in a weighted global warming impact of about 2 mPET from use and the increased number of washing and drying processes will result in a weighted global warming impact of about 4 mPET from use - the product life cycle excl. use being unchanged. For a normal good quality T-shirt - i.e. one T-shirt used in one year - it is seen that the difference will amount to about 100%.

For a T-shirt the above mentioned alterations of the use stage are not the most likely to be caused by changes in the dyeing process. For a table cloth, however, this issue is relevant, because surface treatment of the textile is used in order to allow cleaning the cloth with a wet rag instead of washing, drying and ironing it.

For the T-shirt, however, another issue is very relevant, namely the colouring of other textile products during washing in the use stage. Just one case of such colouring will result in the shortening of the lifetime of maybe 10 - 20 other textile products resulting in very large environmental impacts. The washing fastness of the T-shirt is thus a decisive product property that should not be negatively influenced by the process modification in the dyeing and rinsing.

Alterations in the use processes are as well as the life time seen not to have very decisive influence on the environmental performance of the T-shirt.

6.2.4 Technology specific environmental indicators, TSIS

Parameters resulting in significant environmental impact will for a specific technology relate to the process and/or to the product.

The process dimension of environmental performance

The process dimension of environmental performance is the performance of the process itself. In practice the workers at the dyehouse are aware of which process parameters, chemicals, etc. that are decisive for the environmental impact.

This environmentally performance of the dyeing process is very much related to:

- dyestuff fixation percent
- heavy metals in dyestuffs
- consumption of salt to perform the dyeing
- use of environmentally hazardous cations
- specific water consumption (l/kg textile)
- specific energy consumption (MJ/kg textile)

These properties are watched and are used for optimizations.

The product dimension of environmental performance

The product dimension of environmental performance is the influence of the process on the product's performance. In this case first and foremost the lifetime of the T-shirt but also the performance in the other stages of the life cycle, e.g. performance during use.

The environmental performance of the product referring to lifetime is determined by a number of key properties:

- washing fastness
- rub fastness
- water fastness

Washing fastness

Washing fastness determines the durability of the colour during washing in the use stage. The test is done by washing at 60°C in 30 min. of the dyed textile together with white test textiles of cotton, wool, PET and PA. Washing powder without optical brightener must be used. Colouring of the test textiles are rated on a scale from 1 to 5.

Rub fastness

Rub fastness determines how coloured a white cotton test textile gets when rubbed on the dyed textile at 20°C, both dry and wet. Test described in ISO 105-X12 (ASIM ISO 105-E01).

Water fastness

This determines the fastness of the dye during wear, 37°C and moisturized at low pH (DIN 54006).

Referring to other stages in the life cycle there are several similar international approved product tests available.

6.2.5 **Conclusions**

In this case it is documented:

- that a cleaner technology should always be assessed both in the process and in the product dimension.
- that the product dimension, i.e. the life cycle of the product, can be influenced by the technology and that this influence is environmentally decisive.
- that 30-40% environmental improvement of the dyeing and rinsing processes can be lost by e.g. less than 1% shortening of the lifetime. Influences on the use and disposal stages are of similar importance.
- that environmental performance can be controlled by "technology specific indicators" which are the process parameters or product properties that are decisive to the environmental performance.
- that the environmentally important process parameters of dyeing and rinsing are well known and used routinely by process operators and managers in the textile industry. Similarly, the environmental properties are measured on a routine basis before products are sold.

6.3 Surface treatment case: Zinc plating of steel sheet

Process to be assessed

The process to be assessed in the present case is the zinc plating of steel items. Even though there are many varieties of zinc plating: 1) Cyanide zinc, 2) Cyanide free alkaline zinc, 3) Acid zinc and many others - zinc plating is considered as a general technology. Zinc plating is the most widespread plating process in the world, and regardless of the type of zinc plating, the cleaner technologies influencing the environmental performance of the processes, are the same.

Product to be assessed

The product that is to be assessed in the present case is a zinc plated steel sheet, used, for example, in a washing machine.

Superior service

The superior service of the zinc plating is to serve as rust prevention of steel items. In this case a zinc plated steel sheet has been chosen to represent the product. The functional unit is:

The functional unit

A zinc plated steel sheet with the dimensions 1m x 1m x 0.0006m with a lifespan of 14 years.

(This does not mean that the object is worn out after 14 years).

6.3.1 Reference technology, process and product dimension

The reference process: Zinc plating, alkaline, cyanide free

The process of zinc plating (a reference, without any cleaner technologies implemented) is shown in a schematic outline in Figure 6.3.1.

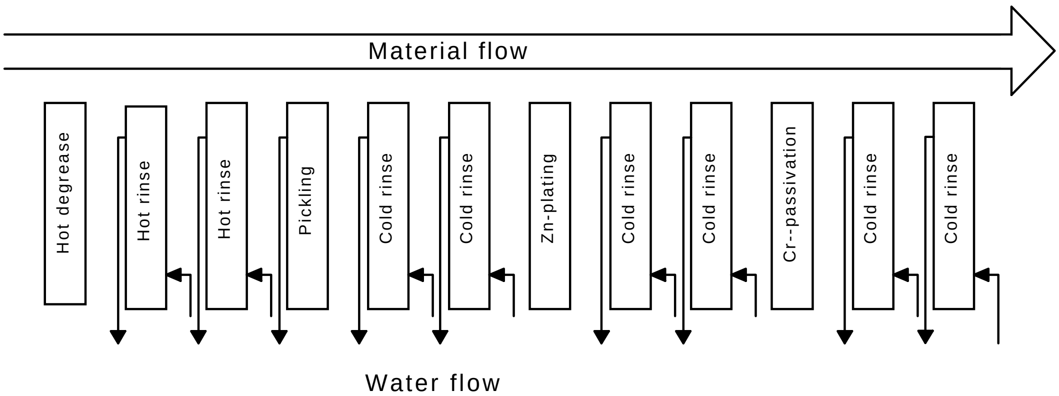

***Figure 6.3.1**: Zinc plating process*

Degreasing, rinsing

The steel sheet is degreased in a hot alkaline solution. Afterwards it is rinsed in two hot rinses, having separate water supply, and steam is used for heating. No reuse of rinse water in the pre-treatment operations.

Pickling, rinsing

In order to neutralize the degreaser and to remove any oxide film or layer of corrosion product, the sheet is pickled in a solution of muriatic acid (HCl). After pickling, the sheet is rinsed in cold water having a separate water supply.

Zinc plating, rinsing

Zinc plating is carried out in an alkaline, cyanide free solution, at room temperature. The plating thickness is approx. 10mm. The solution consists of sodium hydroxide, zinc oxide and some proprietary brighteners. After plating, the sheets are rinsed in two tanks, having a separate water supply. There is no backfilling of rinse water to the plating bath.

Passivation

The zinc-plated sheets are finally immersed into a chromic acid (Cr(VI)) based, passivation solution, which forms good adherence properties for subsequent painting. The parts are rinsed in two tanks having a separate water supply. No reuse of water takes place.

Drying

The last operation in the zinc plating line is the drying, using hot air.

The reference product: Life cycle of a zinc-plated steel sheet

A simplified life cycle of a steel sheet is shown in Figure 6.3.2.

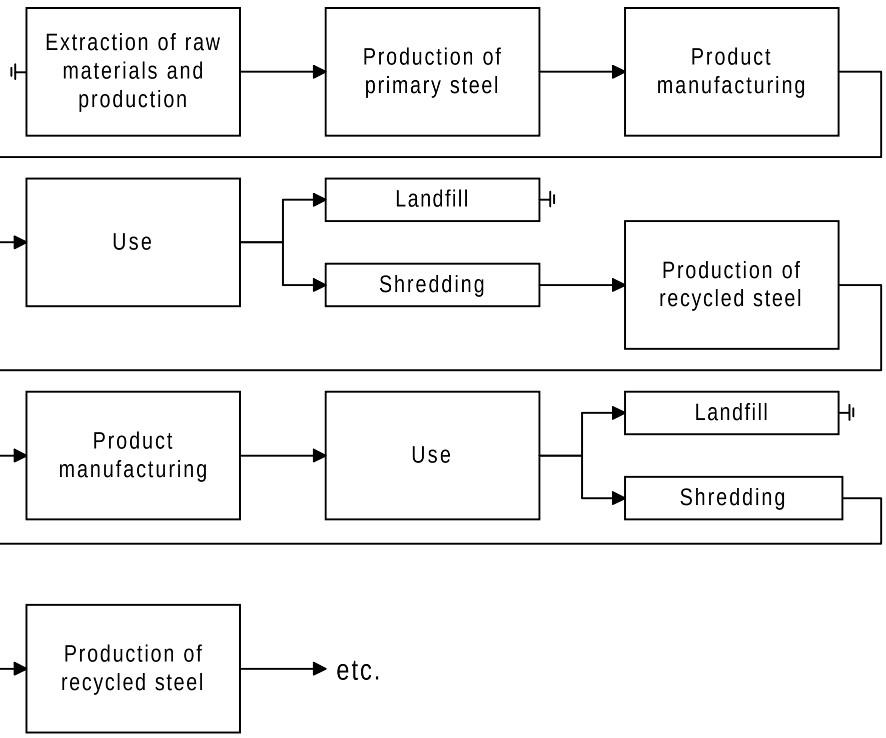

***Figure 6.3.2**: Lifecycle for a zinc plated steel sheet*

Extraction of raw materials

The life cycle of steel sheets starts with the extraction of the various raw materials all being components in steel.

Production of primary steel

The production of primary steel is the first production process in the life cycle of steel, where the steel is processed into metal sheets or other intermediate products.

Product manufacturing

In this stage the steel is processed and given those qualities desired in the product in which it is to be incorporated.

Use

The use stage is not of interest in this work. This is due to the defined functional unit, where there are no environmental interventions from the use stage.

Disposal

After use the product in which the metal sheet is a part of is disposed. There are two ways in which this product will be disposed of as shown in Figure 6.3.2. If the product is sent to landfill the steel sheet will be treated as bulk waste. If the product is recovered via a shredder the steel will be reused in other products. After the shredding process the steel is ready to be processed into new products via melting. In order to obtain a uniform steel quality in recycled products the recycled steel is mixed with a fraction of primary steel. After this process the steel is again ready to be processed for use in new products. Zinc evaporates from the steel melt and ends as dust in an exhaust filter. Afterwards it can be sent for recycling.

It is in the product manufacturing that we find the zinc-plating process.

Discussion of process versus product system

In a product life cycle, Figure 6.3.2 we are provided with an allocation problem. This is due to the recycling of steel. The allocation is done by use of a material grade allocation as described in the Danish EDIP method and will not be described further.

Environmental impacts

From a product LCA of zinc plated steel sheets (system 0), Figures 6.3.3 and 6.3.4, it can be seen that the extraction of raw materials and processing of these is the most dominant stage.

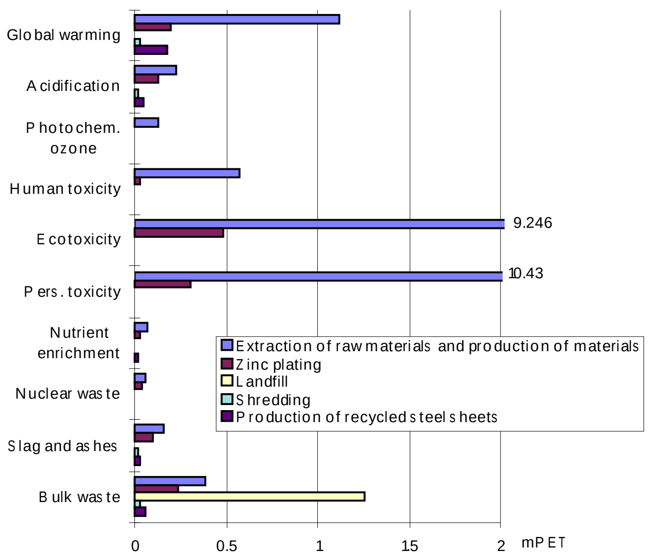

***Figure 6.3.3**: Weighted environmental impact potentials for a zinc-plated steel sheet*

In all the impact categories in the environmental profile this stage is dominant or very noticeable. The zinc plating process is not the most dominant, but is still very noticeable, except in the formation of photo-chemical ozone. The only impact derived from landfill is that of bulk waste and here it can be characterized as the dominant stage. The impacts from the shredding process are mostly derived from energy consumption. The production of recycled steel sheets is also noticeable in most of the impacts, but mostly in the contribution to global warming.

Regarding toxicity, human, eco and persistent it can be seen that the raw materials extraction process and the zinc-plating process are the most significant.

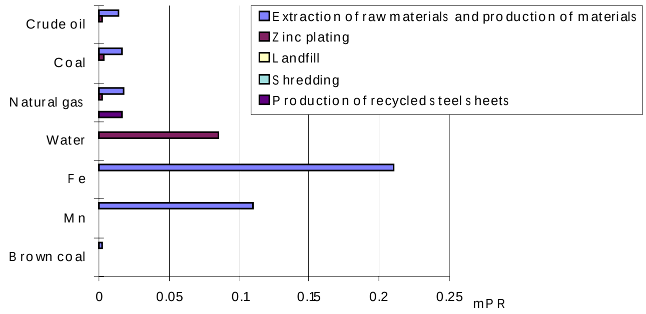

***Figure 6.3.4**: Weighted resource consumption for a zinc plated steel sheet*

The resource profile, Figure 6.3.4, is also characterized by the extraction and processing of raw materials. The only other processes that are noticeable is the production of recycled steel (natural gas) and zinc-plating (water).

The assessed technology, zinc plating contributes to the products environmental performance in several ways. The contributions to the environmental interventions from the product are not very large and a reduction of these would not change the environmental profile of the product much, but a reduction in the consumption of water would give considerable changes to the resource profile and it would also eliminate the discharge of zinc from the process.

Often an increased quality of the zinc plated steel item would not change the lifetime of the item. This is due to the item often being part of a larger product, e.g. a washing machine where other factors as the lifetime of the motor or electronics would be the decisive factor of the lifetime of the product.

The process dimension of environmental performance is the performance of the process itself.

This performance relates:

- consumption of chemicals
- consumption of water
- consumption of energy
- emissions to air
- emissions to water
- emissions to soil

The product dimension of environmental performance

The product dimension of environmental performance is the technology's influence on the product's performance. The environmental performance of the product is determined by a number of key properties. In the case of a zinc-plated steel sheet these are:

- Corrosion resistance (ASTM B 117 salt spray test, ISO 3768)
- Adhesion (ASTM B 517, ISO 2819)

Investigated scenarios

In order to identify the various EPIs at level 2 in the indicator model several systems have been assessed and compared. These systems are:

System 0 One functional unit. Fraction of steel recycled after use = 40%
System 1 Lifetime of zinc-plated steel sheet increased to 20 years
System 2 Lifetime of zinc-plated steel sheet reduced to 10 years
System 3 Fraction of steel recycled after use increased to 90%
System 4 Fraction of steel recycled after use decreased to 20%
System 5 Introduction of cleaner technology in the zinc plating process

Discussion of process versus product system

Identification of level 1 EPIs

In this work primary level EPIs are defined as those EPIs derived directly from the preliminary LCA, e.g. global warming, acidification, etc. In the following different alterations to the product system are simulated and used to identify EPIs derived from alternated processes/stages. These are:

Product

- altered lifetime of the zinc-plated steel sheet, e.g. the washing machine. As mentioned earlier, this is not done by increasing the quality of the zinc plating, but other qualities in the washing machine.

Product

- altered disposal scenarios.

Product + process

- implementation of cleaner technology solutions in the zinc plating process. The product and product quality is unchanged.

Comparison of products (LCA)

The following is an investigation of the results of altered stages in the product life cycle.

Simulation of altered lifetimes of the zinc plated steel sheet

Lifetime

In order to illustrate the consequences of altered lifetimes three examples have been chosen:

- System 0: 1 zinc-plated steel sheet per functional unit.
- System 1: 0.7 zinc-plated steel sheet per functional unit.
- System 2: 1.4 zinc-plated steel sheet per functional unit.

The systems are illustrated in Figures 6.3.5 and 6.3.6

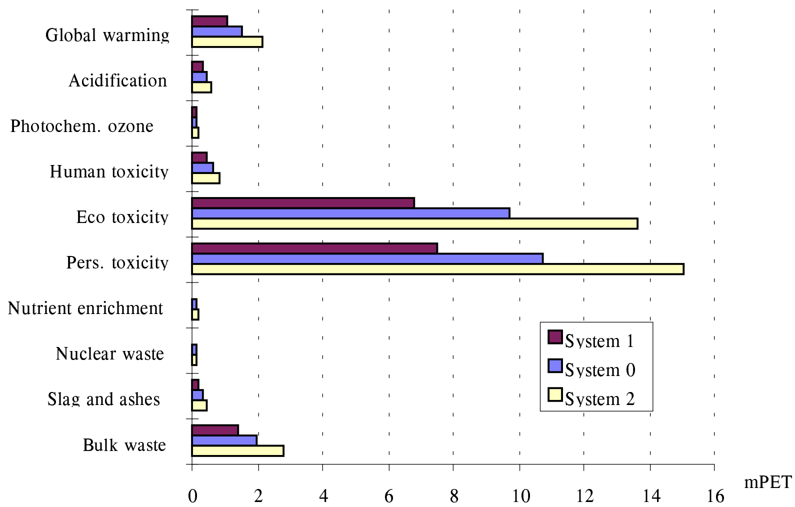

Figure 6.3.5: *Weighted environmental impact potentials for systems 0, 1 and 2*

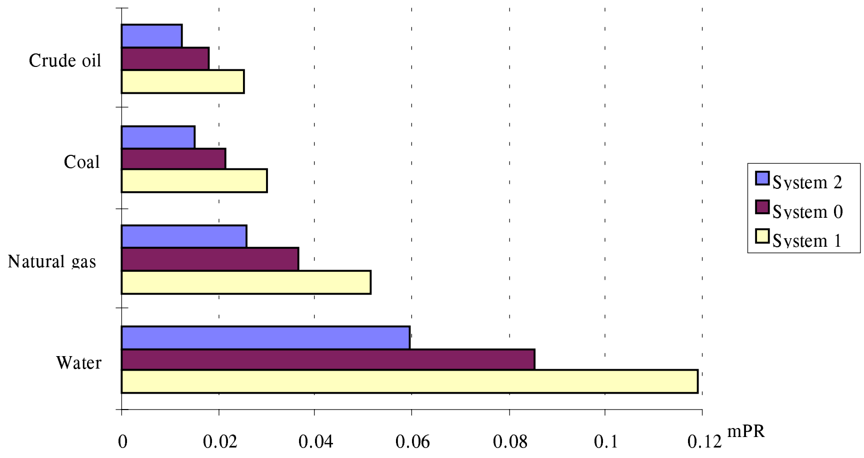

Figure 6.3.6: *Weighted resource consumption for systems 0, 1 and 2*

If one looks at the environmental profile, Figure 6.3.5, it can be seen that the life time of the zinc-plated steel sheet has a considerable effect on all the contributions to the environmental impacts. In the resource profile, Figure 6.3.6, the same can be seen.

Altered disposal scenarios

In Western Europe 40% of used steel is recycled. The remaining 60% is sent to landfill. This is illustrated in system 0.

An optimized system (system 3) is exemplified with 90% of the used steel being recycled and finally system 4 shows the effects when 80% of the used steel being treated as landfill waste.

A comparison of these systems is shown in Figures 6.3.7 and 6.3.8.

The environmental profile, Figure 6.3.7 shows considerable reductions in contribution to all impacts, especially toxicity and bulk waste, when increasing the recycling fraction.

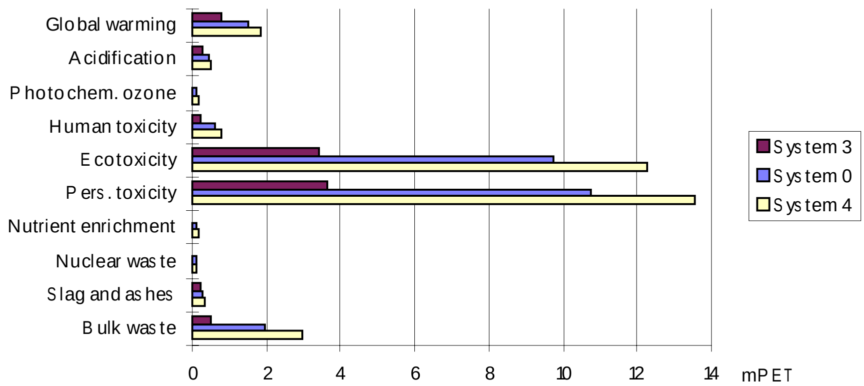

Figure 6.3.7: *Weighted environmental impact potentials for systems 0, 3 and 4*

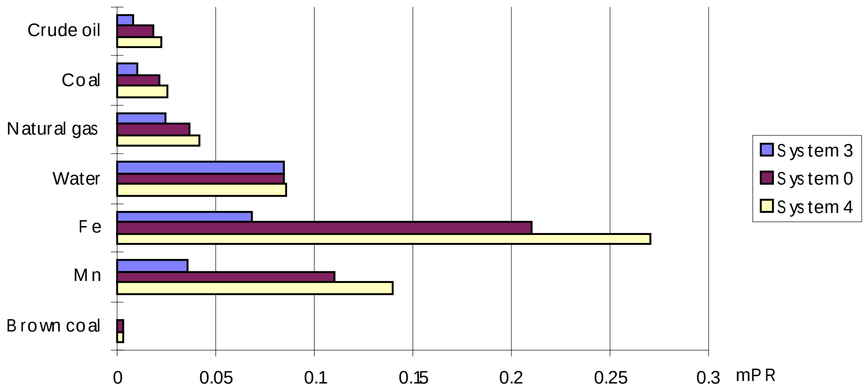

***Figure 6.3.8**: Weighted resource consumption for systems 0, 3 and 4*

The resource profile, Figure 6.3.8, shows the same tendencies as the environmental profile. The only deviation is that of water consumption. This is due to the zinc-plating process being the main contributor to this impact as shown in Figure 6.3.4, and is not influenced by alternating disposal systems.

Comparison of technologies

Process

As mentioned earlier the investigated process is that of zinc plating. In a cleaner technology project done by the IPU the main differences between the old process (system 0) and the new "cleaner" process (system 5) are:

- The plating metal is kept in the process line
- The water consumption is reduced to a minimum
- Hot rinses are converted to room temperature rinses
- In return, there is a consumption of evaporation power in the reverse flow system.

The new process is shown in Figure 6.3.9.

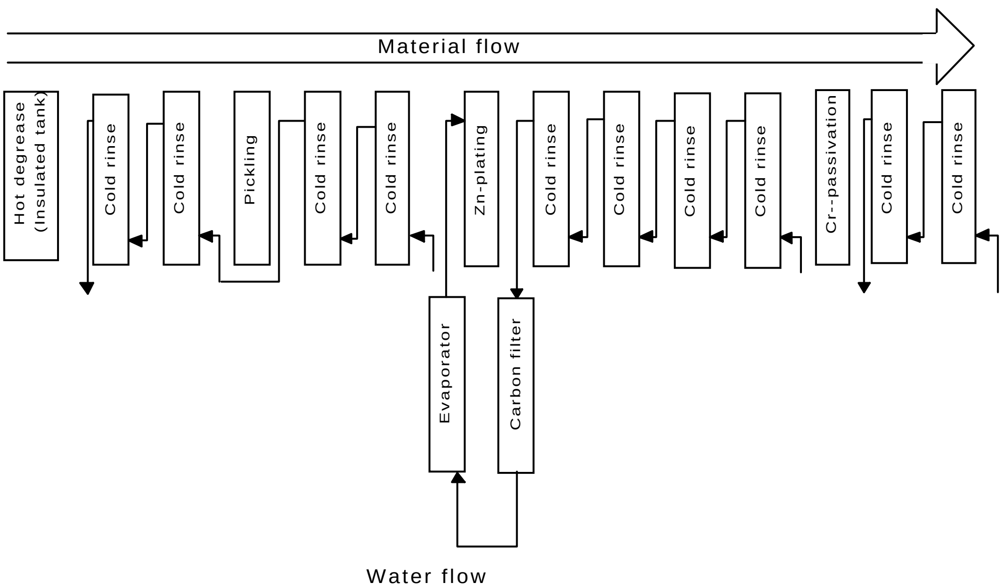

***Figure 6.3.9**: Process diagram for modified, "cleaner" zinc-plating process.*

Enclosed graphs, see appendix, show the importance of introducing extra rinse tanks to reduce the water consumption and thereby the evaporation need and the extra power need for this purpose. The Figures for the two situations are as follows:

In the case of an annual production of zinc plating of 70,000 m^2 the water need for rinsing in a 4-tank-system will be **190 m^3/year** presuming that the rinse criterion (concentration in the last rinse) is: 1 ppm.

Presuming that the rinse criterion is unchanged and the annual production also is the same, the water need in a 2-tank-system will be **2650 m^3/year.**

The environmental and the resource profiles of the product system are shown in Figures 6.3.10, 6.3.11 and 6.3.12.

Product

As presumed the environmental profile in Figure 6.3.10 does not show any considerable reduction in environmental impact, except from a small decrease in the impacts from eco and persistent toxicity.

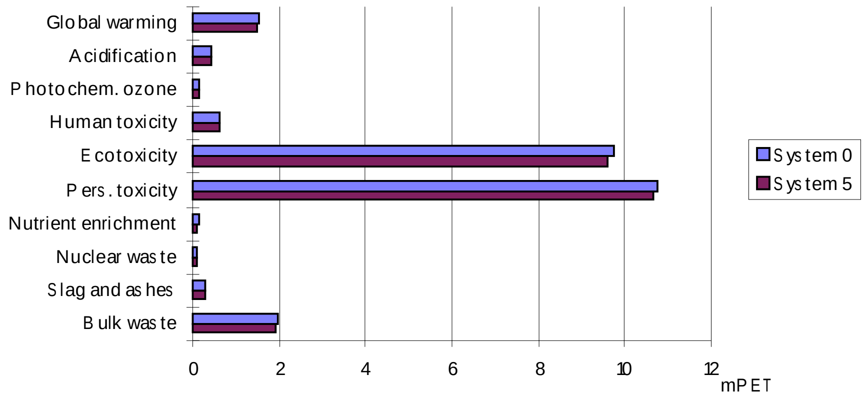

***Figure 6.3.10**: Environmental profile for product systems 0 and 5*

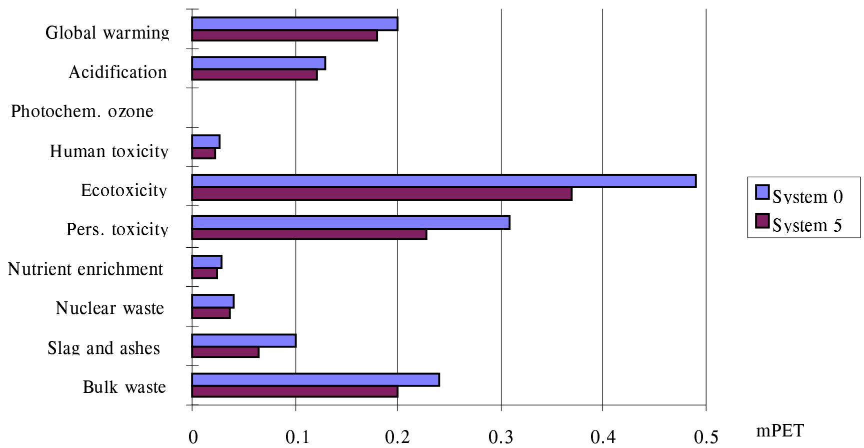

***Figure 6.3.11**: Environmental profile for zinc plating process, system 0 and 5*

If one only looks at the zinc-plating process, illustrated in Figure 6.3.11, the reductions are much more significant. Here the reductions of eco and persistent toxicity are more noticeable.

As Figure 6.3.10 the resource profile of the whole product system, Figure 6.3.12, only shows very few changes. All the fossil fuels and metals are virtually unchanged, but the water consumption is reduced by approx. 50% (the resource profile for the process does not reveal any other changes and is therefore not shown).

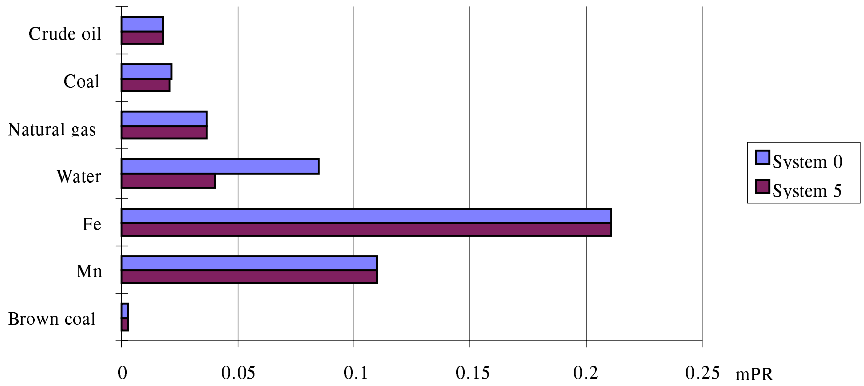

Figure 6.3.12: *Resource profile for product systems 0 and 5*

Discussion of process versus product system

Comparing the reference system to the simulations several conclusions can be made:

- There is not one stage of the product life cycle which dominates, but different stages dominate different impact categories.
- The investigated cleaner technology scenarios result mainly in a reduction of ecotoxicity, persistent toxicity and water consumption.
- If an overall reduction of the impacts is desired it is necessary to combine various changes, e.g. increased recycling rate and introduction of cleaner technologies in the zinc plating process.
- Cleaner technology initiatives that have an effect on the product quality, do not always affect the product life time, because this is often decided by other factors.
- At this stage nothing can be concluded regarding the working environment, though it is certain that this impact would have a considerable effect on the appearance of the final profiles.

The product dimension, key product properties

Depending on the use of the zinc-plated product the importance of the quality will vary. In products like a washing machine the zinc-plated steel will not have much of an effect, but if the zinc-plated object can be identified as the significant part of a product, e.g. a lamp post, the quality will be of the highest importance.

According to the involved parties the quality can be measured by the following quality tests/key product properties (these have been quantified earlier, and will therefore not be explained further here, but just stated):

- Corrosion resistance
- Adhesion

The process dimension

Changes in the process dimension will not have any considerable effects on the environmental interventions. There are only few exceptions: eco, persistent toxicity and water consumption. Expressed as EPIs these are:

- Dragout of Zn (heavy metals) and chemicals
- Water consumption