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Environmental management — Eco-efficiency assessment of product systems — Principles, requirements and guidelines (ISO 14045:2012)

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National foreword

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Foreword

This document (EN ISO 14045:2012) has been prepared by Technical Committee ISO/TC 207 “Environmental management”.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2012, and conflicting national standards shall be withdrawn at the latest by November 2012.

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Endorsement notice

The text of ISO 14045:2012 has been approved by CEN as a EN ISO 14045:2012 without any modification.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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ISO 14045 was prepared by Technical Committee ISO/TC 207, *Environmental management*, Subcommittee SC 5, *Life cycle assessment*.

Introduction

Eco-efficiency assessment is a quantitative management tool which enables the study of life-cycle environmental impacts of a product system along with its product system value for a stakeholder.

Within eco-efficiency assessment, environmental impacts are evaluated using Life Cycle Assessment (LCA) as prescribed by other International Standards (ISO 14040, ISO 14044). Consequently, eco-efficiency assessment shares with LCA many important principles such as life cycle perspective, comprehensiveness, functional unit approach, iterative nature, transparency and priority of a scientific approach.

The value of the product system may be chosen to reflect, for example, its resource, production, delivery or use efficiency, or a combination of these. The value may be expressed in monetary terms or other value aspects.

The key objectives of this International Standard are to:

— establish clear terminology and a common methodological framework for eco-efficiency assessment;

— enable the practical use of eco-efficiency assessment for a wide range of product (including service) systems;

— provide clear guidance on the interpretation of eco-efficiency assessment results;

— encourage the transparent, accurate and informative reporting of eco-efficiency assessment results.

Environmental management — Eco-efficiency assessment of product systems — Principles, requirements and guidelines

1 Scope

This International Standard describes the principles, requirements and guidelines for eco-efficiency assessment for product systems, including:

a) the goal and scope definition of the eco-efficiency assessment;

b) the environmental assessment;

c) the product system value assessment;

d) the quantification of eco-efficiency;

e) interpretation (including quality assurance);

f) reporting;

g) critical review of the eco-efficiency assessment.

Requirements, recommendations and guidelines for specific choices of categories of environmental impact and values are not included. The intended application of the eco-efficiency assessment is considered during the goal and scope definition phase, but the actual use of the results is outside the scope of this International Standard.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14040:2006, *Environmental management — Life cycle assessment — Principles and framework*

ISO 14044:2006, *Environmental management — Life cycle assessment — Requirements and guidelines*

ISO 14050:2009, *Environmental management — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14050 and the following apply.

3.1
product
any goods or service

[SOURCE: ISO 14021:1999, 3.1.11]

3.2
product flow
products (3.1) entering from or leaving to another product system

[SOURCE: ISO 14040:2006, 3.27]

3.3
product system
collection of unit processes with elementary and *product flows* (3.2), performing one or more defined functions, and which models the life cycle of a *product* (3.1)

[SOURCE: ISO 14040:2006, 3.28]

3.4
environmental aspect
element of an organization's activities or products or services that can interact with the environment

Note 1 to entry: A significant environmental aspect has or can have a significant environmental impact.

[SOURCE: ISO 14001:2004, 3.6]

3.5
environmental performance
measurable results related to *environmental aspects* (3.4)

3.6
eco-efficiency
aspect of sustainability relating the *environmental performance* (3.5) of a *product system* (3.3) to its *product system value* (3.7)

3.7
product system value
worth or desirability ascribed to a *product system* (3.3)

Note 1 to entry: The product system value may encompass different value aspects, including functional, monetary, aesthetic, etc.

3.8
product system value indicator
numerical quantity representing the *product system value* (3.7)

Note 1 to entry: To express the product system value indicator, various kinds of units such as physical and monetary units or relative gradings and scoring may be used.

3.9
eco-efficiency indicator
measure relating *environmental performance* (3.5) of a *product system* (3.3) to its *product system value* (3.7)

3.10
eco-efficiency profile
eco-efficiency (3.6) assessment results relating the life cycle impact assessment results to the *product system value* (3.7) assessment results

3.11
weighting factor
<eco-efficiency> factor derived from a weighting model, which is applied to convert an assigned life cycle inventory result, a life cycle impact category indicator result, or a product system value indicator to the common unit of the weighting indicator

3.12
sensitivity analysis
systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study

[SOURCE: ISO 14040:2006, 3.31]

3.13
uncertainty analysis
systematic procedure to quantify the uncertainty in the results of a life cycle inventory analysis and/or product system value assessment due to the cumulative effects of model imprecision, input uncertainty and data variability

Note 1 to entry: Either ranges or probability distributions are used to determine uncertainty in the results.

[SOURCE: ISO 14040:2006, 3.33, modified — "and/or product system value assessment" has been inserted.]

3.14
unit process
smallest element considered in the life cycle inventory analysis or product system value assessment for which input and output data are quantified

[SOURCE: ISO 14040:2006, 3.34, modified — "or product system value assessment" has been inserted.]

3.15
critical review
<eco-efficiency> process intended to ensure consistency between an *eco-efficiency* (3.6) assessment and the principles and requirements of the International Standards on eco-efficiency assessment

[SOURCE: ISO 14040:2006, 3.45, modified — "Life cycle assessment" has been replaced by "eco-efficiency assessment".]

3.16
comparative eco-efficiency assertion
claim in *eco-efficiency* (3.6) regarding the superiority or equivalence of one *product* (3.1) versus a competitor's *product* that performs the same function

Note 1 to entry: This definition does not interpret, change, or subtract from the requirements of ISO 14044 on comparative assertions.

4 General description of eco-efficiency

4.1 Principles of eco-efficiency

4.1.1 General

The following principles are fundamental and serve as guidance for decisions relating to both the planning and the conducting of an eco-efficiency assessment.

4.1.2 Life cycle perspective

An eco-efficiency assessment considers the entire life cycle from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end-of-life treatment and final disposal. Through such a systematic overview and perspective, the shifting of a potential impact between life cycle stages or individual processes can be identified and assessed with a view to an overall eco-efficiency.

4.1.3 Iterative approach

Eco-efficiency assessment is an iterative technique. The individual phases of an eco-efficiency assessment (see Figure 1) use results of the other phases. The iterative approach within and between the phases contributes to the comprehensiveness and consistency of the eco-efficiency assessment and the reported results.

4.1.4 Transparency

Due to the inherent complexity in eco-efficiency assessment, transparency is an important guiding principle in executing an eco-efficiency assessment, in order to ensure a proper interpretation of the results.

4.1.5 Comprehensiveness

An eco-efficiency assessment considers all attributes and aspects of environment and product system value. By considering all attributes and aspects within one eco-efficiency assessment, potential trade-offs can be identified and assessed.

4.1.6 Priority of scientific approach

Decisions within an eco-efficiency assessment are preferably based on scientific data, methodology and other evidence. If this is not possible, decisions based on international conventions may be used. If neither a scientific basis exists nor international conventions can be referred to, then decisions may be based on value choices.

4.2 Phases of an eco-efficiency assessment

An eco-efficiency assessment comprises five phases:

a) goal and scope definition (including system boundaries, interpretation and limitations);

b) environmental assessment;

c) product system value assessment;

d) quantification of eco-efficiency;

e) interpretation (including quality assurance).

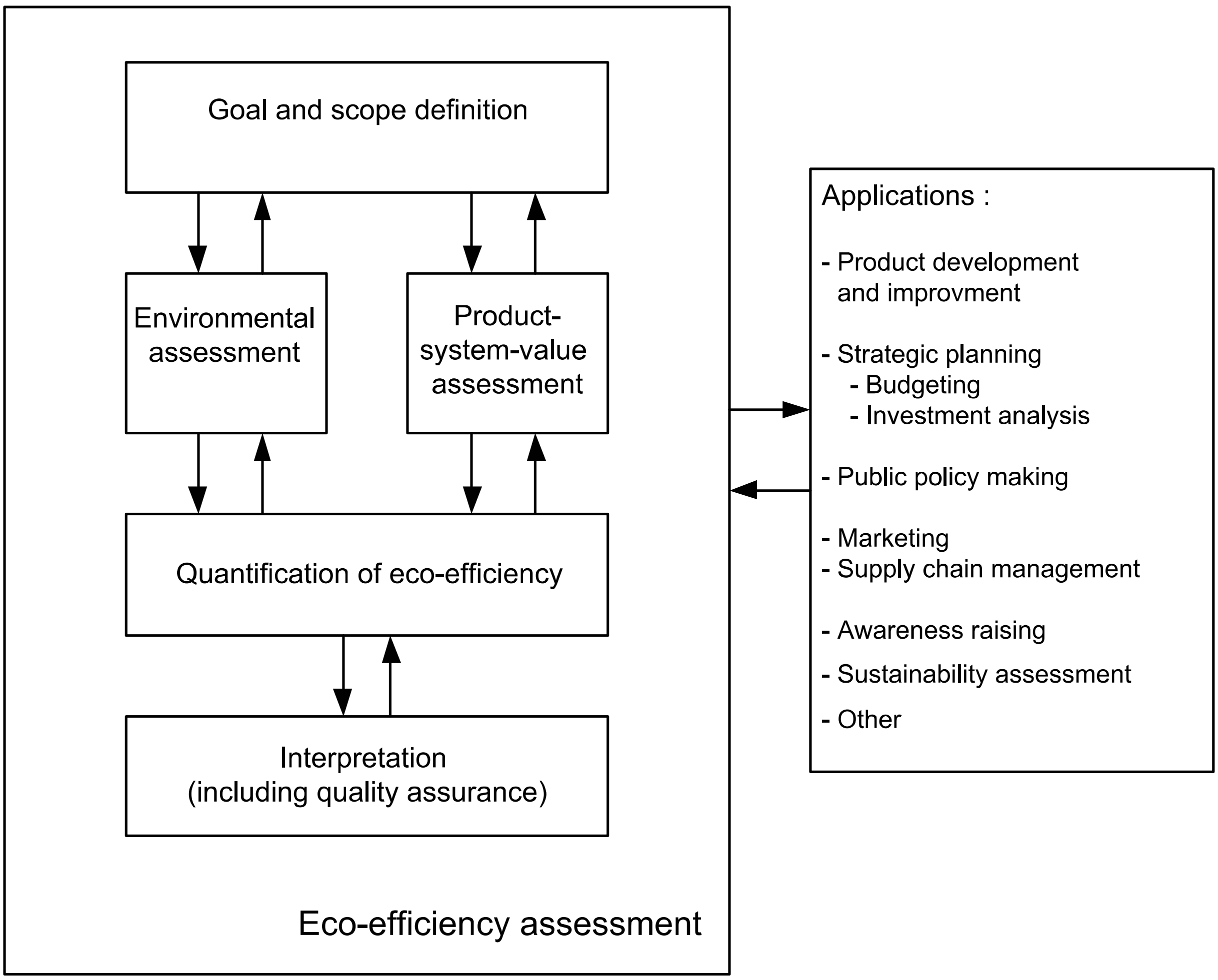


Figure 1 — Phases of an eco-efficiency assessment

4.3 Key features of an eco-efficiency assessment

An eco-efficiency assessment is an assessment of the environmental performance of a product system in relation to its value.

Eco-efficiency is a practical tool for managing environmental and value aspects in parallel.

The result of the eco-efficiency assessment relates to the product system, not the product per se. A product cannot be eco-efficient, only its product system which includes the production, use, disposal, i.e. the full life cycle, can be. Also, eco-efficiency is a relative concept and a product system is only more-or-less eco-efficient in relation to another product system.

5 Methodological framework

5.1 General requirements

Eco-efficiency assessments shall include goal and scope definition, environmental assessment, product system value assessment, quantifications of eco-efficiency and interpretation.

5.2 Goal and scope definition (including system boundaries, interpretation and limitations)

5.2.1 Overview of requirements

5.2.1.1 In defining the goal, the following items shall be considered and clearly described:

— the purpose of the eco-efficiency assessment;

— the intended audience;

— the intended use of the results.

5.2.1.2 In defining the scope, the following items shall be considered and clearly described:

— the product system to be assessed;

— the function and functional unit;

— the system boundary of the product system;

— the allocations to external systems;

— the environmental assessment method and types of impacts;

— the value assessment method and type of product system value;

— the choice of eco-efficiency indicator(s);

— the interpretation to be used;

— the limitations;

— the reporting and disclosure of results.

5.2.2 The product system to be assessed

The product system shall be defined by its name and the scale, location, time and main stakeholders which are involved.

5.2.3 Function and functional unit

The scope of an eco-efficiency assessment shall clearly specify the functions (performance characteristics) of the product system being studied. A functional unit shall be defined that is consistent with the goal and scope of the eco-efficiency assessment.

One of the primary purposes of a functional unit is to provide a reference for the environmental assessment and for the product system value assessment. Therefore, the functional unit shall be measurable and clearly defined.

5.2.4 System boundary

The system boundary shall be described as specified in ISO 14044.

The system boundary shall be the same for the environmental and the product system value assessment.

5.2.5 Allocations to external systems

Allocations to adjacent systems outside the system boundary shall be identified and allocation principles used shall be described.

5.2.6 Environmental assessment method and types of impacts

It shall be determined which elementary flows, cut-off criteria, allocation rules, impact categories, category indicators, characterization models and weighting methods will represent the environmental aspect in the eco-efficiency assessment. The selection of elementary flows, cut-off criteria, allocation rules, impact categories, category indicators, characterization models and weighting methods shall be consistent with the goal of the study.

Exclusions made for the purpose of the eco-efficiency assessment shall be described and justified.

5.2.7 The product system value

Different stakeholders may encounter different values for the same product system. For instance, the product system value to the consumer may be different from the product system value to the producer, and in turn different from the product system value to the investor.

It shall be described which stakeholder's value(s), type of value(s) and methods used to determine the product system value(s) are to be used in the assessment. The value(s) shall be quantifiable with reference to the functional unit according to the goal and scope of the eco-efficiency assessment.

NOTE The types of product system values can be as follows:

— functional value;

— monetary value;

— other values.

5.2.8 Choice of eco-efficiency indicator(s)

There are several types of eco-efficiency indicators that may be chosen to express a quantitative statement on eco-efficiency.

The eco-efficiency indicator(s) to be used in the assessment shall be described. The evaluation method(s) and the presentation format of the eco-efficiency assessment shall be defined.

For the choice of eco-efficiency indicators, the following requirements apply:

— increasing efficiency at the same product system value shall represent an improved environment;

— increasing efficiency at the same environmental impact shall represent an improved product system value.

5.2.9 Interpretation to be used

The need for the following aspects of interpretation shall be clearly defined:

— an identification of the significant issues based on the results of the environmental and product system value assessment phases;

— an evaluation that considers aspects of completeness, sensitivity, uncertainty and consistency;

— the formulation of conclusions, limitations and recommendations;

— a comparison of eco-efficiency assessment results.

5.2.10 Limitations

The scope in itself defines the conditions under which the assessment is made. In principle, the results are not valid outside the scope.

Choices made to define the scope for the eco-efficiency assessment implicitly also define and limit the applicability of the results from the assessment.

To prevent misuse of the results, the specific applications for which the results are not intended to be used may be identified.

5.2.11 Reporting and disclosure of results

The type and format of the report and the means of disclosure shall be defined.

5.3 Environmental assessment

5.3.1 General

Environmental assessment shall be based on life cycle assessment according to ISO 14040 and ISO 14044.

5.3.2 Life cycle inventory (LCI) results

The result of an LCI study may be used directly as input to an eco-efficiency assessment. For instance, where resource use and emissions predominantly originate from the use of fossil oil, the crude oil flow may be used as the sole environmental input.

5.3.3 Life cycle impact assessment

5.3.3.1 General

Life cycle impact assessment (LCIA), if it is done, shall be in accordance with ISO 14040 and ISO 14044.

5.3.3.2 Impact category indicator results

Life cycle impact category indicator results, as determined according to ISO 14044, may be used for eco-efficiency assessments. Such data will typically result in an eco-efficiency profile, where several environmental aspects are considered in parallel.

5.3.3.3 Weighting

Weighting shall not be used in eco-efficiency assessments for comparative eco-efficiency assertions intended to be disclosed to the public.

If weighting is used for eco-efficiency assessment, additional requirements to those in ISO 14044 apply. The following shall be described:

— weighting principles;

— weighting factors;

— how the weighting factors were determined including:

  — methodology;

  — which stakeholder values have been used to determine the weighting factors.

5.4 Product system value assessment

5.4.1 General

The product system value assessment shall consider the full life cycle of the product system.

There are many ways to assess the product system value, as the product system may encompass different value aspects, including functional, monetary and aesthetic aspects.

In business economics, values created by businesses are equal to profit, that is income minus costs. For customers, it may be the willingness to pay minus costs, often called surplus value. The costs may include price, rental fee, operating charge, etc. Such values are difficult to determine on a life cycle basis because some actors in the supply chain are unwilling to communicate their costs and profits. However, one may estimate changes in such values, either through functional performance (functional value) or through financial costs (monetary value).

5.4.2 Possible product system value types

5.4.2.1 Functional value

The functional value of a product system reflects a tangible and measurable benefit to the user and other stakeholders. The functional value is a numerical quantity representing functional performance or desirability of a product system, and is subject to improvement.

In the eco-efficiency assessment, the functional value is different from the functional unit. The functional value should be measured and related to the functional unit in a quantification of the product system performance. The functional unit provides a reference to which the input and output data are normalized (in a mathematical sense). Therefore, within an eco-efficiency assessment, the functional value may change, e.g. because of product improvement, whereas the functional unit remains the same.

5.4.2.2 Monetary value

Monetary value may be expressed in terms of costs, price, willingness to pay, added value, profit, future investment, etc.

Changes in costs for a single company may represent changes in the product system value over the entire life cycle. If other parts of the product system are affected, for example if the price from suppliers is negotiated to be lower or the price to the customer is raised for the same products, then there is no net change in the product system value.

5.4.2.3 Other values

Other values may include intangible values such as aesthetic, brand, cultural and historical values. These values may be determined by means of interviews, surveys, market research, etc.

5.4.3 Calculation of product system value indicator

The quantification of the product system value shall be carried out by using relevant product system value indicators, as defined in the goal and scope of the eco-efficiency study.

NOTE Examples of functional value, monetary value, other values and value indicators can be found in Annex A.

5.5 Quantification of eco-efficiency

The eco-efficiency results shall be determined by relating the results of the environmental assessment to the results of the product system value assessment, according to the goal and scope definition.

For eco-efficiency assessments intended to be communicated to the public, an eco-efficiency profile shall be determined by relating the LCIA profile to the product system value.

5.6 Sensitivity and uncertainty analysis

Sensitivity analysis is a procedure used to determine how changes in data and methodological choices affect the results of the eco-efficiency assessment. A sensitivity analysis may provide additional information on data choice(s). In an eco-efficiency assessment, several different methods for determination of environmental and product system value indicators may be used. Therefore, a sensitivity analysis should be conducted to assess the consequences on the eco-efficiency assessment results of different choices of methodology and data.

An uncertainty analysis should be conducted to determine how uncertainties in data and assumptions affect the reliability of the results of the eco-efficiency assessment.

An analysis of results for sensitivity and uncertainty shall be conducted for eco-efficiency assessments intended to be used in comparative eco-efficiency assertions intended to be disclosed to the public.

5.7 Interpretation

5.7.1 General

The interpretation phase of an eco-efficiency assessment comprises the following elements, according to the goal and scope of the study:

— the identification of significant issues based on the results of the environmental and product system value assessment phases;

— an evaluation that considers aspects of completeness, sensitivity, uncertainty and consistency;

— the formulation of conclusions, limitations and recommendations.

The requirements and recommendations in ISO 14044:2006, 4.5, shall also apply for the interpretation of an eco-efficiency assessment. In addition, the interpretation shall consider the relationship between the environmental results and the product system value results.

5.7.2 Trade-offs between environmental and product system value indicators

Eco-efficiency indicators address both environmental and value aspects and there are potential trade-offs between changes in environmental and product system value performances. The interpretation of results shall be done transparently and with proper justification.

NOTE Trade-offs can also apply within the environmental aspects themselves, but this is covered by ISO 14040.

5.7.3 Comparison of eco-efficiency assessment results

When a comparison of eco-efficiency results between product systems or within the same product system is made, it shall be based on the same eco-efficiency indicator. The comparative environmental assessment results and the product system value assessment results shall then be separately included in the eco-efficiency assessment report.

If improvements in eco-efficiency assessment results are identified or comparisons based on eco-efficiency assessment results are performed, the following cases should be differentiated:

a) improvement or superiority in both aspects (environmental performance and product system value);

b) improvement or superiority in just one of the two aspects;

c) no improvement or superiority in either one.

The first and the third cases do not contain trade-offs between the two dimensions. In the first case, an improvement/superiority in eco-efficiency can be unambiguously determined.

In the third case, an improvement/superiority in eco-efficiency can be unambiguously denied.

The second case is the most challenging, because of the trade-off between environmental and product system value aspects. In this case, an improvement or superiority of eco-efficiency shall only be reported if the trade-off is clearly communicated and the underlying product system value assumptions are documented and justified.

If a claim of improved eco-efficiency or of superiority of the eco-efficiency is disclosed to third parties for the purpose of comparative eco-efficiency assertions, the eco-efficiency assessment results shall demonstrate an equal or better environmental performance.

6 Reporting and disclosure of results

6.1 General requirements

The eco-efficiency results shall be reported as defined in the goal and scope definition phase of the study.

The results and conclusions of the eco-efficiency assessment shall be completely and accurately reported without bias to the intended audience. The results, data, methods, assumptions and limitations shall be transparent and presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the eco-efficiency assessment. The report shall also allow the results and interpretation to be used in a manner consistent with the goals of the eco-efficiency assessment.

The results of the environmental assessment and the product system value assessment shall be documented separately.

6.2 Further reporting requirements for comparative eco-efficiency assertion intended to be disclosed to the public

6.2.1 For eco-efficiency assessments used in comparative eco-efficiency assertions intended to be disclosed to the public, the following issues shall also be addressed by the report, in addition to those identified in 6.1.

6.2.2 For the environmental assessment, the following shall be addressed:

a) an analysis of material and energy flows to justify their inclusion or exclusion;

b) an assessment of the precision, completeness and representativeness of data used;

c) a description of the equivalence of the systems being compared;

d) a description of the critical review process;

e) an evaluation of the completeness of the LCIA;

f) a statement as to whether or not international acceptance exists for the selected LCIA category indicators and a justification for their use;

g) an explanation for the scientific and technical validity and environmental relevance of the LCIA category indicators used in the eco-efficiency assessment;

h) the results of the uncertainty and sensitivity analyses;

i) an evaluation of the significance of the differences found.

6.2.3 For the product system value assessment, the following shall be addressed:

a) the assumptions made in the product system value assessment phase shall be clearly reported and justified;

b) the methodologies and product system value indicators used in the product system value assessment phase shall be clearly reported and justified;

c) an assessment of the precision, completeness and representativeness of data used;

d) a description of the critical review process;

e) an evaluation of the completeness of the product system value assessment;

f) the results of the uncertainty and sensitivity analyses;

g) an evaluation of the significance of the differences found.

6.2.4 If the results from an eco-efficiency assessment are intended to be used in comparative eco-efficiency assertions disclosed to the public, neither the environmental nor the eco-efficiency assessment results shall be reported as a single overall score or number.

7 Critical review

7.1 General

The critical review process shall ensure that

— the methods used to carry out the eco-efficiency assessment are consistent with this International Standard;

— the methods used to carry out the eco-efficiency assessment are scientifically and technically valid;

— the data used are appropriate and reasonable in relation to the goal of the eco-efficiency assessment;

— the interpretations reflect the limitations identified and the goal of the eco-efficiency assessment;

— the eco-efficiency assessment report is transparent and consistent;

— the final results reflect the scenarios, the variety of data, and the impact of different methods of weighting and allocation identified in the eco-efficiency assessment.

The scope and type of critical review desired shall be defined in the scope phase of an eco-efficiency assessment, and the decision on the type of critical review shall be recorded.

In order to decrease the likelihood of misunderstandings or negative effects on external interested parties, a panel of interested parties shall conduct critical reviews on eco-efficiency assessment where the results are intended to be used in a comparative eco-efficiency assertion intended to be disclosed to the public.

7.2 Critical review by internal or external expert

A critical review may be carried out by an internal or external expert. In both cases, an expert independent of the eco-efficiency assessment shall perform the review. The review statement, comments of the practitioner and any response to recommendations made by the reviewer shall be included in the eco-efficiency assessment report.

If the eco-efficiency assessment results are intended to be disclosed to the public, a critical review by an external expert shall be performed.

7.3 Critical review by panel of interested parties

If the eco-efficiency assessment is intended to be used for a comparative eco-efficiency assertion intended to be disclosed to the public, a critical review by interested parties shall be carried out.

In such a case, an external independent expert should be selected by the original study commissioner to act as chairperson of a review panel of at least three members. Based on the goal and scope of the study, the chairperson should select other independent qualified reviewers. This panel may include other interested parties affected by the conclusions drawn from the eco-efficiency assessment, such as government agencies, non-governmental groups, competitors and industries.

The expertise of reviewers in the scientific disciplines relevant to the environmental and product system value assessment phases, in addition to other expertise and interest, shall be considered.

The review statement and review panel report, as well as comments of the chairperson and any responses to recommendations made by the reviewer or by the panel, shall be included in the eco-efficiency assessment report.

Annex A
(informative)

Examples of functional value, monetary value, other values and value indicators

Table A.1 — Light source life cycle example

Terms	Example	Value indicator (unit)
Product system	Light source life cycle	
Function	Illumination	
Functional value	Brightness	Luminous flux (lumen)
Monetary value	Market price	Price (euro/piece)
Other values	Shape	Consumer ranking (numerical value from 1 to 5)

Table A.2 — Mobile phone example

Terms	Example	Value indicator (unit)
Product system	Mobile phone	
Function	Possibility to use the product for a long time	
Functional value	Durability	Warranty lifetime (years)
Monetary value	Depreciation	Trade-in value (USD)
Other values	Aesthetics	Colour preference by consumer value (numerical from 1 to 5)

Table A.3 — Ecotourism service example

Terms	Example	Value indicator (unit)
Product system	Ecotourism service	
Function	Provision of accommodation and ecotours	
Functional value	Hotel accommodation for tourists	Number of room-nights
Monetary value	Contribution to GDP or contribution to local economy	Turnover (USD)
Other values	Employment opportunities	Number of jobs created

Annex B
(informative)

Examples of eco-efficiency assessment

B.1 General

These examples illustrate the eco-efficiency assessment procedure. The choices made, and methods used, are not prescribed by this International Standard; rather it addresses the way in which they are performed and presented. The given examples are not intended to be used for comparative eco-efficiency assertions.

B.2 Example of eco-efficiency assessment applied to electronics products according to the guidelines for the Japanese electronics industry

B.2.1 General

Eight major electronics companies in Japan voluntarily agreed to develop guidelines for eco-efficiency assessment in order to provide rationalized indicators as a powerful communication tool between manufacturers and customers[1].

In 2006, an eco-efficiency evaluation method was designed to create the indicators for air conditioners, refrigerators, lamps, and lighting equipment; it designated life cycle GHG emissions as their environmental impact. Then, in March 2009, with the addition of a washing/drying machine and a personal computer to the list of products by the Japan Eco-efficiency Forum of Japan Environmental Management Association for Industry (JEMAI), the guidelines were established

These guidelines lay down the methods of calculation and other relevant details regarding the eco-efficiency of six product systems and a “Factor-X” (which expresses the relative level of improvement in eco-efficiency in simple numeric terms), and provide uniform eco-efficiency indicators that can help customers select and purchase more environmentally conscious products on the market.

Based on the “Guidelines for Standardization of Electronics Product Eco-Efficiency Indicators Ver. 2.1” published by JEMAI[2], an example of eco-efficiency assessment for electric lamps is presented below.

B.2.2 Goal and scope definition

B.2.2.1 Goal definition

Purpose of the eco-efficiency assessment:	To promote the change from a conventional product [an incandescent light bulb (Product A)] to an alternative product [a bulb-shaped fluorescent lamp (Product B)], by presenting the difference of eco-efficiencies between these two products
Intended audience:	Customer and everybody who is interested
Intended use of the results:	Calculation of a “Factor-X” (the ratio of the eco-efficiency indicator of Product B compared to that of Product A) and presentation to customers

B.2.2.2 Scope definition

1) Product system to be assessed

Name:	Product A: incandescent light bulb, type 60 (54 W)
	Product B: bulb-shaped fluorescent lamp, type 60 (10 W)
	These two products are made by the same company.
Scale of production:	Product A and Product B: large quantity
Location of life cycle stages:	Production: Product A, Japan; Product B, Indonesia
	Use and waste management: Product A and Product B, Japan
Time of life cycle stages:	Production: Product A and Product B, 2008 model
	Use: Product A, 2008; Product B, 2008-2014 (5,5 h/d)
	Waste management: Product A, 2008; Product B, 2014
Main stakeholders involved:	Customer

2) Function and functional unit

— The function of the product system is illumination. The reason for this choice is because illumination clearly indicates a primary characteristic of lamps and is intuitively understandable by general customers.

— Its functional unit is defined as the illumination of the same luminous flux during 1 000 h of use.

3) System boundary

— Each stage of the product life cycle is included, such as material acquisition, parts production, manufacturing of lamps, packaging staffs, domestic distribution and use.

— For the product system value assessment, the use stage is chosen to represent the product system value.

4) Allocations to external systems

— No allocation to adjacent systems is made.

5) Environmental assessment method and types of impacts

— An ordinary life cycle assessment is carried out in accordance with ISO 14040 and 14044.

— Life cycle GHG emissions are selected to simply evaluate the environmental impact of these products due to the significant effects to global warming and the big concern of customers.

— An environmental impact indicator is quantified by using the total amount of the life cycle GHG emissions according to the functional unit.

— Other life cycle impact categories (for example arising from mercury and UV and electromagnetic radiation from fluorescent lamps) are excluded from the study. After a relevance check, their impacts are considered to be small compared to GHG emissions.

6) Value assessment method and type of product system value

— The functional value for customers is assessed, and a physical quantity is used to express the functional value.

— Each product system's brightness throughout its entire life is selected as the functional value.

— A product system value indicator that represents the functional value is quantified by using the total amount of the life cycle brightness, i.e. the brightness multiplied by the lifetime using a usage scenario based on average and constant conditions. Then, the indicator is normalized according to the functional unit.

7) Choice of eco-efficiency indicator(s)

— In this example, the eco-efficiency indicator is defined as a "product system value indicator divided by the environmental impact indicator".

8) Interpretation to be used

— The following aspects of interpretation are needed for the intended use of the results:

  — the identification of significant issues;

  — an evaluation that considers aspects of completeness and consistency;

  — the formulation of conclusions, limitations and recommendations;

  — a comparison of eco-efficiency results.

9) Limitations

— In the environmental assessment, the results of the LCI study or LCIA except life cycle GHG emissions are not considered to form the environmental impact indicator.

— In the product system value assessment, the functional values other than life cycle brightness are not considered to form the product system value indicator.

10) Reporting and disclosure of results

— An independent review will be conducted. The Factor-X results will be presented in product declarations. A full report will be available on the Internet.

B.2.3 Environmental assessment

— Life cycle assessment in accordance with ISO 14040 and 14044 was carried out using the process analysis method based on the JEMAI-LCA1.10 Database for each product.

— Only the materials and parts used in the final products were considered. Domestic distribution of "1 000 km by using 4-t trucks" was assumed. In the manufacturing stage, primary and average data were collected and used. For use, the "rated electricity consumption" throughout the product lifetime was adopted, so that the power change over the same duration was ignored in the calculations. The lifetimes are: 13 000 h for Product B and 1 000 h for Product A.

— As a result of assessment, it was found that 98 % or more of life cycle GHG emissions were emitted in the use stages for both products. Other impacts produced almost the same results.

— The total amount of the life cycle GHG emissions was presented in units of [kg-CO_2e] to form the environmental impact indicator.

— The total amount of the life cycle GHG emissions for Product B was quite a bit larger than that of Product A due to its long lifetime. However, as the indicator for Product B must be calculated according to the functional unit, the numerical quantity of it became smaller than that of Product A in this study.

— The indicators of two products were calculated as follows:

  — environmental impact indicator of Product A = 2,32 E+01 [kg-CO_2e];

  — environmental impact indicator of Product B = 4,66 E+00 [kg-CO_2e].

B.2.4 Product system value assessment

— In order to create the product system value indicator which is mathematically based on its average and constant conditions, life cycle brightness was defined as “all luminous flux (unit: lm)” multiplied by “utility duration (unit: hour)” according to the guidelines for the Japanese electronics industry[2].

— The measurement method of “all luminous flux” is provided in the following Japanese Industrial Standard: JIS C7801: *Measuring methods of lamps for general lighting*.

— The decrease of “all luminous flux” through the same utility duration as the environmental assessment was not considered.

— The utility duration of each product is defined by its “rated lifetime”. The definition of it is provided in the several Japanese Industrial Standards, such as JIS Z7501, Z7617-2 and Z7620-2.

— The “rated lifetime” of Product B is 13 000 h instead of 1 000 h of Product A.

— The total amounts of the life cycle brightness for these two product systems are quite different. However, as the indicator for Product B must be normalized according to the functional unit, the numerical quantity of it became the same as that of Product A in this study.

— The indicators of two products were calculated as follows:

  — product system value indicators of Products A and B = 8,10 E+05 [lm·h].

B.2.5 Quantification of eco-efficiency

— The eco-efficiency indicator was calculated by dividing the product system value indicator by the environmental impact indicator for each in the units of [lm·h/kg-CO_2e].

— The indicators of two products were calculated as follows:

  — eco-efficiency indicator of Product A = 3,49 E+04 [lm·h/kg-CO_2e];

  — eco-efficiency indicator of Product B = 1,74 E+05 [lm·h/kg-CO_2e].

B.2.6 Sensitivity and uncertainty analysis

— Sensitivity and uncertainty analysis was not carried out in this assessment.

B.2.7 Interpretation

— Factor-X, the ratio of the eco-efficiency indicator of Product B compared to that of Product A is used to clarify the difference of the eco-efficiencies between the two products assessed.

— The Factor-X result (eco-efficiency indicator of Product B/eco-efficiency indicator of Product A) was 4,98. This means the eco-efficiency indicator of Product B (bulb-shaped fluorescent lamp) is about 5 times larger than that of Product A (incandescent light bulb).

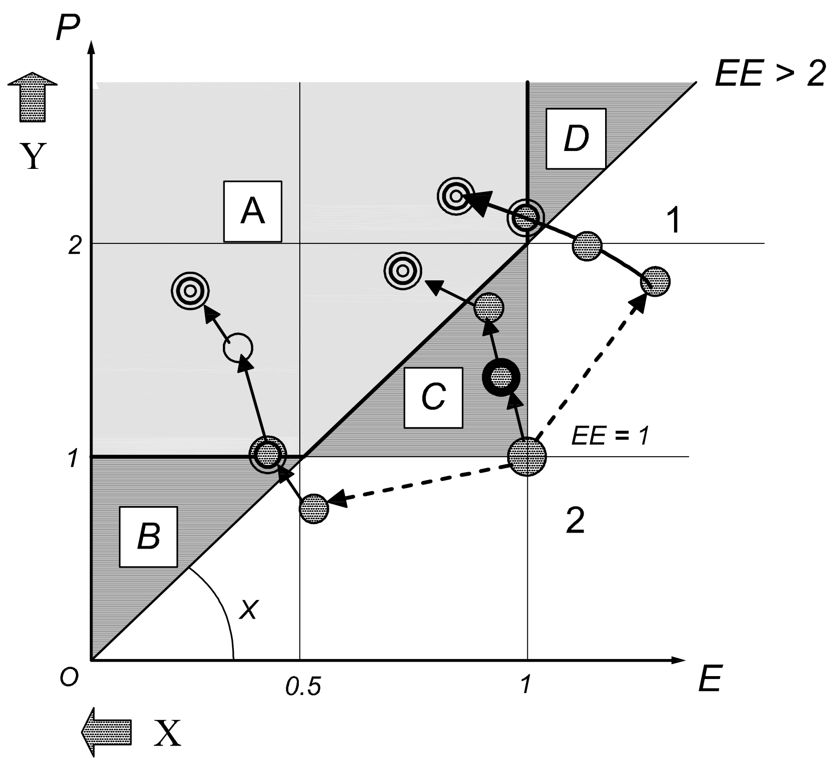
— The decrease of power for illumination and the prolongation of lifetime contribute significantly to the improvement of eco-efficiency because the GHG emissions derived from electricity consumption in the use phase is critical to the environmental assessment results.

— Since several assumptions and simplifications were made in environmental and product system value assessments, this conclusion should be understood with a couple of limitations. For example, if other functional values and indicators focusing on the different aspects were adopted, the eco-efficiency assessment might reach different results.

B.2.8 Discussion

— Figure B.1 shows the product development paths. When an existing product is at the "benchmark product" point, its eco-efficiency (*EE* = *P*/*E*) is defined as 1. Going left and up increases the eco-efficiency, and tan$X$ expresses the eco-efficiency of the development target. If the target is "eco-efficiency (*EE*) $>$ 2", area A is the goal and B is better in the environmental aspect only. Area C shows that the product is steadily developing toward Area A.

— As technology progresses, different paths may be followed; this sometimes involves a drop in environmental performance on the way to achieving the goal. Area D appears to be a bad area to be in due to the higher environmental impact, but passing through this area may be an inevitable step towards the goal as the best available technology is adopted. In this context, when the product system value is increased much more than the decrease of environmental impact, the eco-efficiency may be reported as an "improvement" in a series of product development.



Key

E environmental impact
P product system value
1 new products
2 benchmark product
X reduction of environmental impact
Y improvement of product functions

Figure B.1 — Product development paths

B.3 Example of an eco-efficiency assessment based on the integrated assessment approach

B.3.1 General

By using the QFD (quality function deployment) matrix in the product system value assessment, various characteristics of products are evaluated based on individual preferences; not only the main function but also its special features can be taken into account. Therefore, a business strategy for developing better products can be reflected in the product system value assessment. It will be useful for industry to apply this assessment to product development and improvement. An example of eco-efficiency assessment for home vacuum cleaners is presented.

In this example, the evaluation method for quantifying the functional value based on the QFD is introduced and the total environmental performance was evaluated by the LCIA method.

B.3.2 Goal and scope definition

B.3.2.1 Goal definition

Purpose of the eco-efficiency assessment:	To promote a new product by evaluating its eco-efficiency compared with the old one.
Intended audience:	Business customers.
Intended use of the results:	Calculation of "Factor-X" (the ratio of the eco-efficiency indicator of Product B compared to that of Product A) and presentation to customers.

B.3.2.2 Scope definition

1) Product system to be assessed

Name:	Product A: paper-dust-bag-type home vacuum cleaner
	Product B: cyclone-type home vacuum cleaner
	Both products are made by the same company.
Scale of production:	Production: Product A and Product B, large quantity
Location:	Production: Product A and Product B, Japan
	Use and waste management: Product A and Product B, Japan
Time:	Production: Product A, 2000 model; Product B, 2003 model
	Use and waste management: Product A, 2000-2006, Product B; 2003-2009
Main stakeholders involved:	Customer

2) Function and functional unit

— The function of the product system is defined as its cleaning ability in a comfortable manner. This is because high cleaning ability consistent with usability and amenity is thought to indicate the primary characteristics of vacuum cleaners.

— Its functional unit is defined as one vacuum cleaner for each product system in its entire life cycle (7 years).

3) System boundary

— Each stage of the product life cycle is included, such as material acquisition, parts production, manufacturing of products, distribution, use and end of life.

— For the product system value assessment, the use stage is chosen to present the product system value for customers.

4) Allocations to external systems

— No allocation to adjacent systems is made.

5) Environmental assessment method and types of impacts

— In LCIA, CO_2, SO_X, NO_X, HFC, PFC, SF_6, COD, total N, total P, waste, crude oil, natural gas, limestone and wood are considered to be elementary flows. A hybrid method based on input-output analysis (IOA) is applied to quantify these elementary flows[1].

— In LCIA, global warming, acidification, eutrophication, air pollution and resource depletion are considered. Other impact categories such as indoor air quality and water scarcity are excluded from this study. Category indicators and characterization models are based on the LIME method[2], which is one of the end-point types of the LCIA method developed by the National Project in Japan.

— In addition, the weighting method of the LIME method is applied to evaluate the total environmental performance. The weighting factor in the LIME method was developed by a tried and tested statistical method, considering representativeness, completeness and consistency[2].

— The result of the weighting is used as an environmental impact indicator.

6) Value assessment method and type of product system value

— The functional value for customers is assessed. It is defined as each product system's performance in comfortable cleaning through its entire life.

— In order to express the functional performance, several characteristics of a product are integrated into a single index, applying consumers' preferences derived from a market survey, which means making inquiries about customer needs and/or interviewing customers[3].

— The integrated single index is used as a product system value indicator.

7) Choice of eco-efficiency indicator(s)

— In this example, the eco-efficiency indicator is defined as the "product system value indicator divided by the environmental impact indicator".

8) Interpretation to be used

The following aspects of interpretation are needed for the intended use of the results:

— the identification of significant issues;

— an evaluation that considers aspects of completeness, etc.;

— the formulation of conclusions, limitations and recommendations;

— a comparison of eco-efficiency results.

9) Limitations

— In the environmental assessment, the results depend on the conditions of the hybrid method[1] and the LIME method[2].

— The results of the product system value assessment are concluded with the method[3] and the limited set of quality characteristics.

10) Reporting and disclosure of results

— An independent review will be conducted. Factor-X, the ratio of eco-efficiency indicator of Product B compared to that of Product A, is disclosed with a disclaimer to avoid comparative eco-efficiency assertion. A full report will be available on the Internet.

— The product system value factor and the environmental impact reduction factor are shown on the chart so that the trend of product development and the contribution of both indicators to the improvement of eco-efficiency can be visualized.

B.3.3 Environmental assessment

— A hybrid method based on IOA[2] was utilized for the background data in the LCI analysis.

— The materials and parts used in the final products and the paper bag consumed in the use phase were considered. However, for the cyclone-type vacuum cleaner, since the vacuumed dust is directly carried to a rubbish bin, no paper dust bag is required. In the manufacturing phase, average energy consumptions were applied. Distribution of “20 km by 2 t trucks and 330 km by 4 t trucks” was assumed. In the end-of-life phase, it was assumed that products were transposed to the recycling system, in which iron, copper, aluminium and several kinds of plastics were recycled and the other materials were incinerated and/or disposed of.

— Applying the LIME method, overall environmental impacts were calculated so as to avoid a trade-off amongst impact categories. LCI results were summarized into a single index in a monetary unit, the Japanese yen, to form the environmental impact indicator.

— The indicators of two products were calculated as follows:

  — environmental impact indicator of Product A = 326,5 [Japanese yen];

  — environmental impact indicator of Product B = 318,9 [Japanese yen].

B.3.4 Product system value assessment

— The functional performance of the products to express their functional value was defined in terms of their comfortable cleaning ability and quantified by comparing various quality characteristics in their own units.

— First, customer requirements were correlated with the quality characteristics of a product in the QFD (Quality Function Deployment) matrix as shown in Table B.1. Customer requirements and their importance were derived from the market survey. By making a QFD matrix in this manner, relative important characteristics were identified from the viewpoint of customer satisfaction.

— According to the method proposed by Kobayashi, Y. *et al.* (2005)[3], improvement ratios of quality characteristics were calculated by normalization on the basis of the maximum actual data between two products, as shown in Table B.2. Finally, the functional performance was quantified as a weighted average of improvement ratios to form the product system value indicator.

— The indicators of two products were calculated as follows:

  — product system value indicator of Product A = 0,74 [- (arbitrary unit)];

  — product system value indicator of Product B = 0,96 [- (arbitrary unit)].

Table B.1 — TQFD matrix for a vacuum cleaner

(The full table can be found in Reference [3])

Quality characteristics

Customer requirements	**Importance**	**Dust suction**[W]	**Body weight** [kg]	**Total weight** [kg]		**Brush revolutions per minute** [rpm]	**Degree of luster** [times]	**Noise** [dB]	**Unique filters** [number]
Clean exhaust	3								9
Capacity to pick up anything	9	9				3	1		
Silent	3					1		9	
Ability to remove dust	3								
Capacity to clean in narrow space	3								
Capacity to clean flooring	9	3				9	9		
Easy-to-control body	3		3						
Capacity to clean along walls	9								
Capacity to clean ceiling, etc.	1								
Ease of operation	3		9	9					
High dust suction	9	9						9	
Light brush	3								
Various optional units	1								
Relative importance (%)		16,8	3,2	2,4		9,8	8,0	9,6	2,4

Relationship

9: Strong relation

3: Normal relation

1: Low relation

Table B.2 — Summary of functional value of a vacuum cleaner

(Products assessed were different from those of Reference [3].)

Quality characteristics	Importance	Actual data		Direction	Normalization	
	%	Product A	Product B		Product A	Product B
Dust suction [W]	16,8	570,0	560,0	↑	1,00	0,98
Body weight [kg]	3,2	3,7	3,6	↓	0,97	1,00
Total weight [kg]	2,4	5,3	5,2	↓	0,3	1,00
Brush revolutions per minute [rpm]	9,8	4 200,0	6 000,0	↑	0,70	1,00
Degree of luster [times]	8,0	10,0	2,2	↓	0,22	1,00
Noise [dB]	9,6	55,0	59,0	↓	1,00	0,93
Unique filters [number]	2,4	4,0	3,0	↑	1,00	0,75
			Weighted average		**0,74**	**0,96**

B.3.5 Quantification of eco-efficiency

— The eco-efficiency indicator was calculated by dividing the product system value indicator throughout its entire life by the environmental impact for each in the units of [-/Japanese yen].

— The indicators of the two products were calculated as follows:

  — eco-efficiency indicator of Product A = 0,015 8 [-/Japanese yen];

  — eco-efficiency indicator of Product B = 0,021 1 [-/Japanese yen].

B.3.6 Sensitivity and uncertainty analysis

— Sensitivity and uncertainty analysis was not carried out in this example.

B.3.7 Interpretation

— The ratio of the eco-efficiency indicator of Product B compared to that of Product A is used to clarify the difference of the eco-efficiencies between the two products assessed.

— Factor-X = 1,33 (eco-efficiency indicator of Product B/eco-efficiency indicator of Product A).

— This means the eco-efficiency indicator of Product B (cyclone-type home vacuum cleaner) is about 1,3 times larger than that of Product A (paper-dust-bag-type home vacuum cleaner).

— In addition, both the environmental impact reduction factor and the product system value factor are plotted in Figure B.2 to clarify the evolution strategies of assessed products. Factor-X can be derived by multiplying both the product system value factor and the environmental impact reduction factor together.

— The environmental impact reduction factor = 1,02 (Environmental impact indicator of Product A/ Environmental impact indicator of Product B).

— The product system value factor = 1,30 (Product system value indicator of Product B/Product system value indicator of Product A).

— As a result of the environmental assessment, it was found that environmental impacts in the use phase account for about 75 % of those in the entire life cycle for both products. CO_2 and SO_X emissions, which were mainly derived from electricity consumption in the use phase, were critical to the total results. Due to the increased electricity consumption of Product B, its global warming potential became worse. However, resource depletion indicator improved because the weight of Product B was partially reduced and no paper dust bag was required. As a result, from a life cycle perspective, the environmental impact indicator of Product B improved more than that of Product A. Reduction of the environmental impact in both the use phase and the production phase can make it possible to further improve the eco-efficiency in the future.

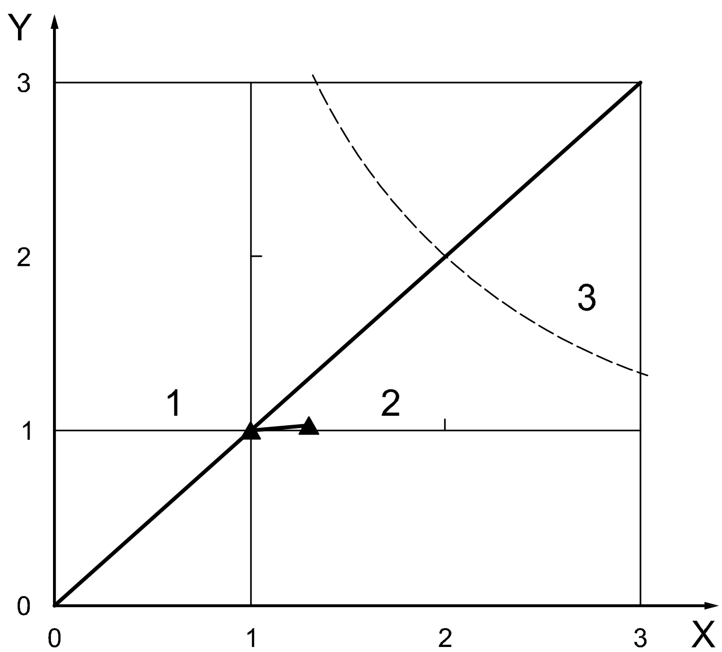
— The product system value factor mainly contributes to Factor-X. Although Product B has both superior and inferior characteristics to Product A, the capacity to clean along walls and floors was improved. According to the customer requirements in QFD matrix, not only the suction power but also additional performances, such as the improved capacity to clean floors and along walls, etc., can provide enhanced value to customers.

— In the environmental assessment, several assumptions are set in LCIA, for example, transport distances and the end-of-life scenario. The results depend on these conditions and the conclusion should be understood in the application of LCI data and the LCIA method.

— In the product system value assessment, the consumer preferences derived from a market survey in Japan are thought to vary in other regions and also over time, according to the market situation, the competitors' situation, lifestyles, etc.

— It is valuable for industry to utilize the eco-efficiency assessment as an internal management tool. While it is important to analyse trade-off among environmental impact categories carefully in the context of LCA practice, the definition and formulation of the eco-efficiency indicators depend on the business strategy of each company.

— This example was intended to focus on the trade-off between environmental impact and functional value, not the trade-off in environmental assessment. From the viewpoint of consistency with the weighted functional value, environmental impacts were summarized into a single score based on the sophisticated LCIA. In this sense, the eco-efficiency indicator in this example applies when presenting an outline of the product's development, as shown in Figure B.2.



Key

X product system value factor

Y environmental impact reduction factor

1 Product A

2 Product B

3 factor 4

Figure B.2 — Factor-X chart

B.4 Application of eco-efficiency assessment based on integrated assessment

B.4.1 General

A petrochemical company in Mexico conducted an analysis of eco-efficiency to evaluate two technology options for increasing the production of an ethylene plant. Ethylene is an olefin feedstock used for a variety of petrochemicals and can join other hydrocarbons such as benzene to produce ethyl benzene, styrene and other olefins useful in obtaining polymers such as different types of polyethylene.

B.4.2 Goal and scope definition

B.4.2.1 Goal definition

Purpose of the eco-efficiency assessment:	Due to the increase in installed capacity from 600 000 t to 900 000 t of ethylene in the Morelos Petrochemical Complex, Mexico, two options of technological improvement have been evaluated with an eco-efficiency analysis: Option A: Update of two cracking furnaces, two new cooling units in the refrigeration section and replacement of the tower which removes the methane (natural gas), minor changes in compression. Option B: Update of two cracking furnaces, a new cooling unit in the refrigeration section and replacement of the tower which removes the methane (natural gas) and a new compressor.
Intended audience:	Internal decision makers.
Intended use of results:	To present a factor which expresses the relative level of improvement in eco-efficiency in simple numeric terms (the ratio of eco-efficiency indicator of Option A vs Option B).

B.4.2.2 Scope definition

1) Product system to be assessed

Name:	Ethylene production system
Scale of production:	600 000 t to 900 000 t per year
Location:	Mexico
Time:	Production: Product A, 2000 model; Product B, 2003 model

2) Function and functional unit

— Production of ethylene to be used as raw material for polyethylene, monomer vinyl chloride, ethylene oxide, styrene, acetaldehyde, among others.

— The functional unit is 1 t of ethylene produced.

3) System boundary

— The product system begins at raw materials extraction and ends when the ethylene is the raw material for other processes. Other life cycle stages are excluded because they do not change the overall conclusions of this study.

4) Allocations to external systems

— No particular adjacent systems to be allocated exist.

5) Environmental assessment method and types of impact

— Environmental impacts were calculated using the life cycle impact assessment method eco-indicator 99 (H)[1], taking into consideration three category end points: human health, ecosystems quality, and resources.

— The impacts were normalized with respect to the base case.

6) Value assessment method and type of product system value

— The product system value is based on the functional value of production of ethylene per day.

7) Choice of eco-efficiency indicator(s)

— In this example, the eco-efficiency indicator is defined as the "product system value indicator divided by the environmental impact indicator".

— The eco-efficiency indicator is calculated with Formula (B.1) and the factor with Formula (B.2) as follows:

$$\text{Eco-efficiency} = \frac{\text{Product value}}{\text{Environmental impact}} \qquad \text{(B.1)}$$

$$\text{Factor} = \frac{\text{Eco-efficiency of the evaluated product}}{\text{Eco-efficiency of the base case product}} \qquad \text{(B.2)}$$

8) Interpretation

— In order to choose between options A and B, the eco-efficiency of these options needs to be compared to that of the current plant.

9) Limitations

— In the environmental assessment, the calculations exclude:

  — construction, infrastructure and capital equipment;

  — human resources and labour.

— The calculations also exclude materials used in trace amounts and substances for which there was insufficient data.

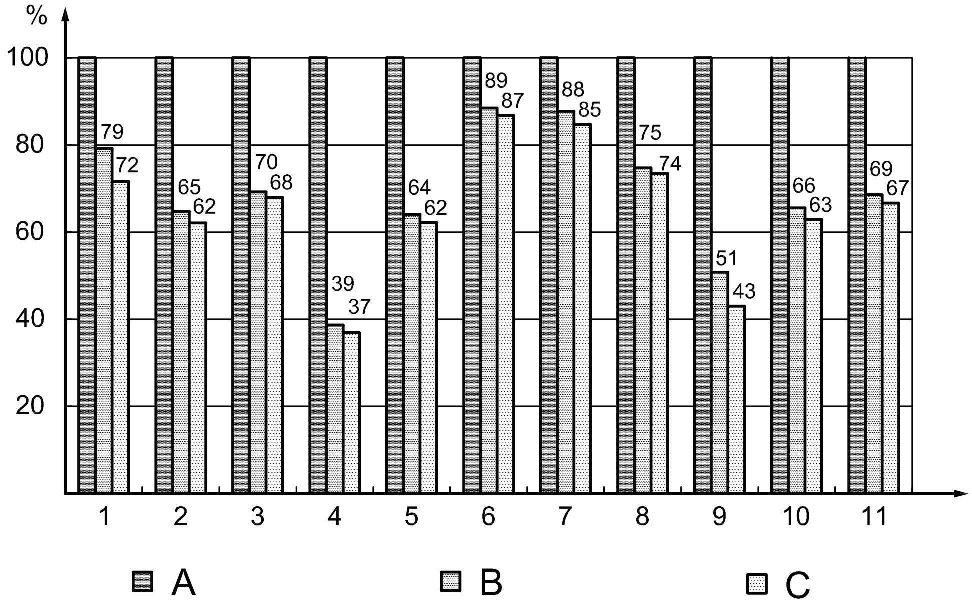
10) Reporting and disclosure of results

— An internal report will be made.

B.4.3 Environmental assessment

— The environmental assessment was carried out using life cycle assessment in accordance with ISO 14040:2006 and ISO 14044:2006 and the Eco-indicator 99 (H) life cycle impact method.

— Figure B.3 shows the impact categories evaluated for options A and B, with respect to the current operation of the ethylene plant.



Key

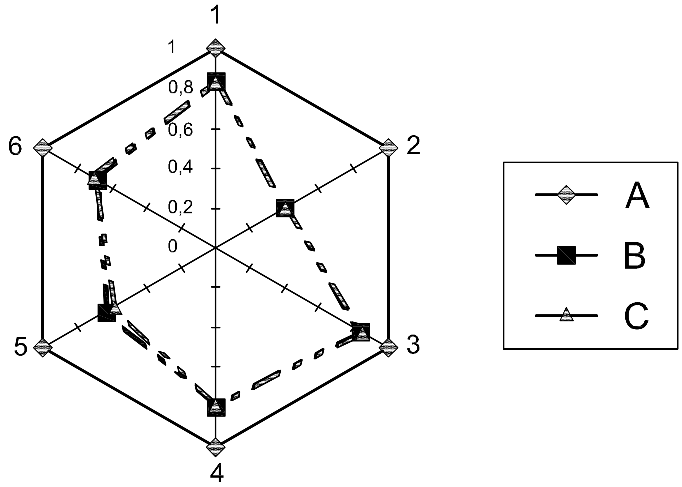
A ethylene base 600

B ethylene expansion 900

C ethylene new burnes

Figure B.3 — Results by category of impact improvement

— Six impact categories were analysed to assess the advantages and disadvantages of the performance of the options examined. These categories were normalized. As shown in Figure B.4, the two options are assessed relative to the current impacts of ethylene plant.



Key

1 carcinogens
2 climate change
3 ecotoxicity
4 acidification/eutrophication
5 minerals
6 fossil fuels
A ethylene base 600
B ethylene expansion 900
C ethylene new furnaces

Figure B.4 — Six impact categories for the different options and normalized values

— Table B.3 shows the improvement in the end-point categories. The three categories are reduced. These data are considered as the environmental impact of the project to calculate eco-efficiency.

Table B.3 — Comparison of the three end-point categorie

	Human health (eco-points)	**Ecosystem quality (eco-points)**	**Resources (eco-points)**
Current plant	74,7	7,2	497,0
Ethylene expansion 900 (Option A)	41,8	5,4	341,4
Ethylene new furnaces (Option B)	40,6	5,3	332,0
Improvements (%)	<44 Option A <45 Option B	<25 (Option A) <26 (Option B)	<31 (Option A) <33 (Option B)

B.4.4 Product system value assessment

— The product system value for the current plant is 1 800 t of ethylene per day (current capacity) and, for options A and B, 2 702 t of ethylene per day (planned capacity).

— All cases are calculated based on the same days of continuous operation per year.

B.4.5 Calculation of eco-efficiency results

The data used for the calculation of eco-efficiency results are shown in Table B.4.

Table B.4 — Data used for the calculation of eco-efficiency results

	Current plant	New expansion (Option A)	New furnaces (Option B)
Capacity (t/d)	1 800	2 702	2 702
Ecopoints LCA[a]	437,9	288,6	280,5

[a] Ecopoints are calculated according to Reference [1].

Eco-efficiency = Product value/Environmental impact

$$\text{Current plant Eco-efficiency} = \frac{\text{Product value}}{\text{Environmental impact}} = \frac{1\,800\ \text{t/d}}{437{,}9\ \text{Pt}} = 4{,}11$$

$$\text{Option A Eco-efficiency} = \frac{\text{Product value}}{\text{Environmental impact}} = \frac{2\,702\ \text{t/d}}{288{,}6\ \text{Pt}} = 9{,}36$$

$$\text{Option B Eco-efficiency} = \frac{\text{Product value}}{\text{Environmental impact}} = \frac{2\,702\ \text{t/d}}{280{,}5\ \text{Pt}} = 9{,}63$$

$$\text{Factor} = \frac{\text{Eco-efficiency of the evaluated product (Option B)}}{\text{Eco-efficiency of the base case product (Current plant)}} = \frac{9{,}63}{4{,}11} = 2{,}34$$

B.4.6 Sensitivity and uncertainty analysis

— Sensitivity and uncertainty analysis was not carried out in this example.

B.4.7 Interpretation

— In comparing the two options with respect to the current plant, there is significant improvement in environmental performance.

— In summary, Option B has the highest eco-efficiency.

B.5 Application of eco-efficiency assessment — Chelating agents

B.5.1 General

This eco-efficiency assessment was originally published by Borén *et al.* (2009), but is revised here to fit the format of this International Standard.

B.5.2 Goal and scope definition

B.5.2.1 Goal definition

Purpose of the eco-efficiency assessment:	With the purpose of assessing different chelating agents from environmental and financial perspectives, an eco-efficiency assessment was carried out for European conditions.
Intended audience:	Primarily product developers, but also purchasers.
Intended use of the results:	The intended use is for product development and communication of product performance to business customers

B.5.2.2 Scope definition

1) Product system to be assessed

Name:	Chelating agents made by four different processes; products A, B, C and D
Scale of production:	Industrial scale
Location of life cycle stages:	Production: Europe; use and waste management: Europe
Time of life cycle stages:	Production: 2007; use: 2007; waste management: 2007
Main stakeholders involved:	Product developer, purchasers

2) Function and functional unit

— Chelating agents are widely used in detergents and cleaners to improve the detergency power.

— In this study, the chelating agents were compared on an equal-weight basis in order to make the study independent of the exact amounts used in the many detergent recipes. The functional unit is 1 t of chelating agent.

3) System boundary

— The product system includes flows related to raw material extraction, processing of raw materials, manufacturing, use, maintenance, recycling/reuse, waste management, and transportation (Figure B.5). The product system excludes the function of different detergent recipes because it is assumed to be the same for alternative A, B, C and D.

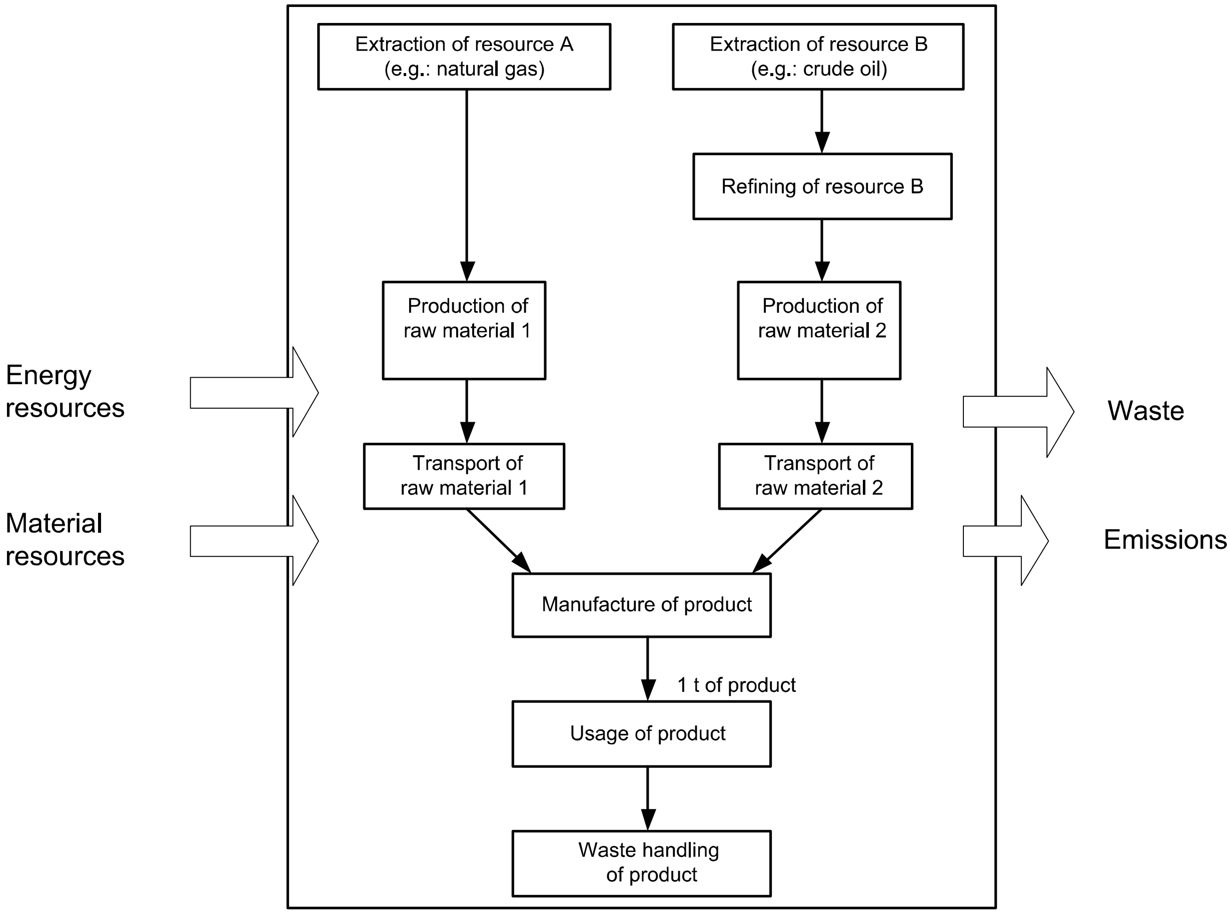


Figure B.5 — System boundary

— Cut-off criteria: 1 % rule

4) Allocation to external systems

— Made according to the economic value.

5) Environmental assessment method and types of impact

— Elementary flows present, as shown in Table B.5.

Table B.5 — Elementary flows assessed

Energy (MJ/FU)			
	Coal	Emissions to water (mg/FU)	COD
	Oil		BOD
	Gas		N-tot
	Waterpower		NH_4-N
	Nuclear		P-tot
	Lignite		AOX
	Recovered/other		HM
	Biomass		HC
			SO_4^{2-}
			Cl^-
Resources (kg/FU)	Stone coal	Waste (kg/FU)	Municipal waste
	Oil		Chemical waste
	Natural gas		Construction waste
	Brown coal		Mining waste
	Sodium Chloride		
	Sulfur		
	Phosphorous		
	Iron		
	Lime		
	Bauxite		
	Sand		
Emissions to air (mg/FU)	CO_2	Land use (m^2/FU)	Forest
	SO_x		Pasture, fallow, bio-agric.
	NO_x		Conv. agriculture
	CH_4		Sealed
	NM-VOC		Roads, tracks, canals
	CFCs		
	NH_3		
	N_2O		
	HCl		

— The impact categories that were considered in the eco-efficiency assessment and applied for different chelating agents were: primary energy consumption, resource depletion, land use, emissions, human toxicity, and risk (referring to occupational health and accidents). The impact category “emissions” is further subdivided into other impact categories (see Table B.6).

— Impact assessment methods used are detailed in Saling *et al.* (2002)[11].

Table B.6 — Impact categories and weighting factors

Impact category	Societal factor S %	Relevance factor R %	Total weighting factor[a] μ %
Resource use	20	4	11
Primary energy use	20	5	13
Area use	10	0,3	2
Toxicity potential	20	20	20
Risk potential	10	10	10
Emissions	20	61	44
Water emissions[b]	35	95	78
Solid waste	15	—	—
Air	50	5	22
Global warming potential (GWP)	50	69	68
Photochemical ozone creation potential (POCP)	20	8	15
Ozone depletion potential (ODP)	20	—	—
Acidification potential (AP)	10	23	17

a Geometric mean of S and R.

b This impact category includes the eutrophication potential of substances emitted to the water recipient.

— In a further weighting process, the impact category results are aggregated into a single indication or statement of the total strain put on the environment. In the presented eco-efficiency assessment method, a weight that expresses the environmental importance of that impact category relative to the other impact categories for a specific region is assigned to each impact category. These weighting factors are a combination of impact category-specific "relevance factors" and "societal factors." For the European relevance and societal factors, see Table B.6. To derive the relevance factor, the result of the alternative with the highest impact in that category is normalized against the total load of the same category in a specific region. This step yields the relative significance of the different impact category results. The societal factors express the importance of each category relative to the other impact categories as perceived by a group of people (see Table B.6). The societal factors are based on the opinion polls in the same region as were chosen for the relevance factors. The societal factors were derived through a public opinion poll (Kicherer, 2005). For more information regarding the weighting methodology and the subsequent integration of ecological and economic data, presented below, see Saling *et al.* (2002)[11] and Kicherer *et al.* (2007)[9].

6) The product system value

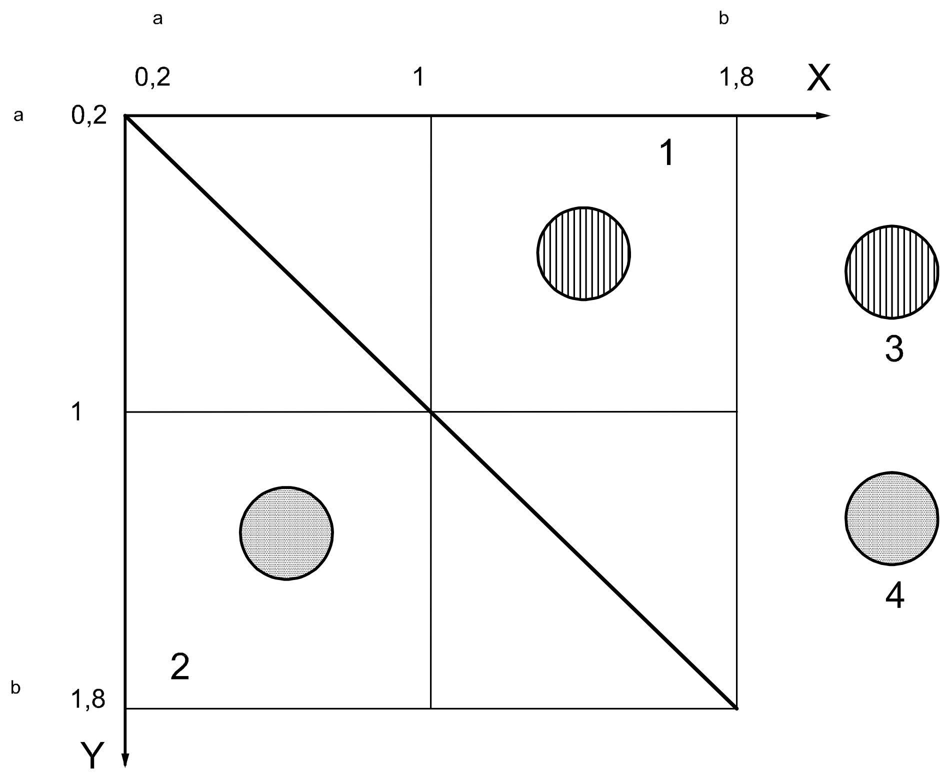
— In this study, the product system value was assessed by using a Life Cycle Costing (LCC) method (Bengtsson, and Sjöborg, 2004[7]); costs associated with environmental impacts are not covered by the LCC since, by definition, external costs are borne by society and reflect environmental impacts of the system under study (Rudenauer *et al.*, 2005[10]). These impacts are covered by the LCA in the environmental assessment.

— The product system value for the customer, based on an equal-weight basis, was the cost savings of the chelating agent for the detergent manufacturer.

— In the eco-efficiency assessment method applied, the total costs of the studied alternatives are normalized with respect to the gross domestic product of the same region that is used in the environmental assessment.

7) Choice of eco-efficiency indicators

— The eco-efficiency method includes a weighting of environmental impacts and costs, resulting in a two-dimensional diagram (see Figure B.6). The eco-efficiency method takes into account the contribution of the studied alternatives environmental impact to the total environmental impact within a certain region. In the same way, the costs of the studied alternatives are compared to the gross domestic product of the same region. Hence, this is a normalization step, which yields two ratios that communicate the significance of the environmental and financial impact. If the environmental impact is greater, for example, more weight will be put on the environmental performance of the studied alternatives. The axes in the diagram are inverted so that the alternative that has the lowest environmental impact and the best financial performance is found in the upper right corner. This alternative is termed the *most eco-efficient alternative* and is hence favoured from an eco-efficiency perspective.



Key

X product system value

Y environmental impact (norm.)

1 high eco-efficiency

2 low eco-efficiency

3 product/Process 1

4 product/Process 2

[a] Low.

[b] High.

Figure B.6 — The eco-efficiency portfolio

8) Interpretation to be used

— The two processes will be ranked and a sensitivity analysis will be made to assess the significance of the difference in environmental impact and life cycle cost.

9) Reporting and disclosure of results

— An internal report will be made.

B.5.3 Environmental assessment

— The results of the impact assessment are shown in Table B.7.

B.5.4 Product system value assessment

— The normalized costs savings that were obtained are shown in Figure B.8.

B.5.5 Interpretation

B.5.5.1 General

Results of eco-efficiency assessment of different chelating agents:

— The impact category results for 1 t of chelating agent are presented for the different alternatives in Table B.7.

Table B.7 — Characterization/impact category results for 1 t of the studied chelating agents[a]

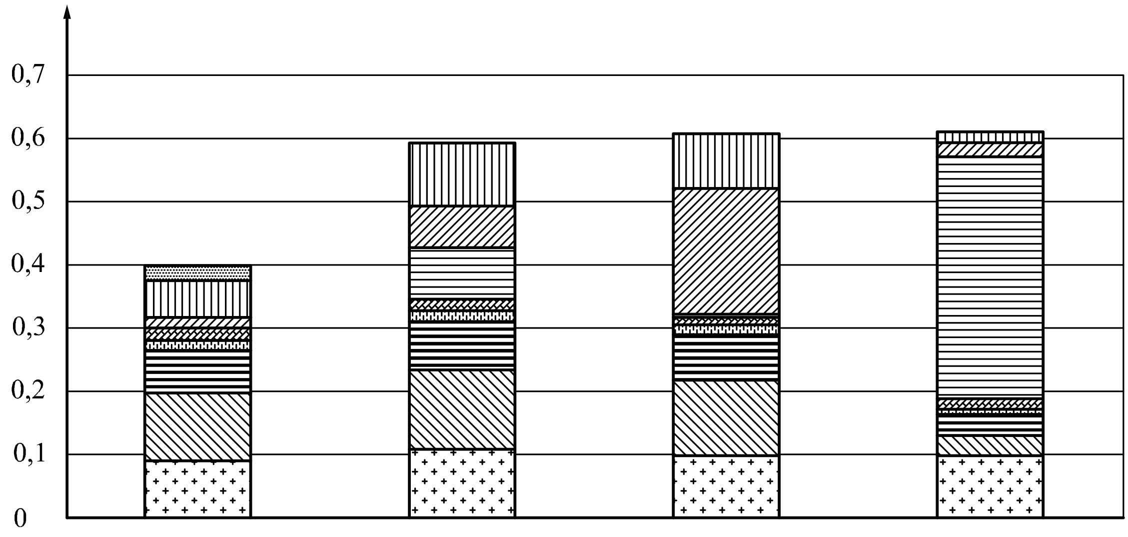
Impact categories	Alternatives			
	A	B	C	D
Primary energy use [GJ]	71	83	77	20
Resource use [ton crude oil equivalent]	1,2	1,4	1,3	1,3
Area use [$m^2 \cdot yr$]	358	3	3	1
Toxicity potential [dimensionless]	0,09	0,34	1	0,11
Risk potential [dimensionless]	0,58	1	0,89	0,18
Global warming potential [ton CO_2 equivalent]	5,1	5,7	5,5	2,7
Photochemical ozone creation potential [kg C_2H_4 equivalent]	1,0	1,1	1,0	0,4
Ozone depletion potential [kg CFC11 equivalent]	—	—	—	—
Acidification potential [kg SO_2 equivalent]	17	15	12	15
Waste [kg]	—	—	—	—
Water emissions [1 000 m^3]	0,6	6	0,2	27

[a] Grey-shaded items constitute emissions.

— From these results, it is clear that a trade-off between the different kinds of environmental impacts is needed in order to generate a priority list of the different chelating agents from a holistic environmental perspective. This trade-off is done via the weighting step. The weighting factors that were used to aggregate the impact category results in a single score, denoting the total environmental pressure of the different alternatives, are presented in Table B.6 and represent European conditions.

— The result of the weighting is illustrated in the bar chart and table in Figure B.7. They show the weighted values for each impact category and chelating agent; the top of the bars denotes the total and final environmental results that were integrated with the economic data in the complete eco-efficiency assessment.

B.5.5.2 Weighted environmental impact



		A	B	C	D
	Area use	0,02	0,000 2	0,000 2	0,000 1
	Risk potential	0,06	0,10	0,09	0,02
	Toxicity potential	0,02	0,07	0,20	0,02
	Water emissions	0,000 9	0,08	0,003	0,38
	AP	0,02	0,02	0,01	0,02
	POCP	0,01	0,02	0,02	0,006
	GWP	0,07	0,08	0,07	0,04
	Energy use	0,11	0,13	0,12	0,03
	Resources use	0,09	0,11	0,10	0,10

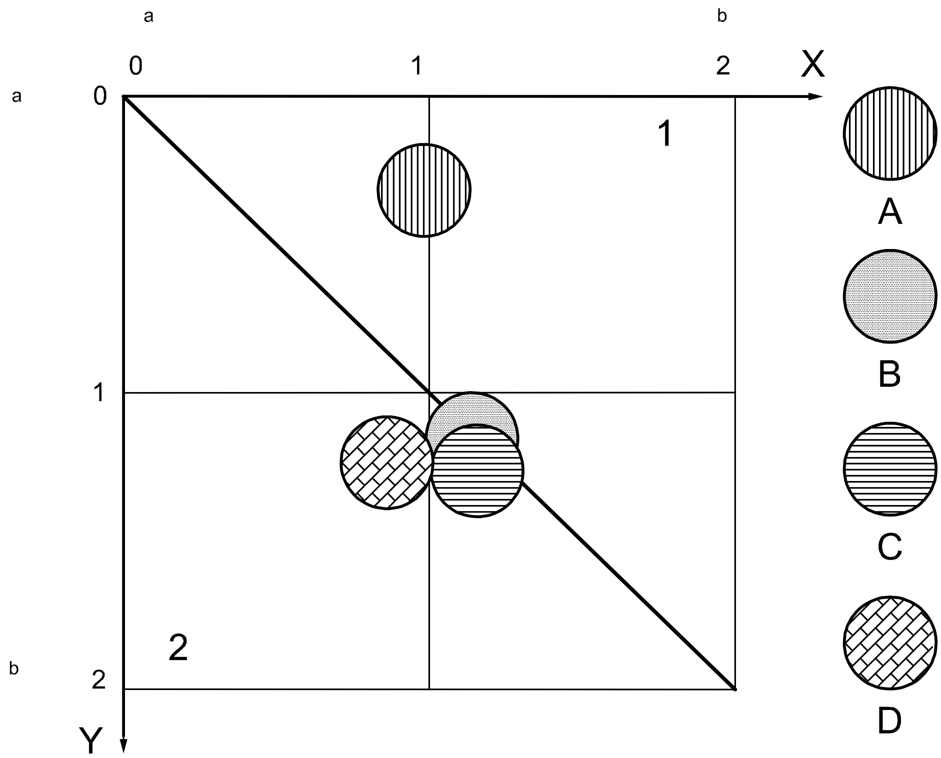
Figure B.7 — Weighted values for the different impact categories and chelating agents

Abbreviations: AP - Acidification Potential; POCP – Photochemical Ozone Creation Potential; GWP – Global Warming Potential

— The result of this study indicates that the product system for chelating agent A has the lowest total environmental impact. A performs well in all important aspects compared with the other alternatives, mainly because it is based on renewable raw materials and is readily biodegradable. Another advantage of A and B is that (unlike D and B) they do not give rise to any phosphorus emissions to water and hence the eutrophication potential of A is minor. The most significant impact of chelating agents is their water emissions, according to the applied weighting methodology. This is due to the fact that a lot of the eutrophication is caused by the use of phosphorous in detergents. More than 60 % of the environmental impact of chelating agent D is due to eutrophication, which is the single impact category that gives this chelating agent a higher environmental impact than agent A.

— With respect to the toxicity potential, A scores much better than C especially; for C, there is limited evidence of carcinogenic effects from exposure. For these reasons, it can be concluded that on an equal mass basis, A is the most environmentally preferred product system. A sensitivity analysis also showed that this result is robust with regard to the region (continent) that is chosen for the weighting.

— The total result, including financial aspects, is presented in Figure B.8.



Key

X product system value

Y environmental impact (norm.)

A Product A

B Product B

C Product C

D Product D

[a] Low.

[b] High.

Figure B.8 — Eco-efficiency diagram

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