Valuation as an element of life cycle assessments

German Federal Environmental Agency method for impact indicator standardization, impact category grouping (ranking), and interpretation in accordance with ISO 14042 and 14043

1999 version

by

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Foreword from the president of the Federal Environmental Agency

The present Federal Environmental Agency manual on the use of valuations in life cycle assessments addresses a burning issue in the environmental debate, namely the priority rankings that should be accorded to various environmental impacts.

Apart from the concerns and rivalries aroused by this issue amongst the members of many disciplines, and the tremendous amount of attention it has attracted amongst the general public, this issue raises fundamental questions about technical, scientific, and political legitimacy.

There is general agreement that rankings of environmental impacts can only be valid if they are based on sound quantitative and qualitative methodologies that are based on (a) a decision-making process that is legitimized by democratic praxis; and (b) the latest scientific advances. Moreover, such a process, and the actors involved in it, must also remain open to reasonable and constructive suggestions for improvement in the interest of consensus-building.

Attempts to conduct a reasoned and productive dialogue in this arena have recently resulted in initiatives such as the “Protecting mankind and the environment” parliamentary commission, and the Ministry of the Environment’s “Stepping stones to sustainable and environmentally compatible development” initiative. Unfortunately, these efforts have yielded the kind of results that would allow for a balanced assessment of the range of environmental impacts that we are faced with today. There are many reasons for this failure to reach a consensus on these issues, including the following:

- the fear of angering environmental activists, who might feel that importance of their role will be diminished if the government steps in;
- concerns that the rankings of various methods could not be persuasively communicated to specialists in the relevant disciplines
- a reluctance to make the hard (albeit viewed as desirable) decisions that would be entailed by ranking environmental impacts

However, there are also those who would welcome the advent of methodological progress in this arena and the implementation of such assessment and ranking methods, which would allow syntheses to be formulated concerning the ecologically superior or equal worth of competing products and systems. But unfortunately, environmental impacts do not fit easily into “value” categories, which means that in order to assess them we must first prioritize them, if we are to achieve the kind of sound, rational, and useful syntheses and conclusions that are indisputably needed here. In such cases, the subjective judgements that come into play in life cycle assessment reports will be readily revealed to their readers by the scientific and procedural underpinnings of the methods applied (and the readers themselves will of course bring to bear their own personal views).

The Federal Environmental Agency has taken it upon itself to propose environmental impact rankings, despite current problems that render this a somewhat daunting task (and in some respects a minefield). The determining factor in making this decision was current international draft standards ISO 14042 and 14023, which expressly authorize life cycle assessment study sponsors (including the Federal Environmental

Agency) to undertake such rankings. However, these standards do not define any specific procedure or values for the ranking process, thus leaving its implementation modalities open to varying interpretations. The standards merely say that a large number of specific approaches, methods, and tools are available for the ranking process.

In view of this intentional methodological pluralism, the Federal Environmental Agency is in an excellent position to take all key environmental impacts into account, thanks to the Agency's wide ranging environmental expertise. Hence the Agency feels that it is incumbent upon it to put forward recommendations in this regard, particularly in view of the importance of meeting the expectations of concerned professionals. Moreover, since we realize that other individuals and organizations may well devise ranking methods that differ from our own, we have indicated in the title of this document that it is the Federal Environmental Agency's method. The present document describes in exhaustive detail the reasons for our having selected and defined this particular methodology.

In the interest of avoiding any misunderstanding, we want to make it clear that this ranking method is intended for use in valuations as an element of life cycle assessments only. The issues that are analyzed in life cycle assessments are generally unrelated to specific local and regional environmental situations. Insofar as an issue relates to a definable geographical area or period of time (e.g. assessments of the environmental compatibility of relatively small hydropower plants), other assessment metrics, tools and/or procedures such as environmental impact assessments must be applied.

But it should also be noted that the application domain of the assessment method proposed here is also limited. For example, it cannot be profitably applied to debates about defining environmental policy priorities, except insofar as life cycle assessments are directly concerned. By the same token, our method should not be applied to key environmental issues in contexts that fall outside the scope of life cycle assessments.

Hence the present document aims to promote achievement of the following life cycle assessment related goals:

- furthering the progress of life cycle assessment method development, particularly in the valuation domain
- improving the quality of the solutions engendered by life cycle assessments
- rendering transparent the methodological, empirical and qualitative "drivers" of valuations in the life cycle assessment system
- enrichment of international dialogues between subject experts concerning a "Federal Environmental Agency valuation method" that generates controversy
- catalyze constructive criticism that will spur optimization of our method

The Federal Environmental Agency life cycle assessment valuation method aims to create a uniform valuation system that can be applied to all life cycle assessments, regardless of the product or process under study. Toward this end, the current valuation methods for life cycle assessments of graphics paper, used oil recycling methods, and packaging for mineral water, soft drinks, juice and wine will be used.

Needless to say, the methods proposed here will need to be carefully (and critically) reviewed at regular intervals and updated (if necessary) in the light of new scientific findings. No satisfactory life cycle assessment valuation method has been devised as yet for areas such as human toxicity and ecotoxicity. This (key) "work in progress" aspect of our method is clearly indicated by its subtitle "1999 version." The Federal Environmental Agency wholeheartedly invites all actors that work in, are concerned with and/or are affected by life cycle assessments and environmental issues in a professional capacity to give us feedback about the Federal Environmental Agency life cycle assessment valuation method presented here.

Andreas Troge

President of the German Federal Environmental Agency

The Federal Environmental Agency's Approach to valuation as an element of Life Cycle Assessment

Life cycle assessment (LCA) is a method to compile and assess environmentally relevant facts using a cross-media approach. Using LCA, a picture can be produced of the environmental impacts of products, processes and services and it thus affords a comparison between alternative products or processes from an environmental perspective.

In the international debate over methodologies, extensive agreement has meanwhile been reached on how to proceed in the performance of the so-called **life cycle inventory analysis**. Life cycle inventory analysis is the arithmetical core of LCA. Its task is to make an inventory of and generate quantitative data on the environmental aspects to be allocated to the respective system under investigation, such as consumption of raw materials, land-use, emissions and discharges.

There is also agreement that in comparing the environmental impacts of systems, no direct conclusions can be drawn solely from the results of life cycle inventory analyses, which may encompass individual data on several dozens of different environmental aspects. That is why LCA provides for the inventory analysis to be followed by a **life cycle impact assessment**. In this step, the results obtained in the inventory analysis for substances with similar environmental effects are aggregated into so-called impact categories. An extensive approximation of the methodological proposals discussed among experts can also be seen in this area.

But satisfactory conclusions for an environmental comparison of the systems studied will normally not be arrived at after completion of the impact assessment, either. For instance, in a comparison of two alternative products the impact assessment will in most cases reveal environmental advantages for the one as well as the other product, depending on impact category. To arrive at sound conclusions in such a case, the environmental pros and cons identified in the inventory analysis and the impact assessment performed for the two products compared will have to be weighed against each other. In the context of LCA, this weighing process is referred to as **valuation**.

However, this valuation cannot be based solely on scientific findings but, rather, is dependent to a large extent upon standards of value. The difficulty here is to combine objective scientific findings with subjective value judgements and, based on this, to derive criteria whose application ensures that the weighing of different environmental aspects takes place in a transparent and reproducible manner.

To this end, the Federal Environmental Agency (Umweltbundesamt – UBA) has developed a method for performing valuation as part of life cycle assessment, which it considers to be an approach which could be used to flesh out the draft framework standards ISO 14042 and 14034. At the same time, the method represents a distinctly improved continuation of the valuation method published in 1995 in the context of a life cycle assessment of beverage containers (UBA-Texte 52/95).

A central feature of the method consists of the ranking of the various impact categories considered in LCA. The method addresses the subjectivity problem by providing for the necessary weighing between different impact categories to be carried out by an assessment body – separate from the actual life cycle assessment. The decisions taken by this body are not exclusively based on the subjective value judgements of its members, though; rather, they also take into account the knowledge available at the time about cause-effect relationships relating to specific environmental impacts. In addition, in performing the assessment the body must abide by certain rules.

The following stipulations have been made for this assessment:

1. **Ecological severity:** An impact category is judged as being the more environmentally harmful, i.e. its ecological priority is deemed to be the higher, the more serious the potential hazard to protected environmental assets in that category is rated to be (irrespective of the current state of the environment).

   The following aspects have to be taken into account here:

   - The potential impact of damage to the protected assets concerned (level and extent of the damage that would be caused by the potential impact; affectedness of different hierarchical levels).
   - The extent to which the harmful effect is reversible.
   - The spatial dimensions of the damage.
   - Uncertainties in predicting the impacts. Uncertainties derive from insufficient qualitative and quantitative knowledge of cause-effect relationships and from the delayed occurrence of the potential damage (time lag).
2. **Distance to target:** An impact category is judged as being the more environmentally harmful, i.e. its ecological priority is deemed to be the higher, the more removed the current state of the environment in that category is from a environmental target.

   Aspects to be taken into account here are:

   - The distance between the state of the environment and a quantified environmental target (e.g. an immission concentration).
   - In many cases, a quantified environmental target does not exist. In evaluating an impact category according to the distance-to-target approach in such cases, use can be made, alternatively, of a scientifically derived estimate of the required reduction in an emission or in the abstraction of a raw material.
   - The current or anticipated trend in the environmental pressure of concern (e.g. as a result of abatement measures taken).
   - The feasibility and effectiveness of the measures necessary to meet the target.
3. **Specific contribution:** An impact category is judged as being the more environmentally harmful, i.e. its ecological priority is deemed to be the higher, the larger the contribution in that category to agreed reference levels, e.g. contribution to the total annual emissions of a pollutant, in Germany.

   The task of the assessment body is to use available information on effect mechanisms, environmental quality targets and the current state of the environment as a basis for ranking impact categories according to the assessment criteria “ecological damage” and “distance to target”, that is to say, to allocate a higher priority to a specific impact category than to another. It should be noted that this ranking constitutes a subjective valuation of the assessment body which has undertaken it and, hence, is not generally valid. By contrast, the criterion “specific contribution” is determined by computation.

The evaluations of all three criteria are combined to formulate a final statement about the ecological priority of the respective impact category considered. In actual life-cycle assessment, the results calculated for the various impact categories can then be weighed against each other by means of the ecological priorities established beforehand.

The methodology developed by the Federal Environmental Agency will be presented in a publication entitled "*Bewertung in Ökobilanzen – Version'99*" (UBA-Texte 92/99). This work is intended to serve, on the one hand, as a contribution of the Federal Environmental Agency to the public discussion about methodological approaches in this field and, on the other hand, as procedural guidance to be followed in life-cycle assessments carried out by or on behalf of the UBA. The publication comprises the following in particular:

- A description of the method of the Federal Environmental Agency which takes into account relevant ISO standards and other work in this field.
- A summary of current knowledge about effect mechanisms, environmental quality targets and the current environmental status in the impact categories usually considered in LCAs.
- A proposal of the Federal Environmental Agency for the ranking of impact categories.

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Introduction: on the status of the Federal Environmental Agency's life cycle assessment valuation method

In recent years, ISO/TC 207 Environment Management standardization work has resulted in considerable progress toward reaching national and international agreements concerning the methods for and realization of life cycle assessments. ISO 14040 and 14041 have been adopted, and the remaining two standards (ISO 14042 and 14043) are slated for adoption in the near future, once all of the contentious issues have been ironed out.

Formal adoption of these standards will place the life cycle assessment system on a sure and internationally recognized footing that will allow for the rapid realization of clear assessments as to whether or not a specific life cycle assessment complies with ISO standards. All future life cycle assessments realized or commissioned by the Federal Environmental Agency will also comply with these standards. The Agency has committed itself to this goal via "Federal Environmental Agency rules for the realization of life cycle assessments" (see section 1.3.2).

One of the most daunting and sensitive tasks entailed by an ISO compliant life cycle assessment is translating into a coherent evaluation the inventory analysis data that was classified and characterized according to impact categories during the impact assessment. The valuation method for life cycle assessments (hereinafter: "FEA Method") that forms the subject of the present document is intended to illustrate how the Federal Environmental Agency intends to carry out life cycle assessments in the future in such a way as to comply with the aforementioned ISO standards. This will involve harmonizing the current Federal Environmental Agency method thus far employed with ISO standards.

This intention is clearly stated in the subtitle of the present report: "Federal Environmental Agency normalization, grouping and interpretation method." This terminology (which has not been used in the literature thus far) evokes a problem that is entailed by the method presented here and for which a solution needs to be found – namely making the distinctive technical terminology used in ISO 14040-14043 understandable for professionals and those users of the present method. However, this cannot and should not involve any attempt to translate the technical terminology used in the ISO standards into generally understandable "popular science" terms for readers that are unfamiliar with the material and have no experience with the relevant matters.

Instead, the FEA Method is addressed to professionals who have an interest in and are familiar with the life cycle assessment system. Our aim here is to show how the Federal Environmental Agency intends to apply ISO standards to interpretations and impact assessments in such a way as to arrive at and implement a standard method for all Federal Environmental Agency life cycle assessments. The Federal

Environmental Agency's studies of environmental quality objectives provided important basic concepts in this regard.

In the present document, the method is described in terms of its individual steps, which culminate in a "valuation" (i.e. an appraisal of the environmental relevance of the product, service or process that is being investigated) whose underlying methodology is optimally transparent for environmental professionals in all relevant disciplines.

1. Introduction

The life cycle assessment is a method of systems analysis that is used to compile and interpret environmental data in an integrated manner that dynamically embraces all relevant media. The elements of the life cycle assessment are illustrated in figure 1.

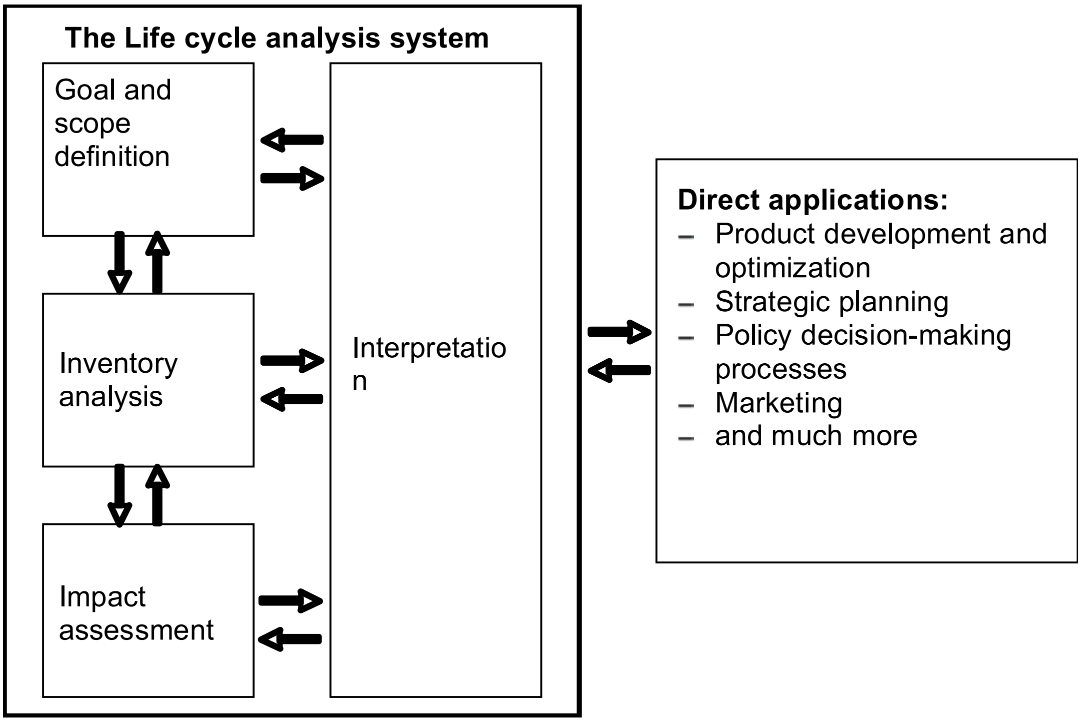

Figure 1: Elements of the life cycle assessment in accordance with ISO 14040

Using the life cycle assessment, the environmental impact of products, processes and services (i.e. raw material extraction, as well as energy, inputs into the environmental media water, air and soil) can be determined, thus allowing for the realization of systematic and highly informative analyses of the environmental impact of the object under investigation.

In recent years, methodological discussions realized within the framework of ISO/TC 207 Environment Management standardization work have resulted in considerable progress toward reaching national and international agreements concerning the methods for and realization of life cycle assessments. Particularly noteworthy in this regard is the work carried out by SETAC (Society of Environmental Toxicology and Chemistry; see section 1.2) and NAGUS (Normenausschuss Grundlagen des Umweltschutzes) of DIN.

In Germany, many manufacturing-sector stakeholders have expressed concerns that implementation of a life cycle assessment valuation method could result in a generally accepted valuation of comparative life cycle assessments that would enable the government to intervene unilaterally and systematically in enterprise product planning processes. However, the life cycle assessment system can only provide support for government environmental policies insofar as government action is perceived as being necessary for overriding reasons having to do with environmental protection. In this context, the life cycle assessment system provides a technical and empirical basis for transparent decision-making (and decisions) that meet the requirements of modern environmental protection processes.

Efforts to define an internationally standardized life cycle assessment valuation method have shown that life cycle assessment valuations must be considered in light of the application domain and methodology of life cycle assessments. Hence, the FEA Method related context that is relevant for these efforts will now be described.

1.1 Principal stipulations of ISO 14040

The following assertions from DIN/EN/ISO 14040:1997 [ISO 14040] (hereinafter: ISO 14040) pertaining to valuations in life cycle assessments are particularly relevant for the FEA Method:

- According to ISO 14040, the main application domain of life cycle assessments is as a basis for decisions concerning ecological improvements in products. This assertion was undoubtedly made in response to the dominant role played by the industrial sector in initiating, financing, and applying life cycle assessments worldwide.
- ISO 14040 also expressly recognizes the role played by life cycle assessments in public policy-making.
- In ISO 14040, the long-since accepted participation by independent experts in numerous major (and published) German life cycle assessments, as well as by stakeholders from the industrial, trade, consumer, labor and environmental communities in Germany, is discussed in ISO 14040 under the “critical review” rubric. The main focus here is on participation by independent experts whose work can be supported by advice from representatives of the groups concerned. According to ISO 14040, comparative life cycle assessments that affect public policy decision-makers (by virtue of having been published) shall undergo a critical review. In the German debate on this matter, two factors have already led to dual project supervision in the guise of a critical review panel and a technical/project committee composed of representatives of the groups affected by the analysis: (a) the desire for the relevant stakeholders to participate in life cycle assessment projects; and (b) the mandatory critical review process in accordance with ISO 14040.
- According to ISO 14040, one of the key goals of life cycle assessments is to formulate comparative assertions. However, if a life cycle assessment is published, special ground rules come into play with respect to, for example, the critical review process, or the elaboration of sensitivity analyses (see section 2.3.2). ISO 14040 expressly states that a life cycle assessment can also demonstrate the environmental superiority of one system over another, or the environmental equivalence of two systems.
- ISO 14040 also states unequivocally that in order to comply with the standard, a life cycle assessment must also include the realization of an impact assessment.
- ISO 14040 further states that the standard also applies to the inventory analysis as a standalone analysis modality, which, while it is to contain an “interpretation,” is not to be regarded as an Impact Assessment. The stipulation is consistent with

praxis in Germany, where many life cycle assessment projects have been expressly designated as Inventory Analyses.

1.2 SETAC's contribution

Whereas ISO workgroups have focused on reaching an agreement on a standardized life cycle assessment framework, defining minimum methodological and procedural requirements, and describing the available methodological and procedural options, for many years now SETAC (Society for Environmental Toxicology and Chemistry) workgroups have been elaborating goals and technical paradigms that serve as a basis for concrete life cycle assessment methods.

The structure of the life cycle assessment as described in SETAC's *Code of Practice* [CONSOLI ET AL. 1993] differs slightly from the four-stage ISO structure, inasmuch as it regards the interpretation process as a constituent of the impact assessment rather than as a standalone element of the life cycle assessment.

SETAC Europe's life cycle impact assessment method was elaborated by the organization's Workgroup on Life Cycle Impact Assessment, whose report defines life cycle impact assessment as follows [UDO DE HAES (ED.) 1996]:

a quantitative and/or qualitative process to identify, characterize and assess the potential impacts of the environmental interventions identified in the inventory analysis

The SETAC Impact Assessment comprises the following elements [LINDEIJER 1996]:

1. Classification
2. Characterization
3. Normalization[1]
4. Valuation

The valuation process consists of the following:

- Weighting
- Sensitivity analyses pertaining to data uncertainties and methodological definitions
- Appraisal

The methodologically relevant assertions made by SETAC's Workgroup on Life Cycle Impact Assessment will now be described [UDO DE HAES (ED.) 1996].

- The results of the classification and characterization work steps constitute a set of indicator results that are derived from various impact categories, which the SETAC group has provisionally defined as follows:

[1] According to SETAC, this is a possible (but inessential) work step

Input related categories: (use of raw materials)	Output related categories: (emission related impacts)
1. Abiotic resources 2. Biotic resources 3. Land use	4. Greenhouse effect 5. Stratospheric ozone depletion 6. Human toxicity 7. Ecotoxicity 8. Photo-oxidant formation 9. Acidification 10. Eutrophication (including oxygen depletion and thermal input) 11. Odour 12. Noise 13. Radiation 14. Accidents

Fig. 2: SETAC impact categories

- In accordance with the Code of Practice [CONSOLI ET AL. 1993], human and ecological health and resources are defined as areas of protection (also referred to as safeguard objects). The key element here is that SETAC also classifies resources as a separate area of protection[2].
- "Valuation" comprises a qualitative and/or quantitative process in which the relative importance of the various impact categories are weighted, while at the same time the sensitivity and error analyses are appraised. Social standards of value play a pivotal role in the valuation process as well.
- Impact category prioritizations should be realized according to the scope of the threat to the area of protection concerned, and in such a way that the following criteria and factors are taken into account:
  - scientific information concerning the relationship between current material flows and the scope and nature of the damage that has been incurred by the area of protection
  - foreseeable future material flow trends
  - reversibility of the damage
  - importance of the damaged area of protection
  - uncertainty concerning the scope of the damage
- SETAC recommends that (a) impact categories be weighted without regard for any specific item that is being investigated for individual life cycle assessments, rather than doing the weighting on a case by case basis; and (b) the operant weighting factors should be reviewed at regular intervals.

[2] These statements pertaining to the three areas of protection (or protected environmental assets) are also part of Federal Environmental Agency policy and are consistent with the proposals advanced in ISO 14042. In its latest position paper, SETAC EUROPE [1999] recommends that the man made environment (like cultural and economic assets) also be classified as an area of protection.

1.3 Outcomes of work on life cycle assessment methodology and implementation

In 1998, “breakthroughs” were achieved at three outstanding forums, as the result of many years of exceptionally committed and at times heated debate in Germany and abroad on the subject of life cycle assessment valuation methods.

1.3.1 The Federal Environmental Agency’s life cycle assessment valuation method project

In 1998, the life cycle assessment valuation method project (launched in 1996 by the Ministry of the Environment and the Federal Environmental Agency), which had long been the subject of controversy, was brought to an end by mutual agreement of the stakeholders concerned [UBA 1999/1]. During the project, an interdisciplinary project committee comprising representatives of the industrial, scientific, environmental/consumer group, labor union and environmental agency domains, worked toward the following goals:

- identification of currently used valuation methods that would be likely to gain widespread acceptance, and those that would not;
- formulating a description of the valuation process; and
- supporting Germany’s contribution to the ongoing ISO standardization activities.

The challenge faced by the committee was to define a valuation system that would constitute a happy medium between arbitrary subjective judgements and “hard” static assessments. The formulations arrived at by the committee provide a useful guide to achieving a consensus that successfully navigates between the Scylla of life cycle valuation and the Charybdis of the consequent conclusions concerning product related environmental policies. Following are some of the committee’s key assertions:

- A life cycle assessment valuation will not potentially trigger any automatic mechanism regarding environmental policy decisions
- Inasmuch as a life cycle assessment valuation is based on stakeholder-specific and individual interests and values, it is intrinsically subjective and cannot be regarded as an objective instrument. Hence, a number of different valuation methods must be applied.
- The design, structure and characteristics of the valuation process (and the attendant methodology) are every bit as important as the assessment method that is selected. An example of the core requirements for this process can be found in the “Federal Environmental Agency rules for the realization of ecobalances” (see section 1.3.2).
- The party that commissions the life cycle assessment study should assume responsibility for defining the goals, design, structure and characteristics of the valuation process, and the methodology that is applied to its realization.

1.3.2 Federal Environmental Agency rules for the realization of ecobalances

An important step toward solving the life cycle assessment "communication gap" between industry and government was taken in May 1998 when, after extensive discussions, Bundesverband der Deutschen Industrie e.V. (BDI) (an industry association), the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, and the Federal Environmental Agency agreed on a formal set of rules entitled *Federal Environmental Agency rules for the realization of life cycle assessments*. In an explanatory statement concerning ISO 14040, the Federal Environmental Agency committed itself to abiding by the following procedural rules:

- Issuance, by the life cycle assessment study sponsor, of clearly formulated descriptions of (a) the relevant issues; and (b) the scope of the envisaged investigation
- Establishment of a project committee composed of representatives of the groups affected in the industrial, consumer/environmental association, and labor union domains
- Project advisory committee input on the following subjects will be factored into the life cycle assessment process: the environmental aspects that are to be considered; the underlying scenarios; the nature of the life cycle impact assessment procedure; selection of impact categories
- Implementation of a critical review process (pursuant to ISO 14040; see page 9) from the beginning of the study, as a rule
- An agreement will be reached concerning the provisioning of life cycle assessment data that is germane to the analysis
- The project advisory committee will be notified at an early stage of the publication modality of the analysis. The procedural rules also contain a passage indicating that business sector stakeholders are to follow a similar procedure to that of the Federal Environmental Agency in realizing their life cycle assessment studies

1.3.3 ISO 14042 and 14043

The FEA Method described below is based on the current draft version of ISO/FDIS[3] 14042 and ISO/FDIS 14043, which apply in particular to impact category prioritization. The following points come into play in this regard:

- According to ISO/FDIS 14042, the impact assessment work steps shown in figure 3 (below) fall into two categories: mandatory and optional elements.

[3] (final draft international standard)

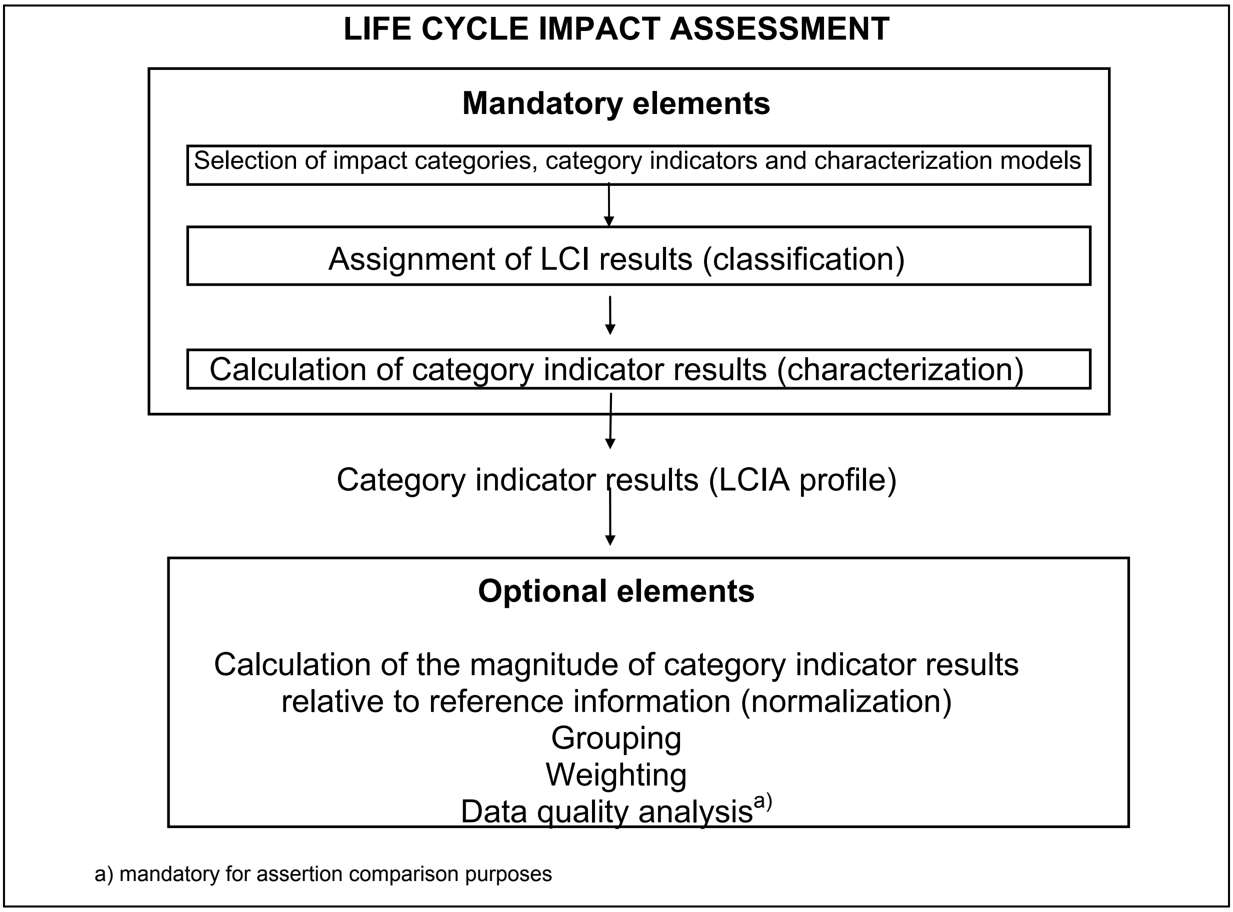

Figure 3: Elements of the life cycle impact assessment (based on ISO/FDIS 14042)

- The optional element “normalization” is defined in ISO/FDIS 14042 as “calculation the magnitude of the category indicator results relative to reference values”. Among the aims of the normalization process is to provide a basis on which to assess the “relative significance of the indicator results” and “lay the groundwork for additional procedures such as grouping, weighting, and interpretation.” This work step is described in greater detail below.
- The “grouping” element: According to ISO/FDIS 14042, the impact category ranking process is to be (a) realized using “a given order or hierarchy, such as high, medium, and low priority;” and (b) based on “value-choices.” As recommended by ISO/FDIS 14042, the Federal Environmental Agency (a) uses the term “priority” as a basis for defining the meanings of the various impact categories; and (b) defines this priority (in the agency’s capacity as “a party”) on the basis of the Agency’s proprietary “value-choices.”
- ISO/FDIS 14042 furthermore requires that “the reasons for selecting the defined normalization and grouping criteria be indicated.” In keeping with this rule, the FEA Method also explains how each of these definitions was arrived at, and which criteria were used in this regard. Neither ISO/FDIS 14042 nor 1403 recommend any criteria (exceeding those in the Standard) that could serve as a basis for establishing the aforementioned priority. Section 10.2 of ISO 14042 states as follows: “The ISO 14042 standard does not specify any specific methodology or support the underlying value-choices used to group the impact

categories." "The value-choices andjudgements within the grouping procedure are the sole responsibility of the commissioner of the study (…)".

- On the other hand, section 5.3 of ISO/FDIS 14043 stipulates that "this international standard does not provide guidance on why an issue may or may not be relevant in a study (…)." But the Standard also says, "A variety of specific approaches, methods and tools are available to identify environmental issues and determine their significance."
- Since the "weighting" element in the sense of "the conversion of indicator results using numerical factors" such as "eco points" or "critical air and water volumes" is regarded as non-ISO compliant in life cycle assessments that provide support for comparative assertions it has been excluded from the FEA Method.

ISO/FDIS 14043 recommends that a workstep entailing "identification of significant issues" be used to transition from the "classification" to the "conclusions and recommendations" phase of the life cycle assessment. The following parameters could potentially come into play here:

- inventory data categories
- impact categories
- "essential contributions for life cycle stages to LCI or LCIA results, such as individual unit processes or groups of processes like transportation and energy production" (ISO 14043)

The "conclusions" and "recommendations" work steps recommended by ISO/FDIS 14043 (in section 7) are particularly relevant to the FEA Method. According to ISO/FDIS 14043, the "conclusions" phase involves publicizing the results of a life cycle assessment, including "identification of significant issues," or the results of discussions during the "classification" phase; in the "recommendations" phase, "specific recommendations to decision-makers should be justified". "Recommendations shall be based on the final conclusions of the study, and shall reflect a logical and reasonable consequence of the conclusions. Recommendations should relate to the intended application as mentioned in ISO 14040."

2. The FEA Method for life cycle assessment valuations

2.1 Underlying principles

In the description of the Federal Environmental Agency's life cycle assessment valuation method (hereinafter: "FEA Method") that follows, in keeping with the classification system used in ISO 14040, a distinction will be made between *normalization/grouping* in accordance with section 2.2 of ISO 14042, and *interpretation* in accordance with section 2.3 of ISO 14043.

All life cycle assessments realized by or for the Federal Environmental Agency are to employ the FEA Method, whose distinguishing features are as follows:

a) Valuation based on a comparative analysis of two systems

b) Oriented toward priority areas of environmental protection

c) Oriented toward existing and target health and environmental statuses

a) Valuation based on a comparative analysis of two systems

In conducting life cycle assessments that aim to compare various systems (i.e. two or more products, processes or courses of action) it is particularly important to establish a hierarchical ranking of indicator results that are associated with diverse impact categories. Such comparative studies are generally characterized by divergent indicator result distributions across the various impact categories that must be rendered comparable for interpretation purposes. On the other hand, life cycle assessments whose sole aim is to analyze weak points and optimization potential in respect to a single impact category can dispense with the aforementioned ranking process since optimization of the same impact category is involved.[4]

The absolute contribution made by impact equivalent values provides relatively little useful information for system comparisons. A category-based comparison of the results produced by two investigation systems provides a good starting point for the data interpretation process. The recommended presentation of results in the form of the T diagram as used thus far by the Federal Environmental Agency [Schmitz et al 1995] appears to be suitable for such comparisons and is retained.

b) Orientation toward priority areas of protection

Life cycle assessments aim to assess the environmental relevance of specific systems. In terms of the valuation process, this means that only those impact categories are to be studied and assessed that presumably pose a threat for priority areas of protection and whose impact category weighting is pegged to the damage that could potentially be engendered by said threat.

[4] Realization of a weak point analysis in an environment management setting only makes sense insofar as a determination is made afterwards as to whether the system in question has changed in terms of ecological optimization. In such a case, the life cycle assessment that is to be realized for this optimization analysis must aim to compare the existing and modified systems, and this system comparison may necessitate a valuation.

Hence in order to assess the harm to an area of protection that could potentially result from ecological change, it is necessary to define "area of protection" explicitly. For it is only on the basis of such a definition that it can be determined whether and to what extent environmental change will also engender ecological damage. Consequently, a change in environmental status can only be regarded as being relevant insofar as said change has a negative impact on an area of protection. And accordingly, the more serious the damage, the more significant the change.

The definition of what constitutes an "area of protection" is mainly determined by a society's basic moral and ethical values, as well as the ethical values of the individuals who make this determination.[5] In Germany, areas of protection are safeguarded by the tenets of environmental law and are generally referred to as the purpose of such laws. The Federal Environmental Agency defines priority areas of protection as being human health, ecosystems, and natural resources. This characterization is also found in the consensus arrived at in international discussions concerning life cycle assessments, and is codified in the ISO/FDIS 14042 standard. However, it has always been eminently clear from discussions and events in the environmental policy domain that areas of protection can be in competition with each other.

Although some environmental domains such as the environmental media water, air and soil are indisputably as worthy of protection as any area of protection one could think of, the catalyst for protecting such media is a direct outgrowth of the protection accorded priority areas of protection.[6]

Life cycle assessment experts disagree as to whether natural resource stewardship constitutes a separate environmental protection goal. As mentioned above, in line with SETAC [CONSOLI ET AL. 1993] and ISO 14040, the Federal Environmental Agency regards natural resources as a priority area of protection within the life cycle assessment system. This is because natural resource protection is a basic principle of sustainable development in the context of intergenerative fair play, and is thus an indispensable precondition for life cycle assessment valuations.

The ecological areas of protection that form the basis for prioritizing environmental impacts are as follows:

1. **Human health**
2. **Ecosystem functions and structures**
3. **Natural resources**

[5] According to Hofstetter [1996], a value system is based on the following three parameters: the society's system of reference (culture and religion), individual value systems within this system of reference (lifestyles), and the timeframe (changes in values).

[6] The environmental media water, soil and air are not classifed as priority areas of protection. However, by no means does this fact call into question the need to safeguard these media. It simply means that environmental media are not automatically subject to protection. Instead the catalyst for protecting such media is a direct outgrowth of the protection accorded priority areas of protection. The anthropogenic change wrought in an environmental medium (e.g. a decline in the pH of a water body) is not in and of itself ecologically harmful. The harm (if any) is engendered solely by the impact of the change on on a priority area of protection – which in in the aforementioned case would be the (negative) impact on the biotopes in the water body.

c) Orientation toward existing and target health and environmental statuses

It is necessary to rank impact categories based on a comparison of the current and tolerable contamination status associated with each such category. This principle is referred to in life cycle assessment discourse as ecological scarcity [Ahbe et al 1990] or distance to target (e.g. [Lindeijer 1996]) and is a widely accepted valuation process option. It follows from this that an environmental domain's need for protection should be ranked higher the greater the gap between its current and target ecological status for the relevant impact category.

2.2 Standardization/classification methods for impact categories in accordance with ISO 1402

2.2.1 Background

Each life cycle assessment study also involves realization of a classification procedure in which the results of the inventory analysis are assigned to various impact categories. The impact categories that are to be applied as a rule to Federal Environmental Agency life cycle assessments are as follows:

Direct adverse impacts on health
Direct damage to ecosystems
Aquatic eutrophication
Terrestrial eutrophication
Use of natural areas
Photochemical oxidant formation/summer smog
Use of natural resources
Stratospheric ozone depletion
Greenhouse effect
Acidification

Figure 4: Mandatory impact categories[7]

In the ensuing characterization process, inventory analysis results are aggregated within these various impact categories on the basis of characterization factors. Within each impact category, the results obtained in the inventory analysis are, by means of characterization factors, aggregated into indicator results (the step called

[7] The following likewise mandatory impact categories do not appear on this list owing to the fact that no classification or characterization paradigm is available for them: pollution that has an adverse effect on humans, plants and animals; radiation; and general risks/threats.

characterization). E.g., "123 kg carbon equivalent" for the "greenhouse gas" category; or a "321 square meter sealed surfaces" for the "use of natural areas" category).

The indicator results for the various impact categories cannot be directly compared with each other either quantitatively or qualitatively. The current state of scientific knowledge does not allow for a determination either (a) whether the greenhouse effect or land use is a more serious environmental threat; or (b) whether a 123 kg carbon equivalent is a greater or lesser threat to ecological areas of protection than a 321 square meter sealed surfaces . The goal of the standardization and classification process is to prioritize the indicator results in preparation for an interpretation process that will encompass all impact categories.

2.2.2 Procedure

During the normalization and grouping phase of the life cycle assessment, the impact indicator results for various impact categories are rendered reciprocally comparable so that an interpretation encompassing all categories can be carried out. This phase also involves assessing the scale of potential environmental damage on the basis of robust criteria. This assessment is then used as a basis for ranking the various impact indicator results in accordance with an ecological priority score that is assigned to each of them.

We will now describe how the assessment criteria for potential ecological damage are arrived at, and how the priority rankings of the impact indicator results are applied.

Note:

1. The more serious the potential hazard for an area of protection in the relevant impact category (irrespective of current environmental status); and

2. the greater the gap between current environmental status in this impact category and ecological sustainability status or another target ecological status; and

3. the higher the impact indicator result is relative to standardized reference values such as the proportion of annual emissions in Germany;

the more environmentally damaging an impact category or a specific impact indicator result is judged to be and the higher the priority assigned to such category or result.

The aforementioned factors are taken into account on the basis of the following criteria:

1. ***Ecological severity***
2. ***Distance to target***
3. ***Specific contribution***

During the standardization and classification phase, the indicator results for each impact category are to be assessed in respect to each of the three criteria indicated above. This assessment results in a priority ranking using a five point scale, where A is the highest priority and E is the lowest.

It should be noted that this priority ranking describes a relationship **between** the various impact categories or indicator results, and that it is **not** to be regarded as an absoultue judgement. For example, if an impact category is given the lowest priority ranking ("E") for the "ecological severity" criterion, this does not necessarily mean that the consequent environmental problem has a low priority in absolute terms, but rather that it has a lower priority **relative** to other impact categories.

Whereas the impact categories for the ecological severity and distance to target criteria are ranked without regard for any specific life cycle assessment, the specific-input criterion pertains to the indicator results of a specific life cycle assessment and must therefore be determined anew for each such assessment.

The *ecological severity*, *distance to target* and *specific contribution* criteria will now be described in greater detail.

2.2.3 Ecological severity

The *ecological severity* criterion is used to assess the severity of the environmental damage associated with an impact category on the following ecological areas of protection: human health; ecosystem structure and function; and natural resources. This assessment is realized without regard for any current environmental status or any indicator result that may have been determined for the relevant impact category in any life cycle assessment.

The following factors are to be taken into account when assessing the ecological severity associated with or attributable to an impact category:

- The potential impact of ecological damage on an area of protection (severity of the damage and scope of the potential impact thereof; the extent to which the elements associated with various hierarchical levels are affected).[8]

  A far reaching impact and the involvement of higher hierarchical levels are to be regarded as more serious.

- The extent to which the damage would be reversible.

  Irreversible impacts are regarded as being more serious.

[8] Example of a hierarchical level: a forest is associated to a higher hierarchical level than a tree, which is in turn is on a higher level than a leaf.

- The size of the physical area that would be involved.

  Ubiquitous impacts are regarded as being more serious than impacts that occur in a delimited area.[9]

- Uncertainty as to the impact prognosis. Uncertainty in this context pertains to a lack of quantitative and/or qualitative data concerning the relevant cause and effect relationships, as well as the time lag for the occurrence of a potential ecological severity.

  The greater the uncertainty, the more serious it is adjudged to be.

The (comparative) assessment of the ecological severity associated with the various impact categories is realized by an appraisal panel, which employs a discursive-subjective weighing process. In order to ensure that the panel reaches its decision on the basis of sufficient information that is as equally distributed as possible amongst the various environmental domains, it is provided with empirical data that is relevant to the environmental impacts and their associated impact categories. The impact of said data and the aforementioned four factors on the panel's assessment varies according to the mindsets of the panelists, and thus these factors cannot be set off against each other. In other words, it is likely that different panels will come to varying conclusions based on the identical data.

An overview of the relevant ecological severity information can be found in Annex 1, which describes the various possible types of environmental damage for each impact category, broken down by area of protection (human health, ecosystem function and structure, natural resources), with the greatest emphasis being placed on the aforementioned four environmental damage factors. The information presented in Annex 1 was current when the present report went to press, this information should be reviewed at regular intervals and updated if necessary.

The appraisal panel's brief is to rank the impact categories according to the environmental severity associated with them, on the basis of the information in Annex 1 and using the ranking scale referred to above.

The Federal Environmental Agency has decided that, until further notice, the aforementioned ranking procedure will be applied to all life cycle assessments conducted by or for the Agency. This ranking procedure is based on the information laid out in Annex 1, as well as on the values endorsed by the Federal Environmental Agency (see Annex II).[10] The ranking procedure itself should be reviewed approximately every five years and modified if necessary to reflect any changes that may have occurred in the preconditions for the procedure, namely knowledge concerning impact contexts, as well as social values, which can of course change over time.

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[9] This provision may have to be changed if the definition of the objective and the framework of the applicable life cycle assessment urgently necessitate the application of different projections, e.g. if the regional context of the environmental impacts take priority

[10] Section 6.3 of ISO 14042 unequivocally states as follows with respect to the subjective dimension of rankings: "Ranking is based on value-choices (…) Different individuals, organisations and societies may have different preferences, therefore it is possible that different parties will reach different ranking results based on the same indicator results or nomalized indicator results."

2.2.4 Distance to target

The distance to target criterion is used to assess impact categories based on a comparison of the current and the target environmental status of the environment. When this criterion is applied, the larger the gap between the current and target environmental status for a category, i. e. the likelier it is that the potential ecological damage ascribed to this category will occur, the higher the category's ranking.

The following factors are to be taken into account in assessing the distance to target of an impact category:

- The gap between current environmental status and an empirical environmental quality target11 such as immision concentrations. In cases where such environmental targets exist, distance to target is estimated on the basis of the difference between current and target environmental status. However, in the interest of rendering this difference comparable across various impact categories, it should be replaced by the quotients of current and target environmental statuses as a dimensionless value. This value indicates the magnitude by which the current status exceeds the nominal sustainability status or the target environmental status for a specific impact category.

  A larger gap or quotient between the current status and quality target is regarded as being more serious.

- In the numerous scenarios for which no empirical environmental target has been defined, an impact category can be assessed on the basis of its environmental-measure goal[12] in lieu of its distance to target.

  The greater the need for a reduction in environmental impact, the more serious the situation is.

- Any anticipated trend in the relevant environmental stress (e.g. resulting from any measures that may be implemented)

  An increase in environmental stress (e.g. from emissions) is regarded as being more serious as stable or decreased stress.

- The enforceability and efficacy of the measures that must be implemented in order to achieve a specific goal. For example, whether or not a measure is technically feasible (and hence efficacious) may depend on the number and

[11] Environmental quality targets characterize a target environmental status and incorporate scientific, social and ethical elements. These targets amalgamate the state of scientific knowledge with social values concerning areas of protection and protection levels. Environmental quality targets are defined on the basis of specific entities or media that are significant for society and/or the environment and are oriented toward the regeneration rate of key resources or ecological sustainability, as well as toward safeguarding human health, and the needs of current and future generations (UBA 1999).

[12] This type of goal is closely related to the *environmental quality target* parameter for areas of protection and environmental media. An environmental *quality* target describes target environmental status in terms of a suitable and measurable empirical value such as emission concentrations. An environmental-*measure* goal describes the total required reduction in environmental contamination as the difference between current pollution levels and a maximum allowable level (e.g. an emissions level), and thus indicates the total reduction in environmental impact (e.g. emissions) that is required in order to meet an environmental quality target (UBA 1999).

distribution of the sources of emissions involved; whereas the likelihood that a measure can be implemented may depend on whether social and economic changes can be realized.

A low level of enforceability and efficacy is regarded as more serious.

The relevant distance to target information is summarized in Annex 1, broken down by impact category. The information and goals in this Annex were current when the present report went to press, both should be reviewed at regular intervals and updated if necessary.

Impact categories are ranked according their distance to target using the panel procedure and five-point scale described in section 2.2.2.

The Federal Environmental Agency has decided that, until further notice, the aforementioned ranking procedure will be applied to all life cycle assessments conducted by or for the Agency. This ranking procedure is based on the information laid out in Annex 1, as well as on the values endorsed by the Federal Environmental Agency (see Annex II). The ranking procedure should be reviewed approximately every five years and modified if necessary to reflect any changes that may have occurred in the preconditions for the procedure, namely environmental statuses, knowledge concerning impact contexts, as well as social values, which can of course change over time.

2.2.5 Specific contribution (standardization)

The *specific contribution* criterion describes the relationship between the indicator (characterization) results of a specific life cycle assessment and a specific environmental situation in the relevant impact category.

The higher an indicator result is relative to the annual environmental load measured in Germany for the relevant impact category, the higher the result is ranked.

The calculation method for specific contribution is shown in formula 1 below. In this formula, the indicator (characterization) results for each functional unit and each individual impact category are divided by the (likewise aggregated with characterization factors) annual values of the relevant substance in Germany.[13]

$$\text{specific contribution}_{\text{i}} = \frac{\text{IE}_{\text{i,functionalunit}}}{\text{IE}_{\text{i,annualGermany}}} = \frac{\sum_j m_{j,functionalunit} \cdot CF_{ij}}{\sum_j m_{j,annualGermany} \cdot CF_{ij}} \qquad \text{(formula 1)}$$

IE: indicator results in impact category i

m_j: inventory analysis results for substance j

CF_{ij}: characterization factor for substance j in respect to impact category i

[13] If no annual values for Germany are available for specific parameters from an Inventory Analysis, approximate specific input is to be calculated using the available parameter data. In such a case, only the indicator results for these specific parmeters may be included in the specific-input calculation.

However, what matters in ranking the results for various impact categories for a specific life cycle assessment is **not** the absolute specific contribution of the various impact categories, but rather the relative values of the specific contributions when the various impact categories are compared. To this end, the calculated specific contributions, as measured in terms of the highest calculated value in each case, are linearly divided into the following categories:[14]

- A: 80 - 100 % of the maximum value
- B: 60 - 80 % of the maximum value
- C: 40 - 60 % of the maximum value
- D: 20 - 40 % of the maximum value
- E: 0 - 20 % of the maximum value

When two systems are compared using the method described in section 2.3, the smaller of the two indicator results available for comparison is used to determine the ranking of the specific contribution for each impact category.

2.3 Method for the interpretation phase of life cycle assessments in accordance with ISO 14043

In order for a life cycle assessment to be ISO compliant, the issue that is relevant for the definition of the assessment's goals and framework must be clearly and precisely described. The purpose of the interpretation phase of the ISO 14043 life cycle assessment is to address this issue on the basis of the information obtained during the prior phases of the assessment. Toward this end, in the interpretation phase "…the findings from the inventory analysis and the impact assessment are combined together, consistent with the defined goal and scope (…) in order to reach conclusions and recommendations."[15]

The main elements of the interpretation phase of the life cycle assessment are as follows:

- Synthesizing the impact category results, the non-aggregable (and hence non-aggregated) inventory analysis data, and other qualitatively described facts, particularly regional data. Although a life cycle assessment study must by definition pertain to a defined area, in reality there is rarely any spatial relationship between emissions and raw material extraction on the one hand and the impact thereof on the other. However, if the data gathered does nonetheless allow for the definition of such a relationship, it is vital that they be factored into the interpretation of the life cycle assessment. This can be done, for example, in cases where area related information regarding emissions, immission and/or background levels are available.
- Results from investigations of various scenarios are synthesized.

[14] In exceptional cases, this linear subdivision system can be varied. This appears to be justified in cases where, e.g., the specific input of **one** impact category substantially exceeds the values of other categories, with the result that use of a linear category would cause all other categories to be ranked as "very low." Conversely, an impact category whose specific input is substantially lower than all others would be ranked as insignificant and be excluded from further consideration.

[15] ISO 14040, section 5.4

- The validity of the life cycle assessment results is appraised

2.3.1 Synthesis of impact indicator results

In the FEA Method, the impact indicator results of a specific life cycle assessment are synthesized on the basis of a head to head comparison of the two systems (e.g. products or alternative processes). In the following, a method will be described that allows synthesis-based conclusions to be reached based on the comparison of the impact indicator results obtained from an analysis of two systems.

2.3.1.1 Graphic of the impact indicator results

In a first step, the impact indicator results from all impact categories of the two investigation systems under comparison are confronted with a view to calculating the additional burden attributable to each system in such a way that the higher indicator results are determined for each indicator category:

$$\text{additional\_burden}_i = \frac{IE_{i,\max} - IE_{i,\min}}{IE_{i,\min}} \text{(percentage\_amount)} \qquad \text{(Gl. 2)}$$

IE_i: indicator results in impact category i

min, max: smaller/larger of the two values under comparison

The comparison of the results of this calculation can be translated into a T-diagram as shown below (figure 5).

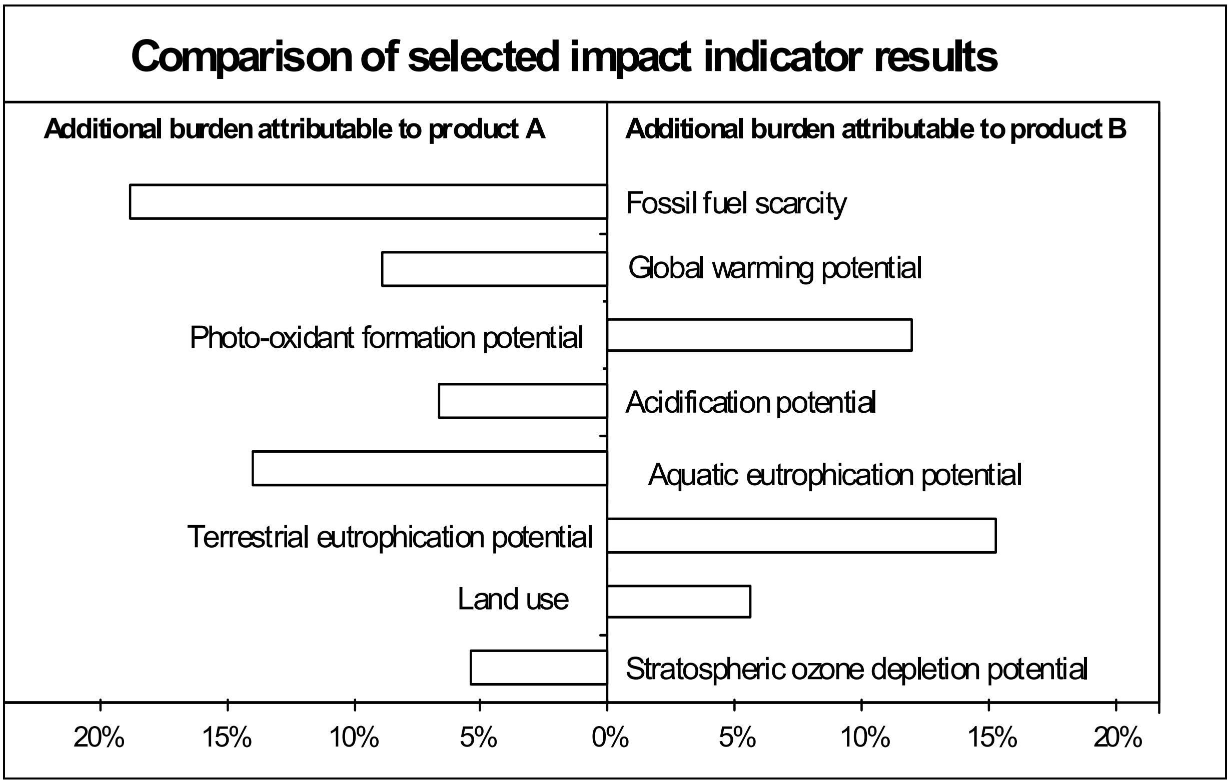


Figure 5: T-diagram showing a comparison of impact indicator results

The orientation of the various bars in the diagram shows which of the investigation systems analyzed exhibits higher indicator results in which impact category, i.e.

which of the two systems is more likely to create environmental pollution in its category. The lengths of the bars represent the additional burden attributable to each system (in percent). However, the graphic does **not** indicate the following:

- the absolute value of the contributions that are associated with the indicator results[16]
- how the various impact categories will be evaluated with respect to their ecological severity and distance to target

Hence, the orientations and lengths of the bars do not, in and of themselves, provide sufficient information regarding the environmental advantages and disadvantages of the two systems. A direct comparison of the bars – with respect to their orientation and length alone – would be invalid.

2.3.1.2 Synthesis of the results of the ecological priority normalization and grouping process

The impact categories under analysis are assessed in terms of their ecological severity, distance to target and specific contribution for the normalization and ranking that are realized during the impact assessment within the context of the grouping process. During the interpretation phase of the life cycle assessment, the aforementioned information and the various ecological priorities derived from it are used to compare the indicator results from various impact categories with each other. In other words, each of the bars in the diagram above is to be characterized in terms of its scope, direction and ecological priority, since this provides an indispensable basis for comparing the bars and weighting them reciprocally during the interpretation process.

Ranking based on the ecological severity and distance to target criteria is realized on the basis of the recommended Federal Environmental Agency ranking system for impact category assessment (see Annex II) and without regard for the specific system that was investigated; ranking based on specific contribution is realized in accordance with the method described in section 2.2.5 of the present document.

The individual verbal assessments of the ecological severity, distance to target and specific contribution (for A through E as per the table below) are synthesized in a balanced manner for each impact category. The hybrid assessment criterion thus obtained will be referred to in the remainder of the present document as “ecological priority.”

The ecological priority of an impact category is assessed using the following verbal scale:

[16] The absolute values of the indicator results are not completely irrelevant for the purposes of life cycle assessment interpretation; only in this phase of the interpretation these values are merely available as relative values based on the quotient derived from equation 2 (see above).

- very high
- high
- medium
- low
- very low

Table 1 shows the basis for a method that allows for a synthesis of ecological severity, distance to target, and specific contribution criteria (being equally weighted) into ecological priority.

Table 1: Determination of an ecological priority assessment criterion based on a synthesis of ecological severity, distance to target and specific contribution criteria assessments.

Verbal assessment rankings for the ecological severity, distance to target and specific contribution criteria			**Ecological priority**
A	A	A	very high
A	A	B	very high
A	A	C	high
A	A	D	high
A	A	E	high
A	B	B	high
A	B	C	high
A	B	D	high
A	B	E	medium
A	C	C	high
A	C	D	medium
A	C	E	medium
A	D	D	medium
A	D	E	medium
A	E	E	low
B	B	B	high
B	B	C	high
B	B	D	medium
B	B	E	medium
B	C	C	medium
B	C	D	medium
B	C	E	medium
B	D	D	medium
B	D	E	low
B	E	E	low
C	C	C	medium
C	C	D	medium
C	C	E	low
C	D	D	low
C	D	E	low
C	E	E	low
D	D	D	low
D	D	E	low
D	E	E	very low
E	E	E	very low

Using this method, each indicator result associated with a system under study and each bar in a comparative T-diagram are assigned a verbal assessment for their respective ecological priorities, which are represented graphically via gray bars (see figure 6).

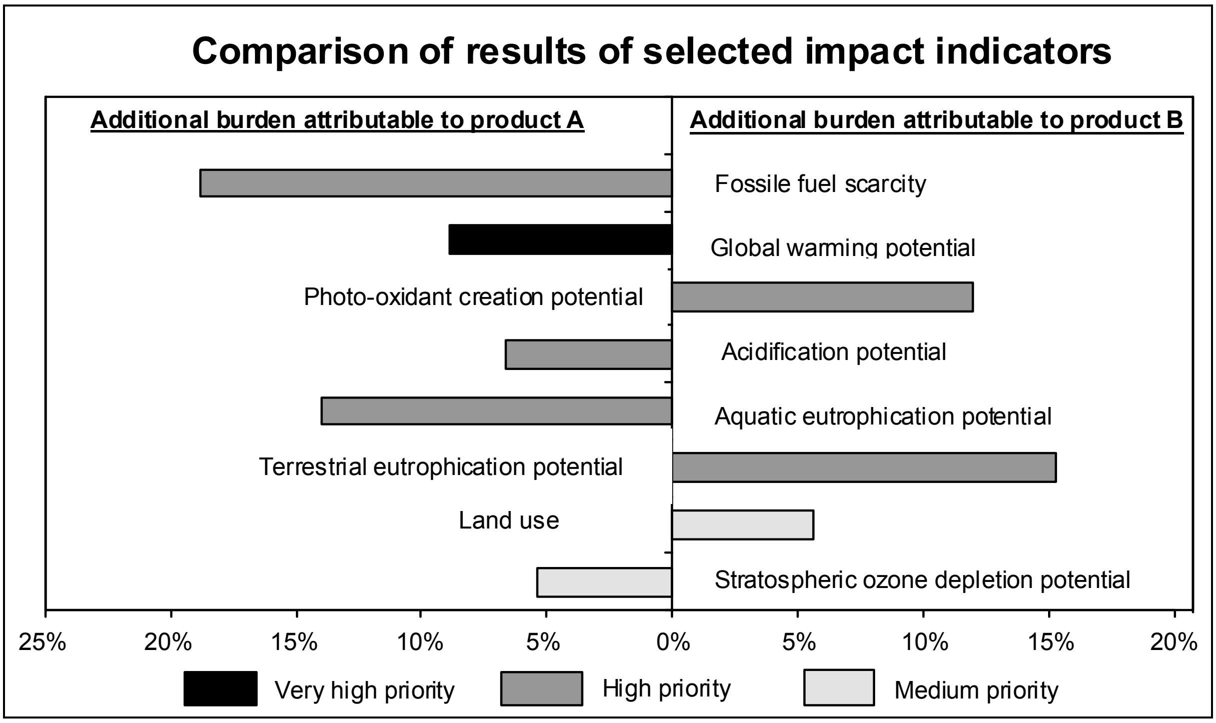


Figure 6: Graphic showing a comparison of ranked indicator results

2.3.1.3 Comparison of prioritized indicator results

The definitive synthesis of all indicator results determined for pairs of compared systems is realized by weighing against each other the various additional burdens that occur in both systems. In this process, the facing bars in the diagram that are associated with comparable percentages and have the same ecological priority (same amount of gray in each bar) are assigned the same value and are weighted reciprocally.

Bars that are associated with differing ecological priorities cannot be weighted against each other since the priority categories (from “very high” to “very low”) are scaled ordinally and thus do not indicate the relationships between the categories.[17] Only in cases where a comparison of two bars, two bar lengths and the attendant ecological priorities (gray shading) pertains to the same system can two bars associated with two different ecological priorities be weighted reciprocally. If this method yields any “orphaned” bars (i.e. any bar that has no counterpart on the opposite side of the chart), the results of the comparison are deemed to be “insignificant.”

Thus, a reciprocal comparison of the various ranked indicator results using this method has one of two outcomes: either one of the systems has decided ecological advantages over the other, or the analysis shows that the difference between the two systems is insignificant.

[17] For example, there is no way of telling whether a “medium” 500% bar should be ranked higher or lower than a “major” 30% bar.

2.3.2 Sensitivity analysis

At numerous junctures in the life cycle assessment process, it is necessary to formulate specifications and assumptions that cannot be proven empirically to a satisfactory degree or that cannot be unequivocally established on the basis of the available quantitative data. Moreover, some of the quantitative data used in life cycle assessments, particularly in studies that focus on a market rather than a specific product, comprise statistical distributions rather than individual values. Consequently the results of life cycle assessments are fraught with a certain degree of uncertainty, which arises at the following junctures in the life cycle assessment process:

- The process data used to characterize the various unit processes generally consist of mean or median values. However, depending on the issue that a specific life cycle assessment happens to be investigating, the extreme values, variances and other deviations associated with these values may be relevant for the study. But this kind of data is often unavailable.
- Already during the modeling phase of the unit processes, definitions and/or assumptions are formulated (e.g. co-product allocations or specific energy mixes) that are not necessarily justified by the available data. Such formulations are of course fraught with uncertainty.
- This also holds true for scenario modeling, where formulations are devised for system parameter descriptions (e.g. recycling rates, transport distances) and methodological decisions (e.g. system allocation for recycling).
- Methodological uncertainties also crop up during the characterization phase of the impact assessment. The characterization factors used for these assessments are based on natural-science paradigms whose uncertainties and estimations of error taint or skew the characterization factors.

In view of these uncertainties, it is crucial that all life cycle assessments integrate an error discussion such as the one described in the sensitivity test section of ISO/FDIS 14043. Ideally, this mechanism will provide insight into the impact on life cycle assessment results of uncertain data, parameters, and/or methodological assumptions.

In such a sensitivity analysis, the parameters that are deemed likely to affect the assessment results are varied and the changes induced thereby (in the results) are evaluated. This type of analysis should be realized following each phase of the life cycle assessment.

Scenarios with variant parameters can be analyzed in parallel with the main scenario, insofar as these parameters can be identified at the outset of the study. Alternatively, a sensitivity analysis can be conducted via an iterative step on completion of the calculations for the main scenario.

The sensitivity analysis significantly impacts life cycle assessment results by providing key insight into (a) the robustness and validity of the results; and (b) dependencies associated with each of the various parameters.

The sensitivity analysis procedure for the life cycle assessment interpretation process consists of the following three phases:

1. Selection of sensitive parameters
2. Screening analysis
3. Scenario analysis

These three phases will now be described.

2.3.2.1 Selection of sensitive parameters

The parameters that are to be analyzed with respect to their sensitivity must first be selected. The bulleted list in section 2.3.2 can be used as a checklist in this regard.

In selecting the parameters, the variance ranges that will be applied to the values deemed sensitive must be defined, and this must be done in such a way that all available information regarding real scenarios is encompassed by these ranges. The reasons for deeming certain parameters sensitive (and therefore for selecting them) and for the definitions of the variance ranges are to be explicitly stated in the final report.

2.3.2.2 Screening analysis

In the interests of minimizing the work involved in carrying out the large numbers of sensitivity analyses entailed by each life cycle assessment, it is advisable to estimate the sensitivity of the selected parameters through realization of a screening analysis in advance of the life cycle assessment study per se. This can be done using a screening indicator that roughly correlates with the anticipated results of the life cycle assessment.[18]

2.3.2.3 Scenario analysis

Scenarios whose screening analyses perceptibly impact life cycle assessment results should be analyzed exhaustively. In other words, in such cases complete life cycle assessments should be conducted on the basis of variations in the sensitivity conditions, which may vary considerably depending on the goal of the life cycle assessment concerned. For example, status quo analyses tend to be based on variance ranges that are reflective of real market figures and conditions, whereas prognosis studies will take account of conditions that are likely to emerge in the foreseeable future.

Additional scenarios can also be elaborated by varying the allocation rules, characterization factors and other methodological principles that are applied to life cycle assessments.

[18] The indicator known as Cumulated Energy Demand (CED), which represents the total of all energy that will be converted by the system of interest during its life cycle, may well be suitable for the screening analysis. However, the validity of this indicator should be investigated before it is applied to the interpretation of any future life cycle assessment.

2.3.3 Significance analysis

The significance analysis is used to estimate the environmental load engendered by the system of interest (or to compare the loads attributable to two systems) relative to the overall ecological situation or specific types of ecological problems.

The significance analysis also aims to enable policy-makers and other decisionmakers who use life cycle assessments to assess the potential environmental benefits of their decisions, with a view to confronting these benefits (on completion of the life cycle assessment) with the economic, social and other costs entailed by these decisions. The significance analysis should be based on relevant and appropriate reference data such as annual emissions for Germany.

The significance analysis is not to be confused with the determination of specific contribution, even though both processes are based on the same or similar data. The difference lies in the fact that specific contribution is determined solely on the basis of a quantitative reciprocal comparison of the various impact indicator results measured via the life cycle assessment (see section 2.2.5), whereas a significance analysis compares the system of interest with the overall situation or with other systems.

2.3.4 Appraisal

The appraisal is the phase of the life cycle assessment in which all information of the inventory analysis and the impact assessment is synthesized in accordance with the defined goal and investigation framework of the life cycle assessment with a view to reaching conclusions and making recommendations.

This is done by means of the following two-phase procedure:

1. The results from the inventory analysis and impact assessment are synthesized for **each** scenario that was investigated, as follows:
   a. Ranked indicator results
   b. The following key results of the inventory analysis, insofar as they have not already been factored into the impact assessment:
      - Material flows that were not reduced to elementary flows in the inventory analysis (e.g. secondary raw materials, or material flows that cannot be traced/identified owing to a lack of data)
      - Substances that are not amenable to aggregation using the impact assessment method that was selected for the study
      - Qualitative or other information from the inventory analysis
      - Information concerning specific areas and timeframes (depending on the life cycle assessment's defined goal and the information available for it)
2. Synthesis of the results pertaining to all scenarios
   The synthesis of all scenarios allows life cycle assessment results and conclusions to be formulated in terms of various key factors such as the following:
   a. Parameter driven assertions (and the associated statistical ranges of the relevant parameters) as to, for example, which parameter configuration renders the main scenario results invalid

b. Assertions regarding the statistical probability of the assertions made (assuming that the statistical distribution of the main parameters is known)

c. To what extent does altering the assumptions underlying the framework definition of the life cycle assessment alter the assessment’s results?

The results of the appraisal comprise the following elements:

- a series of clear, unequivocal and unassailably logical conclusions concerning the relative advantages and disadvantages of the systems studied for the environment, relative to the conditions that were investigated
- an assessment of the reliability of these conclusions
- an assessment of the significance of the aforementioned advantages and disadvantages relative to other system groups

Glossary

Aggregation: synthesis of individual informational elements expressed as informative aggregate parameters such as impact indicators

Interpretation: in a life cycle assessment, a process (in accordance with DIN EN ISO 14040) whereby the results of the inventory analysis or impact assessment or both are synthesized in accordance with the defined goal and investigation framework of the life cycle assessment with a view to reaching conclusions and making recommendations. XX

Valuation: a phase in the life cycle assessment system where inputs in the various input categories are weighted so as to allow them to be compared with each other, with a view to formulating further interpretations and syntheses of the results of an impact assessment. (CONSOLI ET AL. 1993)

Characterization: process whereby inventory analysis results are converted into a standardized unit (e.g. carbon equivalents for greenhouse gases) and converted results are synthesized within the relevant impact category (in accordance with ISO/FDIS 14042: 1999; see the latter for a detailed definition)

Characterization factor: a factor which, after being extrapolated from a model, is used to convert previously categorized inventory analysis results into a standardized impact indicator unit (ISO/FDIS 14042: 1999)

Distance to target: estimated distance between the present and target environmental status of a product, service or other entity within a specific impact category (see section 2.2.4)

Sorting: classification of impact categories on a nominal scale based on characteristics such as emissions and resources, or on global, regional and local parameters. (in accordance with ISO/FDIS 14042: 1999)

Elementary flow:
material or energy entering the system being studied that has been drawn from the environment whithout previous human transformation or material or energy leaving the system being studied that is released into the environment without subsequent human transformation.

Goal and scope definition: The first (and mandatory) phase of a life cycle assessment see sections 4.2 an 5.1 in DIN EN ISO 14040)

Appraisal: final stage of the valuation phase in which information from the previous phases, including qualitative information and estimates regarding certainties, are synthesized (in accordance with UDO DE HAES (ED.) 1996)

Weighting: procedure involving conversion of the indicator results using numerical factors that are based on specific values. Weighting is not to be used to formulate comparative assessments that are intended for publication. (in accordance with ISO/FDIS 14042: 1999)

Indicator results: see category indicator results

Classification: a process in which inventory analysis results are assigned to impact categories (in accordance with ISO/FDIS 14042: 1999)

Normalization: a process in which previously calculated impact category results are compared to one or more reference values (ISO/FDIS 14042: 1999)

Ecological hazard: a criterion for assessing impact categories in terms of the severity of the environmental damage associated with these categories that is sustained by ecological areas of protection (see section 1.1).

Grouping: assignment of impact categories to one or more categories. This process can involve either sorting or ranking. (in accordance with ISO/FDIS 14042: 1999)

Priority: ranking criterion for impact indicator results, encompassing the following sub-criteria: ecological hazard, distance to target, and specific contribution. (for further details (to some extent concerning the concept of ecological priority as well), see section 2.2)

Ranking: a process whereby impact categories are ranked on an ordinal scale, according to criteria such as a defined sequence or hierarchy, or high, medium or low priority (in accordance with ISO/FDIS 14042: 1999)

Life cycle inventory analysis: a phase of the life cycle assessment in which the inputs and outputs of a specific product system over the course of its life cycle are synthesized and quantified. (DIN EN ISO 14040)

Specific contribution: a normalization-based criterion that describes the scope of an impact category result relative to a standardized reference value (see section 2.2.5)

Environmental aspect: elements of the activities associated with organizations, products and services that interact with the environment (DIN EN ISO 14040)

Environment quality target: describes a target environmental status

Life cycle impact assessment: phase of a life cycle assessment in which the scope and significance of the potential environmental impact of specific product system are identified and assessed. (DIN EN ISO 14040)

Life cycle impact indicator and impact category indicator: quantifiable indicator of an impact category. (ISO/FDIS 14042: 1999)

Category indicator results: the result of characterization, obtained by converting inventory analysis results into impact indicators and syntheses within an impact category (in accordance with ISO/FDIS 14042: 1999)

Impact category: key environmental classifications to which inventory analysis results can be assigned (ISO/FDIS 14042: 1999)

Bibliography

AHBE U. A. 1990 — Ahbe, S., Braunschweig, Müller-Wenk, R.,: *Methodik für Ökobilanzen auf der Basis ökologischer Optimierung*, BUWAL SRU 133, Bern, October 1990

BELTRANI 1997 — Beltrani, G.: *Safeguard Subjects - The Conflict Between Operationalization and Ethical Justification*, Int.J.LCA 2 (1), S. 45-51, 1997

BRAUNSCHWEIG ET. AL. 1994 — Braunschweig, A., Förster, R., Hofstetter, P., Müller-Wenk, R.: *Assessment und Weiterentwicklung von Bewertungsmethoden für Ökobilanzen - Erste Ergebnisse*, IWÖ-Diskussionsbeitrag Nr. 19, St. Gallen, August 1994

BRAUNSCHWEIG ET. AL. 1996 — Braunschweig, A., Förster, R., Hofstetter, P., Müller-Wenk, R.,: *Developments in LCA Valuation*, IWÖ-Diskussionsbeitrag Nr. 32, St. Gallen, March 1996

CONSOLI ET AL. 1993 — Consoli, F. u. a., *Guidelines for Life-Cycle Assessment: A "Code of Practice,"* SETAC, Brussels, Pensacola, 1993

DIN EN ISO 14040:1997 — DIN EN ISO 14040:1997, *Umweltmanagement - Ökobilanz - Prinzipien und allgemeine Anforderungen*, Beuth Verlag, Berlin, August 1997

GIEGRICH ET AL. 1995 — Giegrich, J., Mampel, U., Duscha, M.*: Bilanzbewertung in produktbezogenen Ökobilanzen - Assessment von Bewertungsmethoden, Perspektiven*, in: Umweltbundesamt (Hrsg.): Methodik der produktbezogenen Ökobilanzen, Umweltbundesamt Texte 23/95, July 1995

GOEDKOOP 1995 — Goedkoop, M.:*The Eco-Indicator 95*, Amersfoort 1995

HABERSATTER 1991 — Habersatter, K.: Ökobilanz von Packstoffen Stand 1990, Schriftenreihe Umwelt Nr. 132, BUWAL, Bern, 1991

HOFSTETTER 1996 — Hofstetter, P.: *Towards a structured aggregation procedure* in: Braunschweig, A., Förster, R., Hofstetter, P., Müller-Wenk, R.,: *Developments in LCA Valuation*, IWÖ-Diskussionsbeitrag Nr. 32, St. Gallen, March 1996, p. 123-211

HOFSTETTER U. SCHERINGER 1997 — Hofstetter, P. and Scheringer, M.: Schutzgüter und ihre Abwägung aus der Sicht verschiedener Disziplinen, vorbereitende Unterlagen des 5. Diskussionsforums Ökobilanzen, ETH Zürich, October 1997

ISO 14040 — *ISO 14040:1997, Environmental management - Life cycle assessment -Principles and framework*, Paris, June 1997

ISO/FDIS 14042:1999 — *ISO/FDIS 14042:1999, Environmental management - Life cycle assessment - Life cycle impact assessment*, Paris, 1999

ISO/FDIS 14043:1999 — *Committee Draft ISO/CD 14043.2, Environmental management - Life cycle assessment - Life cycle Interpretation*, Paris, 1999

KLÖPFFER U. VOLKWEIN 1995 — Klöpffer, W., Volkwein, S.: *Bilanzbewertung im Rahmen der Ökobilanz*, 8. Internationaler Recycling Congress, Fachkongreß Ökobilanzen, Berlin, 6.12.1995

LINDEIJER 1996 — Lindeijer, E.: *Normalisation and Valuation* in: Udo de Haes, H.A. (ed.): Towards a Methodology for Life Cycle Impact Assessment, SETAC-Europe, Brussels, September 1996

MÜLLER-WENK 1997 — Müller-Wenk, R.: Safeguards Subjects and Damage Functions as Core Elements of Life-Cycle Impact Assessment, IWÖ-Diskussionsbeitrag Nr. 42, St. Gallen, March 1997.

MÜLLER-WENK U. BRAUNSCHWEIG 1996 — Müller-Wenk, R., Braunschweig, A.: Comments and proposals to the Eco-indicator 95 impact assessment method in Braunschweig, A., Förster, R., Hofstetter, P., Müller-Wenk, R.,: *Developments in LCA Valuation*, IWÖ-Diskussionsbeitrag Nr. 32, St. Gallen, March 1996, S. 212-240

PAULINI 1996 — Paulini, I.: *Arbeiten des Umweltbundesamtes zur Methodik der Wirkungsabschätzung*, Seminar “Produktbezogene Ökobilanzen IV” within the framework of UTECH ´96, Berlin, February 1996

SCHMITZ U. A. 1995 — Schmitz, S., Oels, H.-J., Tiedemann, A.: *Ökobilanz für Getränkeverpackungen,* Umweltbundesamt Texte 52/95, Berlin, August 1995
(English version: *Life-cycle assessment for drinks packagings systems,* Umweltbundesamt Texte 19/96, Berlin, March 1996)

SETAC EUROPE 1999 — SETAC-Europe (WIA-2): *Best Available Practice Regarding Impact Categories and Category Indicators in Life Cycle Assessment*, Int.J.LCA 4 (2), S.66-74, 1999

UDO DE HAES (ED.) 1996 — Udo de Haes, H.A. (ed.): *Towards a Methodology for Life Cycle Impact Assessment*, SETAC-Europe, Brussels, September 1996

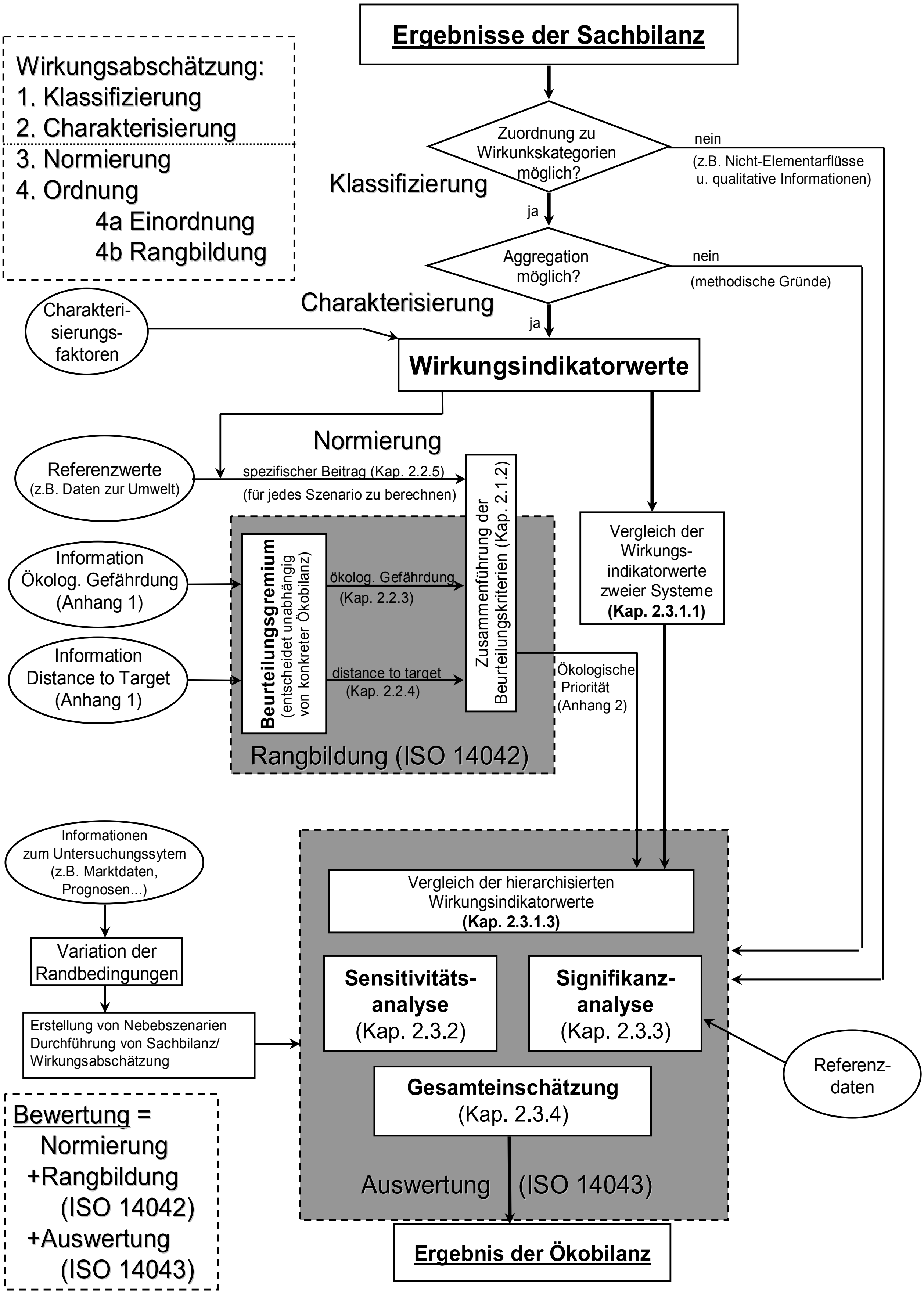
UDO DE HAES 1996 — Udo de Haes, H.A.: *Discussion of General Principles and Guidelines for Practical Use* in: Udo de Haes, H.A. (ed.):

Towards a Methodology for Life Cycle Impact Assessment, SETAC-Europe, Brussels, September 1996

UBA 1999/1 Umweltbundesamt (ed.), Institut für Wirtschaft und Ökologie der Universität St. Gallen (IWP-HSG): *Bewertung in Ökobilanzen, Projektbericht und Projektdokumentation*, in: UBA-TEXTE .../99 (in press).

UBA 1999/2 Umweltbundesamt: Ziele für die Umweltqualität, eine Bestandsaufnahme, Entwurf, July 1999 (unpublished)

VOLKWEIN ET AL. 1996 Volkwein, S., Gihr, R., Klöpffer, W.: *The Valuation Step Within LCA, Part II: A Formalized Method of Priorization by Expert Panels*, Int.J.LCA 1 (4), p.182-192, 1996



Wirkungsabschätzung:
1. Klassifizierung
2. Charakterisierung
3. Normierung
4. Ordnung
4a Einordnung
4b Rangbildung
Ergebnisse der Sachbilanz
Zuordnung zu Wirkunkskategorien möglich?
nein
(z.B. Nicht-Elementarflüsse u. qualitative Informationen)
Klassifizierung
ja
Aggregation möglich?
nein
(methodische Gründe)
Charakterisierung
ja
Charakteri-sierungs-faktoren
Wirkungsindikatorwerte
Normierung
Referenzwerte
(z.B. Daten zur Umwelt)
spezifischer Beitrag (Kap. 2.2.5)
(für jedes Szenario zu berechnen)
Zusammenführung der Beurteilungskriterien (Kap. 2.1.2)
Vergleich der Wirkungs-indikatorwerte zweier Systeme
(Kap. 2.3.1.1)
Information Ökolog. Gefährdung (Anhang 1)
Information Distance to Target (Anhang 1)
Beurteilungsgremium
(entscheidet unabhängig von konkreter Ökobilanz)
ökolog. Gefährdung
(Kap. 2.2.3)
distance to target
(Kap. 2.2.4)
Ökologische Priorität (Anhang 2)
Rangbildung (ISO 14042)
Informationen zum Untersuchungssytem (z.B. Marktdaten, Prognosen...)
Variation der Randbedingungen
Erstellung von Nebebszenarien Durchführung von Sachbilanz/ Wirkungsabschätzung
Vergleich der hierarchisierten Wirkungsindikatorwerte
(Kap. 2.3.1.3)
Sensitivitäts-analyse
(Kap. 2.3.2)
Signifikanz-analyse
(Kap. 2.3.3)
Referenz-daten
Gesamteinschätzung
(Kap. 2.3.4)
Auswertung (ISO 14043)
Ergebnis der Ökobilanz
Bewertung =
Normierung
+Rangbildung
(ISO 14042)
+Auswertung
(ISO 14043)

Impact assessment:
Classification.
Characterization.
Normalization.
Grouping.
Sorting.
Ranking.

Characterization factors.

Reference values
(e.g. environmental data).

Ecological severity information
(Annex 1).

Distance to target information
(Annex 1).

Information regarding investigation s
(e.g. market data, projections etc.).

Variance of condition
related parameters

Elaboration of alternative scenarios
Inventory analysis/impact assessment

Valuation =
Normalization
+ Ranking
+ Interpretation

Ergebnisse der …	Inventory analysis results
Zuordnung…	Can the results be allocated to impact categories?
ja	yes
Klassifizierung	Classification
ja	yes
Aggregation…	Can the results be aggregated?
Wirkungsindikatorwerte	Impact indicator values
Normierung	Normalization
Spezifischer Beitrag	Specific contribution (see section 2.2.5)
für jedes …	(to be calculated for each scenario)
Beurteilungsgremium…	appraisal panel (reaches its decisions without regard for any specific life cycle assessment)
Zusammenführung…	Synthesis of assesment criteria (see section 2.1.2)
ökolog. Gef. …	Ecological severity (see section 2.2.3)
Ökolog. Prior. …	Ecological priority (see Annex 2)
Vergleich der Wirkungs- …	Comparison of the impact indicator values from two systems (see section 2.3.1.1)
nein	no
z.B.	Non-elementary flows and qualitative information
Methodisch …	methodological reasons
Rangbildung…	Ranking
Vergleich der hierarchisierten…	Comparison of ranked impact indicator values (see section 2.3.1.3)
Sensitivitäts…	Sensitivity analysis (see section 2.3.2)
Signikanz…	Significance analysis (see section 2.3.3)
Gesamt…	Appraisal (see section 2.3.4)
Auswertung	Interpretation
Referenzdaten	Reference data
Ergebnis der…	Life cycle assessment results

Annex 1

Classification system for the "ecological severity" criterion and for distance to target

Table of contents

Background

In the impact assessment phase of a life cycle assessment, the impact potential of the inventory analysis data is described and estimated, i.e. the data is “translated” into its potential environmental impacts. The aim of doing this is not to determine and assess actual environmental impacts, since this is completely ruled out for a life cycle assessment owing to the absence of spatial, temporal, and empirical points of reference.

In order to develop a viable method for all possible environmental impacts and the interplay between them, these impacts must first be assigned to impact categories which ideally will be based on scientific and ecologically transparent and well founded criteria. It is then determined whether any methods or indicators are available that would allow for aggregation of the inventory analysis data in respect to the relevant impact potential.

In principle, this aggregation phase solely entails consolidating a substantial volume of inventory analysis data into an impact-potential metric within an impact category, as is done for the greenhouse effect into global warming potentials (GWP). The process of valuating a life cycle assessment study would be greatly simplified if the various impact categories were intrinsically homogeneous, i.e. if, methodologically speaking, each category could be reduced to one single variable. Unfortunately, this is not possible for all categories under all circumstances, particularly categories whose synthesis encompasses substantial numbers of very different impacts, above all with respect to “direct damage to ecosystems” and “direct adverse impacts on health”.

The Federal Environmental Agency’s list of impact categories can be found in figure 4 of the main text. The criteria and principles applied by the Agency to rank the various impact categories will now be described. Until now, it has not been possible to rank ecological severity and distance to target for the “direct adverse impact on health,” and “direct ecosystem damage” impact categories owing to inconsistencies in the characterizations that have been realized for impact assessments. Consequently, the identified substances and the quantities thereof are assessed via individual substance assessments as part of concluding logical (verbal) appraisals. This must be done in such a way that the substances that were factored into the inventory analysis for the various scenarios considered are assessed directly.

Consequently, the Federal Environmental Agency recommends that for the time being, no impact assessment aggregation be realized for the “direct adverse impact on health” or “direct ecosystem damage” categories. Hence the observations in the next two sections only apply in a general sense.

1. The “direct adverse impact on health” category

1.1 Classification principles for the “ecological severity” criterion

The present section addresses the issue of direct adverse effects on human health. Unlike the procedure for all other impact categories (except for direct ecotoxicity) where the negative impact of the processes of interest constitutes a collateral (secondary) rather than a primary impact on the area of protection, in the following the primary impact on the area of protection will be described. However in order to address this issue meaningfully, it is first necessary to describe the “human health” area of protection, since this concept forms the basis for the entire discussion that follows.

Health – according to the definition that is commonly used worldwide – is a “state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.”[19] This WHO definition of the “environmental health of humans” is based on the principle that human health can be adversely affected not only by the direct impact of chemicals, radiation, noise, and biological agents, but also by indirect effects induced by the wider physical, mental, social and aesthetic environment. As a result of this realization, life cycle assessment studies now investigate and evaluate both primary *and* secondary effects on human health. However, it is simply beyond the realm of possibility, from both a practical and methodological standpoint, to base life cycle assessments on WHO’s extremely wide ranging definition of health, since the data gathered for the inventory analysis is woefully inadequate for such an approach. Hence life cycle assessments are concerned with neither the psychological, the social nor aesthetic dimensions of the human environment, but focus instead on the impact of environmental factors such as chemicals, noise, and radiation.

Moreover, every valuation phase of a life cycle assessment must be based on a clear definition of exactly whose potential health problems are being studied and evaluated. The analysis that follows is based on the assumption that this definition includes all persons now living, and all future generations, and by extension, to all areas of protection (and area of protection paradigms) for all of humanity, everywhere in the world, without any distinction with respect to race, ethnic group, place of residence, nationality, or social class. Unlike ecotoxicity, the human toxicity domain centers around the health of individual persons, although in some cases effects on specific population groups are also studied (e.g. the effect of endocrine disrupters on fertility).

[19] The definition stems from WHO, which has expanded it a number of times since its inception in 1948, most recently in 1992 when the concept of sustainability was added.

1.1.1 The “human health” area of protection (with respect to toxic chemicals)

1.1.1.1 Mechanisms of action

The present section discusses the direct adverse health effects of toxic substances. In this domain, there are many different types of adverse health effects (end points) whose qualitative characteristics vary greatly.

Toxic substances can be roughly classified according to short/long term effects (with respect to the substance’s duration of action, or the duration of the disorder provoked by the substance), as well as end point, which includes the following: mild or acute conditions, inflammations (e.g. of the eyes, skin, or mucosa), organ disorders (e.g. of the liver, lungs or kidneys), irreversible organ damage, allergies, sensitization, immunotoxicity, neurotoxicity, genotoxicity, genetic disorders, reproductive disorders, carcinomas, and premature death. The severity weighting for the various end points attributable to chemical substances – which include (generally mild) sensitivity disorders, as well as acute/life threatening disorders, acute pain, and premature death – vary interindividually.

The actual effects that occur are determined in all instances by (a) intrinsic toxicity (dose-effect relationship) of the substance concerned; (b) the location on or within the body on/through which the substance acts; and (c) the frequency and duration of action. In addition, any previous disorder and/or any background pollution may also exacerbate the effect induced by a chemical substance. The foregoing may not apply in cases where two or more substances act concurrently and their effect is aggregated, multiplied or potentiated, but relatively little is known about such clinical scenarios in any case. Another area of uncertainty (albeit one that applies to all impact categories) is that only known end points can be studied, taken into account and thus evaluated. Throughout history there have been effects that went unnoticed for many years, a prime example of this in recent times being the endocrine effects of chemicals. Also relevant in this regard is the extreme sensitivity of certain individuals to very low doses of various chemicals (MCS, multiple chemical sensitivity). Such phenomena fly in the face of the conventional toxicological wisdom, which holds that the dose engenders the toxicity and that low doses do not produce a detectable effect. However, it is also possible that as yet undiscovered mechanisms of action will engender “new” effects.

1.1.1.2 Reversibility, irreversibility and duration

Broadly speaking, the acute symptoms of many end points tend to be more reversible than chronic effects, although end points such as sensitization are egregious exceptions to this “rule.” The non-reversible effects are those associated with reproduction toxicity, neurotoxicity, organ toxicity and cancer.

The timeline for the manifestation of symptoms is determined by the end point that comes into play. As a rule, acute effects such as inflammation appear instantaneously or after a very brief exposure period, whereas chronic symptoms may appear after months or years of exposure, and may persist. Cancer is characterized by relatively long latency periods.

It is often the case (though this too is a rule to which there are numerous exceptions) that the effects of a substance become less reversible the longer they persist, assuming that the dose is sufficiently high.

1.1.1.3 Spatial extent

Spatial extent cannot be measured or assessed in terms of geographical regions, for what is involved (although here too it is difficult to establish a direct relationship between a specific area of protection and a specific impact category) is the number of persons that are exposed to and harmed by a substance worldwide. And this in turn is determined by regional localization, as well as the nature, quantity and distribution of the offending emissions. In the vast majority of cases, individuals are exposed to emissions most directly by breathing them in, but can also be exposed via soil, water, or deposited substances that make their way into the food chain, or via water (drinking or otherwise). In such cases, substantial spatial differences between emissions and exposure may occur, particularly owing to worldwide food transport.

1.1.2 The “human health” area of protection (with respect to noise)

1.1.2.1 Mechanisms of action

The acoustic energy radiated by acoustic sources is transformed into heat energy within seconds via their propagation paths. Hence the “noise” impact category should only be factored into valuations to the extent that the noise affects or can affect the persons concerned. A valuation based solely on acoustic emissions can produce skewed assessments if no correlation with noise emissions is established. The present section describes various types of health related (end point) noise effects.

<u>Hearing damage</u>

Exposure to extremely loud noise can provoke acute hearing damage as the result of mechanical overload of the sensory cells.

Chronically high levels of noise can provoke chronic damage in the sensory cells by placing undue stress on cell metabolism.

<u>Stress related cardiovascular disease</u>

Exposure to noise can provoke non-specific stress reactions in the cardiovascular system (changes in blood pressure and cardiac frequency, contraction of the peripheral blood vessels, stress hormone excretion). Sensitization and acclimatization play a key role in determining response duration. Although transient manifestations of these reactions are not clinically relevant in most instances, long term shifts in the individual’s physiological equilibrium can induce chronic pathologies in the cardiovascular system.

Studies on the correlation between traffic noise and heart attacks show a consistent tendency toward increased risk in individuals who are exposed to noise levels exceeding 65 to 70 dB(A) on a daily basis (as measured out of doors), and to 5-10 dB(A) at night. Exposure to traffic noise in excess of 65 dB(A) appears to increase the risk of heart attack by approximately 20 percent.

Sleep disturbance provoked by noise

Exposure to noise during sleep can directly induce the following effects:

- changes in sleep depth, with or without awakening
- curtailment of total, deep, or dream sleep time
- vegetative reactions (e.g. cardiac frequency, blood pressure)
- biochemical reactions

  or can indirectly induce the following effects:
- diminished subjective sleep quality
- diminished work efficiency the following day

Avoidance of sleep disturbance is one of the key preconditions for healthy home environments.

Noise related disturbances

Individuals may experience the following phenomena as constituting a disturbance: environmental noise, disruption of activities such as conversations and relaxation, watching TV and work, as well as the need to counteract noise by closing windows or going to another room. Such disturbances diminish the individual’s sense of physical, psychological, and social well-being.

1.1.2.2 Reversibility, irreversibility and duration

The effects of short term noise are generally reversible, with the exception of pathologies such as acute hearing damage provoked by extremely loud noise. Persistent noise-induced sleep disturbance, as well as stress related shifts in the equilibrium of physiological systems, can provoke cardiovascular disorders in the long term. The timeline for the manifestation of such disorders is difficult to determine owing to the fact that noise is only one of many risk factors for cardiovascular disease.

1.1.2.3 Spatial extent

The various sources of noise that must be factored into life cycle assessment valuations are classified in various ways according to their scale.

Small-scale noise pollution that solely affects the immediate environs is to be taken for granted when it comes to product manufacture, use and disposal. In product manufacturing contexts, a distinction must be made between noise pollution within the factory (immissions) and noise pollution that affects the factory’s neighbors (emissions). The quality goals that are applied to life cycle assessment valuations should be consistent with the noise pollution scenario involved.

Large-scale noise pollution can occur in connection with product transport. In such cases the scope of the pollution is mainly determined by the extent of the transport routes involved and the transport method employed.

1.2 Basis for determining distance to target

1.2.1 Chemical substances

Aggregation of the substance flows that are toxic to humans and the environment is a sine qua non for determination of distance to target in these impact categories (see Introduction). The requisite substance properties from the inventory analysis must be identified and classified within the framework of the impact assessment.

In the interest of establishing guideposts for the valuation process, in the list below we define general long term substance-policy environmental action goals that should be used to interpret life cycle assessments, in lieu of quantifiable distance to target values. The virtue of these goals is that they take account of substance properties that play a particularly significant role for both impact categories (i.e. toxicity to humans and health) and hence can be used as guiding principles for the valuation process.

3. The irreversible input of persistent[20] and/or bioaccumulated[21] chemical substances (xenobiotics) is to be completely avoided, regardless of the toxicity of the substance concerned. The same holds true for metabolites that exhibit the aforementioned properties.
4. Inputs of carcinogenic or mutagenic substances, or of chemical substances that are toxic to reproduction, is to be completely avoided. The same holds true for metabolites that exhibit these properties.
5. Anthropogenic release of natural substances with persistent and/or bioaccumulated properties, or that are carcinogenic, mutagenic, or toxic for reproduction, are not to provoke an increase in geogenic or biogenic background pollution.
6. Anthropogenic inputs of toxic,[22] ecotoxic or (for that matter) natural substances not covered by any of the aforementioned categories is to be reduced to the absolute minimum that current technology[23] will allow. The same holds true for metabolites that exhibit these properties.

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[20] Refers to input whose scope of distribution precludes retrieval using a reasonable amount of resources (e.g. retrieval would necesssitate the use of undue amounts of energy) and within a reasonable timeframe.

[21] Persistent substances break down very slowly due to the fact that their biological or abiotic breakdown process is extremely lengthy, or the substance reaches its sink very slowly. From a compartment standpoint, persistence can be characterized in terms of its half-life, although mineralization gradients and the scope of bound residues should also be taken into account. Inasmuch as bioaccumulated substances are substantially enriched by the organisms (as compared to their concentration in the surrounding medium), the bioaccumulation process can be characterized by the relevant enrichment factors (e.g. BCF) and uptake and excretion properties.

[22] The differentiation of toxicological endpoints (i.e. determination of properties that are carcinogenic, mutagenic or toxic to reproduction) is currently a subject of controversy among scientists.

[23] The “metric” referred to here is meant to be a catalyst for steady advances in the relevant technical and scientific fields, and is not meant to be a fixed value, which in most settings cannot be achieved using currently available technology.

7. Any increase in the input of substances that are not amenable to retrieval owing to the scale of their distribution and/or their low interchange gradient is to be avoided, regardless of any known effects or other intrinsic[24] properties of the substances concerned.

1.2.2 Environmental noise impact

In view of the subjectivity inherent to environmental noise valuations, life cycle assessment studies should valuate the impact of environmental noise based on the anticipated adverse effects at the population group rather than the individual level. Environmental noise impact can vary according to the place and time of its occurrence, as well as the activity that is envisaged or realized. Particularly sensitive and/or vulnerable population groups such as children should be included in noise impact assessments if necessary, depending on the situation that is being analyzed. In carrying out quantitative assessments of noise emissions, the immision locations that fall within the scope of the criteria below should be defined.

Under normal circumstances, the following environmental quality objectives should be applied to noise impact assessments:

- Hearing damage can be avoided in most instances if the maximum noise level is 115 dB(A) or less and the 24-hour mean noise level is 70 dB(A) or less.
- In the interest of avoiding traffic noise induced cardiovascular disease, mean daytime noise levels outside residential buildings should not exceed 65 dB(A).
- Sleep disturbance can be avoided for the most part if mean bedroom noise levels are 30 dB(A) or less, subject to a maximum of 45 dB(A).
- As a rule, no substantial adverse effects will occur in dwellings where mean nocturnal noise level is less than 25 to 30 dB(A) and mean daytime noise level is less than 30 to 35 dB(A). These conditions are achieved with tipped-open windows and exterior nocturnal levels below 40 to 45 dB(A) and exterior daytime levels below 45 to 50 dB(A). Mean exterior daytime levels in excess of 50 to 55 dB(A) are increasingly associated with diminished quality of life. Studies have shown that the adverse effects associated with aircraft noise are more severe than for vehicular traffic noise, and that the effects associated with rail vehicle noise are less severe than for vehicular traffic noise. Various German laws[25] specify point source criteria which, if fulfilled, would prevent substantial amounts of noise pollution.

[24] Also referred to as inherent substance properties, which means properties all or most of which are determined by the substance itself and whose scope is not determined by the ecosystem in question

[25] The following German statutes are relevant in this regard:
Verkehrslärmschutzverordnung (16. BImSchV) for traffic noise
Sportanlagenlärmschutzverordnung (18. BImSchV) for sports stadium noise
For noise generated by manufacturing and commercial facilities: Technische Anleitung zum Schutz gegen Lärm (TA Lärm)

Comparisons with the aforementioned quality objectives should be realized according to type of source and in a manner that differentiates between the various locations affected and the various times at which pollution loads occur.

The number of persons affected is also a key ranking criterion. NOEC (no observed effect concentration) (e.g. 55 dB(A) for individuals who mainly do desk work at production facilities) pursuant to the statute entitled *Arbeitsstättenverordnung* can be used as a benchmark for assessing the impact of noise.

To assess the noise attributable to an individual specific product, the noise immissions characteristically generated by the product and the number of persons that could potentially be affected by the immissions are to be compared on a case by case basis.

In assessing transportation related noise emissions, it is crucial to bear in mind that transportation routes that are at a sufficient distance from areas that merit protection from noise pollution could potentially be disregarded

2. The “direct ecosystem damage” impact category

2.1 2.1. Classification principles for the “ecological severity” criterion

The present section addresses the issue of direct adverse effects on ecosystems. Unlike the procedure for all other impact categories (except for direct adverse effects on health) where the negative impact of the processes of interest constitutes a collateral (secondary) rather than a primary impact on the area of protection, in the following the primary impact on the area of protection will be described. Hence, by way of an introduction to this issue, we will briefly describe the classic ecotoxicological assessment procedure and the principles underlying it.

The biosphere is impinged upon by a host of anthropogenic factors such as energy, thermal, mechanical, acoustic, optical and chemical burdens, and incurs direct damage from ecosystem pollutant inputs. In order to assess the potential ecological damage attributable to pollutant input, the impact of the relevant substances on flora, fauna and microorganisms, as well as the consequent functional and structural changes in ecosystems, must be taken into account.

In view of the extreme complexity of ecosystems, in order to gain a complete picture of the threats to their viability, the effects of each substance of interest on all of the ecosystem’s species and abiotic factors must be assessed, together with the potential impact of any interactions that may occur between input substances. Under no circumstances is an impact assessment of only one substance on a species at one particular juncture ever sufficient. On the other hand, the kind of dynamic and comprehensive analysis that is in fact needed is ruled out by the inherent complexity of ecosystems. Therefore, impact assessments must be based on a broad spectrum of species whose ecological (trophic) functions and exposure path or paths are representative of the ecosystem as a whole.

The selected species are studied in terms of various end points, using standardized acute, long-term or chronic biotest procedures wherever possible. Individual-species tests are limited in terms of their applicability to an ecosystem as a whole, and researchers attempt to get around this problem by using ecosystem test systems. However, these systems are expensive and have certain deficiencies (replicability, representativeness, selection of suitable end points etc.). NOEC, LOEC, LC- and EC values[26] are generally extrapolated from exposure tests which, to put it reductively, describe the correlation between the concentration of a substance and the effects it provokes. Although such lab experiment-derived values constitute toxicological values that indicate the severity of the harm that might be incurred by aquatic or terrestrial organisms, they cannot be used as a basis for forecasting environmental impact. Various safety factors are incorporated into assessment models in an attempt to make up for the lack of data. However, a prognostic ecosystem model that would simulate all

[26] NOEC: No Observed Effect Concentration
LOEC: Lowest Observed Effect Concentration:
LC: Lethal Concentration
EC: Effect Concentration

environmental functions and structures is out of reach due to the vast numbers of naturally occurring plant and animal species that come into play, as well as the incalculable factor constellations of abiotic and biotic conditions, and anthropogenic influences. It is also fruitless to try to identify the most sensitive target organism, since the “most sensitive” response of any given organism will vary according to the substance it is exposed to. Hence the situation with respect to ecotoxic effects is far more diffuse than for impact categories such as acidification, global warming (only a limited number of gases comes into play), ozone depletion, eutrophication and so on. Whereas the number of substances that provoke effects and the number of receptors is virtually infinite.

The decisive factor for estimations of ecotoxicological burden using currently available techniques is which substance is emitted in which compartment (local, regional, global) during which life cycle. This means that PEC (predicted environmental concentration) values must be calculated in such a way that they can be related to the relevant PNEC (predicted no effect concentration) values. The extent to which the factors arrived at are uncertainty or certainty factors depends on the extent to which the data is complete or incomplete. In assessing ecotoxicological burden, for reasons of simplicity it is assumed that PEC/PNEC of less than 1 is relatively certain, although ecological risk cannot be completely ruled out either, for this type of calculation does not take into account the potential long term impact of persistent substances that are bioaccumulable or non-absorbable. Owing to their properties, such substances should be regarded as *per se* hazardous, even if the harmful effects provoked by their exposure concentrations are (as yet) unknown.

Ecotoxicological effects can be extremely severe (e.g. tributyl tin-containing antifouling agents that are applied underwater to ships’ hulls and which inhibit snail reproduction). They can also provoke problems at the local level (e.g. pesticides and biocides) or global level (PCB as a persistent organic chemical that is uptaken by human and animal fatty tissue). However, in most cases it is not possible to determine which substance from a specific emission provokes specific known effects, even if it is known with certainty that certain stretches of water, certain soil, or other media have high levels of chemical pollution, and effects can be detected in the relevant ecosystems. But in such cases, the observed effect is virtually always provoked by a series of chemicals. In occasional (best case) scenarios, it is possible, with a great deal of effort, to identify specific substances that are major contributors to toxicity.

Another area where reliable ectotoxicity prognoses are unobtainable concerns the reversibility of a specific effect, which raises this question: Does the ecosystem recover from the toxicological burden quickly, slowly, or not at all?

2.1.1 The “ecosystem functions and structures” area of protection

2.1.1.1 Mechanisms of action

The present section discusses ecosystem hazards that are provoked directly by toxic substances. In this domain, there are many different types of end points whose qualitative characteristics vary (or can vary) very widely.

Toxic substances can be roughly classified according to short/long term effects (with respect to the substance’s duration of action, or the duration of the disorder provoked by the substance), as well as end point. For the latter parameter, the following effects are analysed in LCA (among others): effects on key metabolic functions; organ damage; reduced fertility; fetal damage; genotixicty and mutagenicity (changes in the genetic material); hormone system pathologies; reduced life expectancy; impaired swarming behavior; neurotoxic effects; and directly lethal effects. The end points associated with these effects include the following: mild, acute, and life threatening pathologies in individual plants and animals; species shifts; reduced ability to survive in certain regions; worldwide extinction of certain species, and thus a loss of biodiversity.

The actual effects that occur are always determined by (a) the intrinsic toxicity (dose-effect relationship) of the substance concerned; (b) the location on or within the body on/through which the substance acts; and (c) the frequency and duration of action. Other factors that come into play are an organism’s or a population’s prior toxicological burden; background environmental pollution; and prior toxicity in the ecosystem itself. These factors determine which additional inputs will provoke harmful effects. The foregoing may not apply in cases where two or more substances act concurrently and their effect is aggregated, multiplied or potentiated. Relatively little is known about such scenarios. Another area of uncertainty (albeit one that applies to all impact categories) is that only known end points can be studied, taken into account and thus evaluated. Toughout history there have been effects that went unnoticed for a long time, a prime example of this in recent times being the endocrine effects of chemicals.

d) Aquatic ecosystems:

Aquatic ecosystems can be polluted by point source inputs (e.g. sewage lines, runoff from suspect areas/farms etc.) as well as by diffuse inputs (e.g. runoff from farmland/contaminated areas, precipitation, product elution etc.).

> To illustrate the kind of dynamic that is meant here, we will now describe an environmental disaster that occurred in 1986 at Basel, a riverside town in Switzerland downstream from the headwaters of the Rhine, involving a fire at the Sandoz chemical factory, one of the largest in Switzerland.27 As a result of the incident, extremely large amounts of extinguishing water mixed with various insecticides (Propethamphos, Disulfoton, Parathion, Fenitrothion and Oxadixyl) were discharged into the Rhine. This in turn provoked the extinction of the entire

[27] However, it should be borne in mind that such incidents do not fall within the scope of life cycle assessments, which only concern themselves with emissions resulting from “regular” production or usage scenarios.

eel population of the Upper Rhine (200,000 t), massive losses of trout and other aquatic species, as well as invertebrate species. Fish also died as much as 400 km from the input point, despite the fact that the concentrations of individual pesticides were far lower than the applicable LC50 values.28 This was probably attributable to the elevated toxicity resulting from the presence of mixtures of the various chemicals.

It is an indisputable fact that environmental disasters such as this harm the ecosystem. However, in less egregiously acute situations, in which, for example, “only” changes in species frequency are observed, it is virtually impossible to attribute specific ecological damage to specific emissions. And this in turn raises the issue as to the origin of the emissions and whether or not they are genuinely harmful for the species or ecosystem concerned, since (a) natural ecosystems are subject to constant change, and (b) many effects of pollution are observed long after the offending input has occurred, e.g. in cases where concentrations of a contaminant in the environmental medium are so low that they provoke chronic pathologies or cancer rather than sudden death, or they reduce the population by causing reproductive damage. Moreover, some substances such as the following accumulate in the food chain and do not provoke pathologies until reaching their endpoints:

DDT. DDT is an insecticide that renders the eggshells of insectivorous birds and birds of prey so brittle that the birds are unable to brood properly.

PCB and other halogenated carbons: These substances weaken the immune systems of aquatic mammals. For example, the increased seal mortality rate observed during a seal virus epidemic in the Kattegat-Sakagerrak area in 1988 and 1989 was undoubtedly the result of exposure to pollutants. The low gestation rate of Baltic Sea seals has also been attributed to exposure to halogenated carbons, since unusually high concentrations of these substances have been detected in seals with reproductive organ malformations.

e) Terrestrial ecosystems:

Terrestrial ecosystems can be damaged by inputs from the air, direct chemical inputs into the soil or groundwater (e.g. agrochemicals such as pesticides and fertilizer, percolation water, and waste dump gas emissions), as well as by sewage sludge or compost inputs. Direct product emissions also play a major role, particularly inputs from construction materials (stadium surfaces, ground sealing surfaces, and groundwater sealing injection systems). Soil contamination can also be caused by oil refineries, electroplating plants, chemical plants and many other types of industrial facilities.

A substantial portion of air pollutants are deposited on leaves, resulting in direct harm not only to the leaves, but also to leaf-dependent organisms that are susceptible to the various pollutants. Moreover, rainwater can transport the pollutants to the ground, thus harming ground-dwelling organisms as well as the animals that feed on them.

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[28] The concentration of a material that will kill 50 percent of the test subjects

Over time, the pollutants reach the soil structure, where they can damage soil organisms or can be transported to plant leaves via root uptake. The death and breakdown of the leaves re-inserts the pollutants in the soil, where in some cases they are leached out by groundwater. Non-biodegradable substances or substances that do not break down or break down very slowly may also remain in the ecosystem for lengthy periods.

2.1.1.2 Reversibility, irreversibility and duration

Broadly speaking, the acute symptoms of many end points tend to be more reversible than chronic effects. The non-reversible effects are those associated with reproduction toxicity, neurotoxicity, organ toxicity, cancer, and, of course, direct causes of death. It is often the case (although this is also somewhat of a generalization) that the effects of a substance become less reversible the longer they persist, assuming that the dose is sufficiently high.

The extent to which ecosystem damage is reversible depends on numerous factors. The question arises as to whether a pollutant is biodegradable (i.e. whether it can be broken down by naturally occurring elements in the ecosystem); mobile (i.e. it can be transported within the ecosystem); or bioavailable (i.e. whether the organisms in the ecosystem can uptake the substance; if they can, the substance can cause harm solely to the organisms that are farther down the food chain). In addition, the timeline of the effects (potential or otherwise) is determined by local pollutant concentrations, and by whether the substance is input continuously or discontinuously.

The extent to which such effects (potential or otherwise) are reversible (see above; correlation between duration of effect, concentrations, and substance combinations) or irreversible (e.g. complete disappearance of a species from an ecosystem, breakdown or complete transformation of ecosystems) depends on their scope.

The timeline for the manifestation of symptoms is determined by the end point that comes into play. As a rule, acute effects appear instantaneously or after a very brief “incubation” period, whereas chronic symptoms may appear after months or years of exposure.

2.1.1.3 Spatial extent

Spatial extent cannot be measured or assessed in terms of geographical regions, for what is involved (although here too it proves difficult to establish a direct relationship between a specific area of protection and a specific impact category) is the number of animal and plant individuals and species that are exposed to and harmed by a substance worldwide. And this in turn is determined by the regional localization, nature, quantity and distribution of the offending emissions. In the vast majority of cases, organisms living in the environment are exposed to emissions most directly by breathing them in, but can also be exposed via soil, water, or deposited substances that make their way into the food chain, or via water. In such cases, there may be substantial spatial differences between emissions and exposure.

2.2 Basis for determining distance to target

see section 1.2

3. The “aquatic eutrophication” impact category

3.1 Classification principles for the “ecological severity” criterion

3.1.1 The “ecosystem functions and structures” area of protection

3.1.1.1 Mechanisms of action

Primary effect

Elevated concentrations of the eutrophying pollutants phosphorus and nitrogen provoke excessive propagation of plankton algae and/or higher-order aquatic plants. The overabundance of plant biomass resulting from this process can be used by primary consumers to a very limited extent and breaks down microbially after death via oxygen consumption.

Phosphorus is a growth-limiting factor in most inland waterbodies, whereas nitrogen has this effect in the Baltic Sea and central North Sea. Although nitrogen limitation can also occur in inland waterbodies during the midsummer months, its effect is neutralized by atmospheric nitrogen-fixating plankton algae.

Secondary effects

Waterbody overfertilization provokes the following uncoupling process in aquatic substance flows: Although nutrients and the biomass produced thereby can be used optimally by fauna and flora in waterbodies when nutrient supplies are low, under overfertilization conditions biomass and nutrients sink to lakebottoms where they are broken down by oxygen depletion.

As a result, broad areas of deoxygenated lakebottom are no longer suitable habitats for higher organisms, and this in turn can lead to massive fish death. Moreover, elevated pH values resulting from overfertilization, in combination with elevated ammonium concentrations resulting from biomass breakdown can provoke the formation of fish-toxic ammonium, culminating in reduced species diversity. A minute number of plankton or individual dominant plankton species proliferates massively. The water turbidity engendered by plankton algae leads to the disappearance of underwater vegetation, while persistent eutrophication promotes the development of marsh plant communities. This in turn destroys habitats that are particularly important for the early stage development of fish, insect larvae and multitudinous other organisms. In addition to this species and structural depletion of waterbodies, nutrient-rich sediment can be whirled up from vegetation-free shallows, thus resulting in the release of additional nutrients.

Overabundant nutrients in flowing waterbodies are not retained in the water but are transported to the sea, engendering eutrophication in coastal areas.

The outward manifestations of this eutrophication are similar to those observed in lakes (depending on flow rate), but have a less serious impact on the water itself, since the constant oxygenation engendered by the water flow mitigates the effects of oxygen depletion and reduces nutrient deposits in sediment.

3.1.1.2 Reversibility, irreversibility and duration

Aquatic ecosystems have varying nutrient buffering capacities and mechanisms that allow nutrients to be input without engendering any substantial visible changes in the ecosystem structure. However, if this buffering capacity is overtaxed, a chain of events known as rapid eutrophication is set in motion (particularly in lakes) that leads to persistent nutrient release from the ecosystem, even if inputs cease. These types of positive feedback mechanisms, particularly in lakes and slow-flowing waters, are: the release of nutrients from anoxic sediment that were bound to the (formerly) oxic sediment in the earlier eutrophication phase, and overfertilization-driven changes in and the destruction of nutrient binding biotic structures such as riverbank and underwater vegetation.

Hence in most lakes this eutrophication process can at best be reversed in the long term. Although attempts are made (after eliminating external nutrient input) to suppress this “internal fertilization” process from the lake sediment through various restoration measures (desludging, sediment treatment, deep-water aeration), sustainable lake rehabilitation without the persistent use of external measures and energy (e.g. for deep water aeration and dephospating) can oftentimes only be achieved in deep waterbodies or those with high flow-through.

The visible effects of eutrophication in flowing waterbodies and lakes with high flow-through rates can be reversed with varying degrees of rapidity (after external nutrient inputs have been eliminated), depending on waterbody type. This process can take anywhere from several years to several decades, depending on internal nutrient load and water exchange time. However, inasmuch as in such cases the nutrients are transported to the sea, this process merely shifts the eutrophication to coastal waters.

3.1.1.3 Spatial extent

Eutrophication of inland waterbodies is a problem in virtually all densely populated industrialized countries. Although in recent decades, flowing waterbody pollution engendered by phosphorus and putrefying organic substances has been substantially reduced in Germany through the expanded use of sewage treatment technologies, water eutrophication remains a virtually omnipresent problem. Phosphorus inputs into Germany’s inland waterbodies are currently some ten times higher than natural phosphorus inputs. Nitrogen input whose eutrophying effects are mainly observed in coastal areas and are chiefly ascribable to farming, has scarcely been reduced at all. The nutrient retention capacity of German waterbodies has been drastically diminished and eutrophication greatly exacerbated by the virtual omnipresence of engineering structures in flowing waterbodies in Germany.

3.1.2 The “human health” area of protection

3.1.2.1 Mechanism of action

Massive propagation of phytoplankton algae can lead to health problems for bathers and via drinking water. During the summer, lakes often have an algal bloom that releases toxins that can provoke allergic or even toxic reactions in bathers. Blue algae toxins also occur in drinking water.

The propagation of coli bacteria associated with eutrophication also increases microbial pressure in waterbodies.

Water purification for the whole gamut of human uses (drinking water, process water and irrigation water) is becoming increasingly complex and costly owing to elevated organic substance concentrations.

The rising rate of groundwater nitrate pollution in Germany also poses a human health hazard.

3.1.2.2 Reversibility, irreversibility and duration

With respect to the reversibility of effects on human health, see section 1.1.1.2. As for the human health hazard posed by blue algae toxins via skin contact or drinking water, research in this area is still in its infancy. However, it is suspected that these toxins provoke both acute and subacute effects.

3.1.2.3 Spatial extent

Blue-green algal bloom occurs in virtually all heavily eutrophic waterbodies in these latitudes during the summer. More than 40 percent of Germany’s bathing waters currently fail the one meter depth of visibility threshold for bathing water mandated by the relevant EU directive. This high level of turbidity during the summer months is mainly attributable to blue-green algal bloom. Although toxins are released only by certain blue algae species and under certain conditions, the exact circumstances and conditions involved have yet to be fully described. Toxic effects attributable to blue algae have been reported worldwide.

3.2 Basis for ranking distance to target

According to a Federal Environmental Agency study on the effects and quality objectives of nutrients in flowing waterbodies, the following targets should be adhered to for above-ground flowing waterbodies:

	Quality objective	Area of protection
Nitrate (NO_3)	25 mg/l NO_3 (= 5.7 mg NO_3-N/l)	Drinking water
Ammonium (NH_4)	0.4 mg/ NH_4 for carp waterbodies 0.2 mg/l NH_4 for trout waterbodies	aquatic communities
Phosphorus	0.15 - 0.20 mg/l total phosphorus 0.05 - 0.10 mg/l total phosphorus as an additional target	aquatic communities (protection against eutrophication)

Using these recommendations as a starting point, the International Commission for the Protection of the Rhine has defined a target of 0.15 mg/l total phosphorus and 0.20 mg/l NH4-N (= 0.26 mg/l NH4) total ammonium for the Rhine.

The seven-level LAWA assessment scale defines the following nutrient concentration quality target for level 3 (quality class II):

	Quality target (quality class II)
Nitrogen	≤ 3.0 mg total nitrogen/l
Ammonium	≤ 0.3 mg/l NH_4-N
Phosphorus	≤ 0.15 mg/l total phosphorus

In 1996, these targets were exceeded for German rivers at the following percentages of LAWA's 151 monitoring sites in Germany:

- Total phosphorus: 82 %
- Ammonium: 8 %
- Total nitrogen: 86 %

(based on the 90th percentile, i.e. a target is deemed to have been exceeded at a monitoring site if 10 % of all readings exceed the target threshold.)

For lakes as well, in order to avoid the negative effects of eutrophication, the following compliance with the considerably lower concentrations should be achieved:

- Shallow lakes: 0.04-0.06 mg P/l total phosphorus;
- deep lakes: 0.01-0.02 mg P/l total phosphorus.

4. The “terrestrial eutrophication” impact category

4.1 Classification principles for the “ecological severity” criterion

4.1.1 The “ecosystem functions and structures” area of protection

4.1.1.1 Mechanisms of action

After being transported over long distances, gaseous nitrogen and ammonium emissions and the reaction products thereof (NOx and ammonium) are input into terrestrial and aquatic ecosystems. Anthropogenic nitrogen inputs pose a major ecological threat due to the fact that only minute amounts of nitrogen occur in semi-natural material cycles. Hence terrestrial ecosystems have for the most part adapted to conditions that make useable nitrogen one of the limiting factors in such cycles. Scenarios where organically bound nitrogen exceeds the total requirements of all consumption processes are referred to as eutrophication (i.e. nitrogen oversaturation of the system). Nitrogen poses a greater threat to terrestrial ecosystems than any other nutrient.

All nitrogen is input into forests and other semi-natural ecosystems via the atmosphere. The initial response of vegetation to elevated nitrogen input is rapid growth. However, the more persistent the nitrogen oversaturation in an ecosystem, the greater the risk of nutrient imbalances, since elevated primary growth translates directly into an increased need for other nutrients that are indispensable for survival. If this need for additional nutrients goes unmet, the nutrient balance in the plants can become so deranged that a permanent or periodic nutrient deficiency ultimately sets in.

Forest biological water balances can also exhibit nutrient deficiencies owing to excessive nitrogen input, since the supplementary growth catalyzed by elevated nitrogen input increases the trees’ need for minerals and water. At the same time eutrophication tends to increase the density of ground cover, whose water consumption then rises. This competition provokes early drought stress.

Increased nitrogen supply has numerous other physiological effects on plants, including reduced frost hardiness and heightened susceptibility to infestations of certain pests.

Eutrophication also alters vegetation species composition in forests, moors, heaths and neglected grasslands. Plants that thrive on nitrogen propagate, displacing species that need low nutrient conditions to survive. This results in species loss and homogenization of vegetation types. The shift in flora and fauna species diversity that has been documented in Germany in recent decades is driven not only by drainage measures, but also – and especially – by eutrophication. Inasmuch as approximately 80% of endangered plant species occur almost exclusively at low nitrogen locations, nitrogen input plays a pivotal role in the decline of these rare species.

Competition between young trees and plants that thrive on nitrogen can impair forest regeneration processes. There is also abundant evidence that elevated nitrogen levels inhibit mycorrihiza[29] formation, have an adverse effect on the population density and species diversity of soil organisms, and substantially impair soil habitat functions in general.

Increased nitrogen input also provokes long term soil acidification, which mainly results from atmospheric nitrogen input (see section 10). The acidification driven leaching out of other nutrients can also exacerbate the aforementioned soil nutrient imbalances.

4.1.1.2 Reversibility, irreversibility and duration

Most of the physiological effects described above, as well as elevated susceptibility to pests, can be reversed within a matter of years.

Soil nutrient imbalances induced by nitrogen input are reversible in the medium term, provided that supplementary nutrients such as calcium, magnesium and potassium are input via surface disintegration and/or atmospheric deposition. Although many semi-natural ecosystems are able to amass considerable amounts of nitrogen in organic soil substances and biomass, this storage capacity is limited owing to the fact that following an accumulation phase, nitrogen saturated systems usually release their excess nitrogen into the atmosphere and groundwater as pollutants. Thus the soil itself is transformed into a persistent nitrogen point source.

Changes in biological water balances, particularly those in forest ecosystems, can be reversed in the medium to long term, although this is far from certain owing to the multifaceted ecological interactions that come into play.

Eutrophication induced loss of plant species that depend on low nitrogen habitats is irreversible.

Critical loads (ecosystem specific threshold values for a substance’s input rates) for eutrophying nitrogen have been defined in such a way that the persistent and long term export and immobilization rate is not exceeded (state of equilibrium).

The amount of time that elapses between nitrogen inputs and eutrophication varies from several years to many decades, depending on input levels and ecosystem characteristics.

4.1.1.3 Spatial extent

Anthropogenic eutrophication of terrestrial ecosystems is a phenomenon of both national and international scope. Hence the problem cannot be studied from the German perspective alone, since some of Germany’s nitrogen emissions are transported beyond the country’s borders and vice versa. This applies in particular

[29] A fungus that is essential for tree survival and that forms a symbiotic relationship with the plant roots

to nitrogen, but holds true for ammonium to only a limited degree, since most emissions of this substance are deposited near their point sources. However Germany’s “exports” exceed its “imports.” Hence eutrophication should be analyzed from a European perspective.

Although the spatial extent of eutrophication is both regional and continental, the actual effect of eutrophication in terms of critical load-deposition relation varies considerably from a spatial standpoint. Some regions, such as those with high ammonium emissions and intensive stock-rearing, suffer from massively excessive critical loads of nitrogen, whereas other regions are free of eutrophication and have long term nitrogen input levels that are within tolerable limits.

4.1.2 The “human health” area of protection

Human health is affected only indirectly by eutrophication in that the phenomenon results in elevated groundwater nitrate levels over the long term.

4.2 Basis for determining distance to target

The standard international parameter for the damage potential of eutrophying nitrogen inputs in terrestrial ecosystems is defined as a situation where the critical load[30] is exceeded by current, annual nitrogen input.

The main obstacle to quantifying distance to target lies in the substantial spatial variability and susceptibility (critical load) that come into play, as well as the deposition factor (see above). The target used in the present study is that recommended by the UN ECE Convention on Long-Range Transboundary Air Pollution – namely 95th percentile critical load exceedance (i.e. damage potential, see above).

The damage potential for Europe is quantified using the formula “deposition minus critical load,” where the unit of this critical load exceedance is kg/nitrogen/ha/year. However, this formula is unsuitable, since distance to target is used to rank various impact categories and thus a dimensionless variable is needed. In our view (contrary to the ECE approach), such a variable can be obtained using deposition and critical load quotients rather than the difference between deposition and critical load as a basis.

Critical loads for eutrophying nitrogen are currently exceeded in virtually every susceptible ecosystem (forests, moors, heaths and neglected grasslands) in Germany. The quotient “deposition (1993)/critical load” for susceptible ecosystems is below 1 just about nowhere in Germany, i.e. virtually all such areas suffer from long term eutrophication and deposition exceeds critical load in almost the entire area, in 5 percent of such areas by more than 450 percent. This situation is not likely to change much in the near future, which means that eutrophication will continue apace in virtually all susceptible areas.

[30] ecosystem specific contaminant input thresholds

5. The “land use” impact category

5.1 Classification principles for the “ecological severity” criterion

5.1.1 The “ecosystem functions and structures” area of protection

5.1.1.1 Mechanisms of action

Primary effects

Land use change destroys suitable flora and fauna habitats and thus result in an absolute loss of genetic diversity, and the loss of species, ecosystems, and natural functional relationships, at least in redesignated areas. The populations affected then die out; and if no alternative areas are available and the species concerned is already endangered, or if it and its ecosystem are naturally rare, the species can become extinct altogether.

Depending on the nature and scope of agricultural activities in such areas, this process can also result in the intentional or adventitious introduction of alien species or genetically modified organisms. The ensuing species competition can result in the displacement of existing species, thus altering species composition. The new species can also act on material cycles (water, nutrients, oxygen production) and bring about changes in them. Physical changes in the abiotic environment such as soil compaction may also occur.

In addition, direct removal of certain wild species through hunting, fishing and clearing can lead to changes in ecosystem species composition, and as mentioned above can impinge upon ecosystem functions.

Land use change also affects the quality and quantity of water, soil and air in and around the areas concerned, whereby the alteration in ecological quality varies according to the nature and scope of land use. Thus this phenomenon cannot be described in general terms here. The nature of the ground cover, soil structure, and soil processes affect the functions of environmental media as follows: (a) for soil: soil habitat functions (see above), regulation functions (filter, buffer and transformation functions) and production functions; (b) for water: groundwater recharge, water availability, water retention capacity/runoff; and (c) for air: climate in particular (microclimates, the global climate, and everything in between).

Changes in land use (particularly the linear variety) fragments the functional interactions of ecosystems to varying degrees, depending on the scope and extent of such change.

Hence, the more extensive the intervention in the environment, the greater the loss of ecosystem self regulation capacity. In extreme cases, this capacity can be completely destroyed.

Secondary effects

As the result of the disappearance of certain species and ecosystems and the alteration in abiotic environmental quality engendered by land use changes, species composition changes and other types of ecosystems evolve, insofar as the surface is not sealed.

These changes in the biological components of an ecosystem and in the environmental quality of the areas being used can result in changes in ecosystem functions in the primary area (i.e. the area directly affected) as well as in areas whose functions interact with those of the primary area. This in turn can derange natural control mechanisms such as the water, carbon and nitrogen cycles, which regulate the ecosphere and form the basis for life on earth.

If landscape fragmentation is so extreme that biotopes are cut off from each other, the affected species and biotopes may ultimately die out, and the scope of genetic variation is reduced within individual populations, whose size falls below the minimum for their habitat. This evolution fosters inbreeding, which as a rule reduces species and ecosystem fitness, thus inducing species extinction and alterations in ecosystem typologies.

Genetic diversity enables biological systems to adapt to evolution-driven changes in environmental conditions. The loss of genetic diversity reduces this capacity, and this in turn can lead to population and/or species extinction in the face of climate or other environmental changes. This also holds true for species loss. If a species plays a pivotal role in an ecosystem, its extinction induces change in the system.

Altered topographic relief provokes local climate change.

Changes in vegetation and soil structure impinge upon biological water balance functions as well as compaction and erosion processes.

5.1.1.2 Reversibility, irreversibility and duration

The effects on an area persist for as long as it remains in use. The extent to which ecological restoration can be achieved depends on the type of ecosystem involved, its baseline status, and the scope of the impingement on the system. The development periods for various types of biotopes are listed in table 1. However, the fundamental precondition for restoration is the presence or, insofar as possible, creation of abiotic environmental conditions that foster the biotope development.

Table 1: 5-1: Development periods for various types of biotopes

Age-class ranking	Development period	Examples
I	Less than 5 years	ephemeral ruderal communities; wild herbaceous plant communities (in fields); pioneer stage sandy lawns (grey hairgrass communities); coppice communities; dwarf-rush communities
II	5-25 years	species-poor pastures and tall herb communities; perennial ruderal communities; seam communities; vegetation in eutrophic waterbodies; species-poor oligotrophic grasslands; dispersed rock-plant communities; ruderal bushes and pioneer crops
III	25 -50 years	older (but still relatively undifferentiated) hedges and bushes; oligotrophic silting vegetation; relatively species-poor sedge reed communities; pastures; semi-arid grasses; moors
IV	50-200 years	relatively species-rich vegetation in and around forests, bushes and hedges
V	200-1000 years	Low and transitional moors (secondary growth in floodplains and ponds); old and highly differentiated moors and dry grasses
VI	1000-10,000 years	High moors; low moors with measurable peat depth; forests with old ground profiles

Source: D. Bastian, K. Schreiber: Analyse und ökologische Bewertung der Landschaft, Jena/Stuttgart 1994

Uncontrolled propagation of foreign species and genetically modified organisms is difficult if not impossible to reverse (e.g. introduction of zebra mussels).

Attempts to reintroduce species that have died out often fail, or meet with very limited success in cases where the extinct species had developed a new, no longer existent genotype that was adapted for their specific region.

Although the loss of natural genetic combinations is irreversible, new combinations evolve if the population increases. The worldwide extinction of a species is irreversible.

Changes in soil quality and biological water balance may be either reversible, in which case the baseline status restoration period is determined by the nature and extent of land use; or irreversible (e.g. the altered soil granularity resulting from the refilling of depleted mines necessitates aquifer re-formation, and modifies topographic relief owing to deficient earth mass).

Irreversible change in specific ecosystem elements does not necessarily entail transborder alterations in the control mechanisms that regulate the ecosphere if, for example, redundant species take over the functions of lost species or if a new biological water balance can be established. However, the effects of certain activities such as rainforest clearing and pastureland transformation are irreversible in the absence of replacement mechanisms.

As a rule, the aforementioned primary effects occur immediately, with the exception of the effects of introducing non-indigenous species or removing native species. Population breakdown resulting from reduced and deficient genetic diversity in cases of underpopulation and fragmentation is subject to a time lag whose length is determined by species regeneration time, among other things. Ecosystem transformation attributable to the extinction of key species is likewise a delayed process, as is the impact such mechanisms may have on the ecosphere via the nitrogen and carbon cycles.

5.1.1.3 Spatial extent

The aforementioned effects can occur locally, regionally (e.g. in specific drainage areas or biotope networks) or even globally (e.g. tropical rainforests transitioning to pastures and the consequent climate change; worldwide species extinction), depending on the nature and extent of land use change and the physical location of functions in the ecosystems.

5.1.2 The “human health” area of protection

5.1.2.1 Mechanisms of action

Land use change does not pose a direct threat to human health. However, if “health” is also taken to mean a sense of well being, then land use change could potentially be a contributing factor in the development of psychological strain if open space is at a premium.

Land use change can also reduce natural resource availability to unacceptably low levels, e.g. drinking water or land suitable for food production, particularly at the local and regional level.

5.1.2.2 Reversibility, irreversibility and duration

The aforementioned effects on human health (in the broadest sense of the term) can generally be reversed via revitalization measures; the amount of time required to implement them is determined by the prevailing abiotic and biotic conditions. Although such measures will probably not pose a major problem at the European level, this may not be the case in very densely populated areas and areas subject to severe erosion (e.g. Haiti and certain parts of Africa) resulting from soil compaction or improper farming practices. In such situations, re-greening and obtaining adequate water and food supplies are an extremely daunting proposition.

These effects are subject to a time lag.

5.1.2.3 Spatial extent

The aforementioned effects tend to be local and in the worst case scenario regional (supply and drainage areas). In view of the fact that 800 million persons currently suffer from hunger (FAO, 1996), this situation also has an impact on the development policies of industrialized countries.

5.1.3 The "resources" area of protection

Land use is currently one of the main drivers of habitat extirpation and thus of biodiversity loss, and particularly the irreversible disappearance of genetic resources. Although only a minute proportion of the available species are currently used for practical applications, such use is likely to increase sharply as the result of advances in the field of biotechnology. This applies in particular to the pharmaceutical and food production industries, and environmental technology. Among the key issues addressed by the Convention on Biological Diversity are species protection, sustainable use of genetic resources, and fair distribution of the benefits resulting from the use of such resources.

Far too little information has been gathered with respect to the earth's biodiversity, when one stops to consider that somewhere between 5 and 30 million species are thought to be in existence, and only 1.4 million of them have been described (WBGU, 1994, UNEP, 1995[31]).

Unless we completely restructure our economies and business practices, some 1.5 million species will probably be wiped out over the next 25 years and their genes and ecosystems will be irretrievably lost (WBGU, 1994). This in turn would mean that genetic combinations that would otherwise be of major significance for future generations will be consigned to oblivion.

The range of effects (and thus ecological threats that can potentially be engendered by land use) is extremely broad, but depends on the scope of the activities involved. In cases where data on the extent of the activities concerned is available, it is permissible to deviate from the generally applicable ecological severity ranking. In such cases, the naturalness class method should be applied (also see the discussion on distance to target in 5.2), as was done, for example, in the Federal Environmental Agency's *Ökobilanzen für graphische Papiere*[32].

[31] WBGU: Welt im Wandel - Grundstruktur globaler Mensch-Umwelt-Beziehungen, Bonn 1994; UNEP: Global Biodiversity Assessment, Cambridge 1995.

[32] Umweltbundesamt, Ökobilanzen für graphische Papiere, Texte 22/00, Berlin 2000

5.2 Basis for determining distance to target

Spatially independent distance to target:

According to the 1992 Convention on Biological Diversity, the goal here is to preserve biodiversity, which is defined in the Convention as the variability of a living organism of any origin, and includes intra-species, inter-species and ecosystem diversity.

Achievement of this goal should be seen in light of the fact that the anthropogenic species extinction rate is currently 10,000 times higher than natural species extinction.

Regional distance to target factors in Germany

The following additional targets have been defined for Germany:

- reversal of negative trends that affect endangered plant/animal species and ecosystems
- the creation of a network of ecologically significant areas, 15 percent of which are to consist of non-inhabited zones,[33] in view of the fact that habitat loss poses the greatest threat to biodiversity.

However, it has not yet been scientifically proven that setting aside these additional areas will allow for the preservation of Germany’s biodiversity. Moreover, the quality of these zones, their localization, and the environmental quality of the areas surrounding them are all key factors. Hence merely knowing the size of these areas does not help to achieve the goal of protecting biodiversity, and underscores the difficulty of valuation as an element of non-territory specific life cycle assessments.

In terms of the currently defined targets, it is noteworthy that the list of endangered plant/animal species and ecosystems is growing ever longer. Only about 7 percent of Germany’s territory is currently designated as priority nature protection areas, i.e. nature preserves, national parks, biosphere reserves and natural forest reserves (1997 environmental data[34]).

The two most decisive ecosystem impact factors are the amount of land and the intensity of the activity involved. In the interest of developing an assessment tool for these factors, the Federal Environmental Agency has elaborated a life cycle assessment methodology, that, though initially intended for LCA on graphic paper, can be applied to other life cycle assessments as well.[35] This tool will now be

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[33] German federal government: Auf dem Weg zu einer nachhaltigen Entwicklung in Deutschland, Bericht der Bundesregierung anläßlich der VN-Sondergeneralversammlung über Umwelt und Entwicklung 1997 in New York, Bonn 1997

[34] UBA: Daten zur Umwelt - Der Zustand der Umwelt in Deutschland, Ausgabe 1997, Berlin 1997

[35] Jürgen Giegrich, Knut Sturm: *Naturraumbeanspruchung waldbaulicher Aktivitäten als Wirkungskategorie für Ökobilanzen*, interim report on the Federal Environmental Agency’s

described briefly, since its methodology and terminology are applied to the system described below.

Our life cycle assessment tool (hereinafter referred to as the FEA “Naturalness Class Method”) centers around the quantification of land use on the basis of nature-related “measurement units.” These units allow all land areas to be placed in one of seven naturalness classes, which are arranged on a scale of I to VII, with I being the best and VII the worst, i.e. the higher the number, the greater the distance between the area’s current status and an intact ecosystem devoid of land use.

These naturalness classes reflect the extent of human intervention in natural ecosystem processes and how close the areas still are to having a natural status following use.

Table 5-2: Proposed characterization of the seven naturalness classes for land use quantification.

Naturalness class	**Type of use**
Class I	No use for a lengthy period of time, ecosystem intact (e.g. wilderness areas)
Class II	close-to-nature forestry practices
Class III	relatively close-to-nature forestry and agricultural practices
Class IV	semi-natural forestry and agricultural practices
Class V	ecologically relatively unsound forestry and agricultural practices
Class VI	ecologically unsound agricultural practices, extensive farming
Class VII	degraded area or area that has been sealed for a lengthy period

Source: Jürgen Giegrich, Knut Sturm: Naturraumbeanspruchung waldbaulicher Aktivitäten als Wirkungskategorie für Ökobilanzen, interim report on the Federal Environmental Agency’s research project Ökologischer Vergleich graphischer Papiere (FKZ 10350120),
Heidelberg, March 1999

The FEA Naturalness Class Method was developed mainly with forestry uses in Central Europe and the boreal zone in mind.

Distance to target use case for forestry exploitation

Concrete forest related targets have been defined in Germany at both the federal and state levels (at the latter level via the organization known as Länderarbeitsgemeinschaft Naturschutz36 (LANA)). These targets are differentiated according to whether they concern exploited or non-exploited forests.

research project *Ökologischer Vergleich graphischer Papiere* (FKZ 10350120), Heidelberg, March 1999

[36] Nature Conservation Alliance of German states

f) *Forests subject to managed use*

Current status

30 percent of Germany's territory is accounted for by forested areas, many of which are subject to extensive pressures from both natural and anthropogenic sources. Close-to-nature forestry management makes a major contribution to the preservation of biodiversity and other forest ecosystem functions.[37]

For life cycle assessment purposes, land use associated with forestry management can be placed in naturalness classes II through V, whose current percentage distribution in Germany is shown in the following table:

Table 5-3: Land use status of managed forests in Germany as reflected by the percentage distribution of naturalness classes II through V

Land use	Current situation according to percentage of total forested area
Class II	5
Class III	50
Class IV	30
Class V	10

The following should be noted:

- percent of Germany's forests currently have class I status (wilderness areas)
- Classes VI and VII do not apply to forested areas
- Source: Jürgen Giegrich, Knut Sturm: Naturraumbeanspruchung waldbaulicher Aktivitäten als Wirkungskategorie für Ökobilanzen, interim report on the Federal Environmental Agency's research project Ökologischer Vergleich graphischer Papiere (FKZ 10350120), Heidelberg, March 1999
- Total forestal area in Germany as at 1993: 10.42 million hectares

Target status

The target is achievement of close-to-nature forestry management for all managed forest areas.[38] It follows from applying this target to the life cycle assessment method that in the coming years all of Germany's managed forests should be assigned class II (i.e. close-to-nature) forests.

g) *Wilderness areas and non-exploited forested areas*

Current status:

For various reasons, five percent of Germany's forestal areas are not subject to managed use. According to the life cycle assessment method, these wilderness areas are categorized as naturalness class I areas.[39]

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[37] German Federal Government: *Auf dem Weg zu einer nachhaltigen Entwicklung in Deutschland, Bericht der Bundesregierung anläßlich der VN-Sondergeneralversammlung über Umwelt und Entwicklung 1997 in New York*, Bonn 1997

[38]) ibid.

[39]) Jürgen Giegrich, Knut Sturm: *Naturraumbeanspruchung waldbaulicher Aktivitäten als Wirkungskategorie für Ökobilanzen*, interim report on the Federal Environmental Agency's

Target status

The number and territorial scope of wilderness areas should be increased. Toward this end, in 1992 in a policy paper (*Lübecker Grundsätze)*, the Länderarbeitsgemeinschaft Naturschutz[40] stated that 5-10 percent of forestal areas should be or become wilderness areas.[41]

A method similar to that described above could potentially be elaborated for other types of land use such as agriculture and surface sealing.

research project *Ökologischer Vergleich graphischer Papiere* (FKZ 10350120), Heidelberg, March 1999

[40] Nature Conservation Alliance of German states

[41]) Bundesamt für Naturschutz: *Erhalt der biologischen Vielfalt, Wissenschaftliche Analyse deutscher Beiträge*, Bonn, 1997, p. 237

6. “Photochemical oxidant formation/summer smog” impact category

6.1 Classification principles for the “ecological severity” criterion

6.1.1 The “ecosystem functions and structures” area of protection

6.1.1.1 Mechanisms of action

Summer smog is a type of air pollution that is characterized by elevated concentrations of ozone, PAN, hydrogen peroxide, aldehyde, ketone and other photoxidants. Inasmuch as ozone is the main factor here in terms of concentration and effect, in the following we will focus on this aspect of summer smog only. The elevated ozone levels that have the largest environmental impact on Central Europe are for the most part attributable to traffic, industrial activities, power plants, and the residential sector in Europe and Asia (i.e. the Northern Hemisphere).

High ozone levels in Central Europe have an adverse effect on vegetation. The primary effects of ozone are attributable to stoma ozone uptake, which damages cell functions owing to increased oxidation capacity and the formation of free radicals. The outward manifestations of these pathologies include premature aging, reduced vitality, and heightened susceptibility to biotic and abiotic stress factors. Ozone uptake often slows root growth rates relative to those of the above ground plant elements.

The main secondary effects of ozone absorption include changes in species diversity and composition (e.g. primarily observed in broadleaved trees), as well as reduced crop yields, e.g. for rye, wheat, oats, barley, clover, potatoes, wine grapes, melon, and tobacco.[42] These secondary impacts are heightened by the effects of global warming, which the increase in trophospheric ozone also greatly exacerbates since this substance is one of the main greenhouse gases.

6.1.1.2 Reversibility, irreversibility and duration

The AOT40 value[43]also allows for assessments of the acute adverse effects of various peak concentrations and of the chronic effects of persistent, slightly elevated ozone levels – although the results are mainly based on laboratory investigations. In contrast to the results obtained in chamber tests, no “acute” ozone effects have been found in field observations. Instead, the threat appears to consist in “chronic” long term ozone uptake by susceptible vegetation, particularly

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[42] For example, more than two-thirds of the estimated 5 percent crop loss in The Netherlands is attributable to ozone uptake.

[43] AOT40 = accumulated exposure over a threshold of 40 ppb ozone, which is the threshold (critical) level for ozone effects on vegetation. This value is calculated as the sum total of the excessive average hourly concentrations of O3 above 40ppb in the bright hours of the day throughout the whole vegetation period.

in mountainous areas where elevated ozone layers have been detected. However, the possibility cannot be ruled out that tree species in the higher reaches of low mountain regions or the Alps have adapted to exposure to higher background concentrations of photooxidants.

The extent to which the adverse effects of ozone on flora might be reversible and how long the process of restoring baseline status would take are still unanswered questions. The issue of long term changes in ozone levels is further complicated by the fact that the high ozone levels observed in the Northern Hemisphere today relative to those in the 19th century are the result of a very gradual increase. This means that the adverse effects on vegetation have also occurred incrementally, and may no longer be readily detectable by virtue of the flora having adapted to rising ozone levels.

The ozone damage incurred by one-year crop plants during their growth period is irreversible, i.e. the damage is not reversed to baseline status by the time the crops are harvested. This means that the ozone effects on crop plants are irreversible for a minimum of 12 months. On the other hand, no ozone damage is likely to occur in the subsequent year and the same plant if the critical levels (i.e. AOT40, see note 43) are not exceeded, inasmuch as the soil properties will probably not be substantially altered by ozone absorption (in contrast to the impact of acid and certain other inputs).

Ozone damage sustained by annual crop plants persists throughout the vegetation period, until the fall harvest; but the succeeding generation in the following year is not affected, providing that the critical levels are not exceeded again. Ozone effects on up to 100 year old forest trees are probably delayed, although the damage incurred by the generation concerned is at least partially irreversible. Here too, the succeeding generations are unlikely to suffer any adverse effects if critical levels are not exceeded again.

6.1.1.3 Spatial extent

The spatial extent of the areas with critical level exceedance in respect to plant pathology during growth periods (April through September) is the entire Northern Hemisphere between the 30th and 60th parallels. The considerable increase in NOx, volatile organic carbon (VOC), carbon monoxide, and methane emissions in the industrialized nations of Europe, North America and Asia have resulted in an approximately 200 percent rise in background ozone concentrations since the mid 19th century.

Northern Hemisphere background ozone concentrations during the growth period range from approximately 65 to 80 $\mu g/m^3$ (microgram per cubic meter of air), but are only about half this amount in the Southern Hemisphere (30th to 60th parallels). The lower ozone levels in the Southern Hemisphere do not reduce Northern Hemisphere levels due to the fact that the tropospheric dwell time of ozone is shorter than the characteristic several year long mixing times between the two hemispheres over the inner tropical convergence zone (ITC).

Although the spatial extent of summer smog ranges from regional (continental) to global (Northern Hemisphere), the relationship between current ozone concentrations and critical level values varies greatly from a geographical standpoint. Particularly high critical level exceedances are observed in the densely populated regions of Europe, North America and probably Asia.

6.1.2 The “human health” area of protection

6.1.2.1 Mechanisms of action

The observations in the present section apply to ozone, since it is the predominant Central European photooxidant in terms of concentrations and effects.

The biological effect of ozone is mainly characterized by extreme reactivity. The substance mainly acts on the “site of action” itself, i.e. the surfaces of the respiratory tract. Due to ozone’s extremely low water solubility, it is able to invade the lungs, where it attacks tissues that are not protected by mucosa. This can provoke cell membrane changes that are associated with inflammatory processes.

It is presumed that approximately 10-15 percent of the general population (irrespective of population group) is highly susceptible to ozone induced pathologies. The severity of these pathologies is determined by the dose ingested, i.e. the combined effect of concentration, exposure time and respiratory minute volume. The latter factor is increased by physical activity or effort. Hence ozone tends to affect persons who frequently do vigorous exercise or undertake strenuous physical activities for relatively long periods out of doors during summer ozone peaks. In addition, as a precautionary measure, all infants and toddlers should also be classified as a risk group owing to (a) their relatively high respiratory minute volume; and (b) the fact that their immune system is not fully developed, which can increase the risk of infection in the presence of ozone induced irritation.

The following symptoms can be provoked by acute ozone exposure for several hours at a stretch, combined with strenuous physical activity:

- Changes in pulmonary function parameters in children and adults in the presence of ozone concentrations ranging from 160 to 300 µg/m^3
- Reduction of physical stamina at concentrations of 240 µg/m^3 or higher
- Pulmonary tissue inflammation following six hours of exposure to concentrations of upwards of 160 µg/m^3
- Increased asthma attack frequency at concentrations ranging from 240 to 300 µg/m^3.

All of the aforementioned acute effects resolve when the ozone exposure ends.

Symptoms such as tearing eyes (provoked by substances accompanying the ozone), respiratory inflammation, coughing, headache, and breathing problems have been observed with concentrations of 200 µg/m^3 and higher. The severity of eye and mucosa inflammation is for the most part unrelated to physical activity and is chiefly determined by the time spent in an ozone-polluted atmosphere.

In terms of chronic effects, exposure to extremely high concentrations of ozone (such as those observed in Los Angeles in 1985[44]) for a period of years can result in low grade but persistent and in some cases (presumably) irreversible pulmonary function loss. A positive correlation between increased frequency of bronchitis and long term ozone exposure has been statistically proven, although the ozone exposure levels needed for this do not occur in Germany. Ozone is presumably more of a contributing factor in terms of health problems in the regions affected, owing to the presence of PM10s emissions.

In addition to the aforementioned primary, acute and chronic effects, ozone can also affect human health in other ways, e.g. allergenic and genotoxic effects, and possibly carcinogenic effects as well; but these effects cannot be associated with specific concentration levels. It is currently unknown whether the ozone levels observed in Germany could potentially cause cancer.

In contrast to plant pathologies, where mean ozone concentrations are the main determinants of AOT40 values and thus the primary cause of pathologies, human health problems are induced mainly at peak ozone concentrations.

6.1.2.2 Reversibility, irreversibility and duration

The acute effects of ozone that induce functional respiratory pathologies are reversible for the most part and tend to subside within one to three hours. However, extremely high exposure levels can result in minor residual abnormalities after 24 to 48 hours. Exposure to extremely high concentrations of ozone for a period of years can result in persistent and in some cases (presumably) irreversible pulmonary function loss (see above).

The primary acute effects of ozone occur either immediately or shortly after exposure, whereas chronic effects occur several years after acute exposure.

6.1.2.3 Spatial extent

In contrast to plant pathologies, where mean ozone concentrations contribute considerably to pathologies, ozone generally induces human health problems at peak concentrations (over 160 µg/m^3). These high levels occur in the densely populated regions of Europe and North America, as well as (presumably) in Asia at the local and regional level.

6.2 Basis for determining distance to target

Inasmuch as vegetation is more susceptible to ozone than humans, exceedance of ecosystem specific threshold concentrations known as critical levels are used as a yardstick for measuring the hazard potential of ozone exposure. Plant pathology is measured on the basis of critical levels as a cumulative dose known as the AOT40 value (see above).[45] During the primary growth period of crop plants

[44] In that year, mean atmospheric ozone of 400 µg/m^3 per hour was measured for approximately 70 consecutive days

[45] The unit of measure of AOT 40 is ppb h (parts per billion multiplied by hours)

and forest vegetation, the AOT40 value should not exceed, respectively, 3,000 and 10,000 ppb h. In Germany, this period is May through July for crop plants and April through September for forest vegetation during daylight hours, i.e. 6 a.m. to 6 p.m. CET.

Central European AOT40 ozone values for forest and crop vegetation during the vegetation period (April through September) far exceed critical levels in sizeable areas at certain times. This also holds true for Germany in most of whose territory critical levels are exceeded (by up to more than a magnitude of 3), particularly for grain crop and forest vegetation. Unlike mean concentrations, peak ozone concentrations in Germany have declined over the past decade owing to a substantial decrease in emissions of the ozone precursors NOx and VOC since 1985.

Mean ozone concentrations in Germany are largely determined by Northern Hemisphere background ozone levels, which range from 35 to 40 ppb during the vegetation growth period (April through September). Northern Hemisphere background ozone is chiefly composed of (a) a natural stratospheric component; and (b) global photochemically formed ozone in the middle latitudes of the Northern Hemisphere (30 - 60° N), derived from natural VOC sources as well as precursor emissions (NOx, VOC, carbon and methane) from the industrialized countries of North America, Europe and Asia. Northern Hemisphere background ozone concentrations are approximately twice those of the Southern Hemisphere. The long term rise in ozone concentrations at ground level and the troposphere in the middle latitudes of the Northern Hemisphere is almost certainly attributable to the increase in photochemical ozone synthesis resulting from ozone precursors (NOx, VOC, carbon and methane) whose emissions in industrialized countries have increased dramatically since the dawn of the industrial revolution.

Background ozone levels in the Northern Hemisphere are amenable to virtually no reduction in Germany and can only be reduced via actions by EU states to a limited degree. These background levels can only be brought down through efficient long term measures aimed at substantially reducing ozone precursor emissions in extremely broad swathes of the industrialized countries of North America, Asia and Europe.

This problem merits close attention in view of the fact that (a) mean ozone concentrations are the chief determinant of the integral AOT40 value; and (b) owing to the aforementioned high background levels, these concentrations cannot be reduced by ozone reduction measures realized in Germany alone. AOT40 values are generally determined by mean ozone concentrations (40 to 80 ppb) and are relatively unaffected by peak ozone concentrations (i.e. over 80 ppb). Systematic regional differences also come into play in this regard. Coastal ozone concentrations ranging from 40 to 60 ppb generally affect AOT40 values, whereas in low mountain areas concentrations between 45 and 75 ppb determine the integral AOT40 values.

Germany’s substantial AOT40 exceedances are bound to persist in the coming years despite ozone reduction measures, since German reductions of the ozone precursors NOx and VOC will reduce *peak* ozone concentrations, which constitute a health hazard, but will have little or no effect on *mean* ozone concentrations.

According to WHO air quality guidelines, the environmental quality target of protecting human beings against the deleterious effects of ground level tropospheric ozone pollution is 120 µg/m^3 as an 8 hour mean value. In order for ozone concentrations to be reduced permanently, precursor emissions would have to be reduced over a broad area by 70-80 percent relative to 1985 levels. However, reducing these emissions would still fail the environmental quality objective for vegetation protection, whose reduction rate it has not been possible to determine thus far.

7. The “resource use” impact category

7.1 Classification system for the “ecological severity” criterion

“Resource use” means the removal and use of raw materials, energy, organisms and surface area from the natural environment.[46] In life cycle assessment Inventory Analyses, a distinction is made between biotic and abiotic resources.

The “resource use” impact category pertains solely to abiotic resources (raw materials), which comprise resources that are non-renewable within any conceivable human timeframe and which result from former biological processes in the case of coal, petroleum, natural gas and the like, or physico-chemical processes in the case of minerals, rock, and soil. Biotic resources are elements such as timber or fish that are obtained from living organisms. For methodological reasons, biotic resources are assessed not in this impact category, but rather in terms of “land use.” This applies as well to the “area/land” resource category.

The following two criteria should be applied to assessments of the effects associated with resource use:

8. long term availability for human use (for the “resource” area of protection)
9. the ecological damage associated with resource extraction and use (for the “ecosystem function and structure” and “human health” areas of protection)

Ideally, raw material extraction and processing should be regarded as a separate process for life cycle assessment purposes. Unfortunately, this is seldom possible since raw material extraction oftentimes takes place outside system boundaries and primary materials are factored into the life cycle assessment as inputs only, without taking into consideration the ecological damage engendered by the upstream extraction processes. But since raw material extraction is always associated with both of the aforementioned criteria (albeit in varying ways and to varying degrees), it makes sense to regard resource use as a separate category.

The “resource use” impact category is in many ways fundamentally different from the environmental policy domain of “resource conservation.” Life cycle assessment studies should clearly distinguish between the various impact categories so as to avoid double-counting. To this end, our approach classifies biotic resource use under the “land use” impact category.

On the other hand, the environmental goal of resource conservation aims to minimize the overall ecological damage associated with raw material extraction and use as a precautionary measure. In this context, raw material use is a parameter that spans a number of domains and thus provides a complete picture of the ecological damage engendered by raw material extraction and use.

[46] ENQUETE-KOMMISSION (1994): Enquete-Kommission *Schutz des Menschen und der Umwelt* des Deutschen Bundestages (ed.): Die Industriegesellschaft gestalten. Perspektiven für einen nachhaltigen Umgang mit Stoff- und Materialströmen, Economica-Verlag, Bonn

7.1.1 The "ecosystem functions and structures" area of protection

7.1.1.1 Mechanisms of action

After being removed from the environment and used, raw materials are ultimately returned to the environment in the form of waste or other emissions. Among the consequences of this process are that it consumes land, releases pollutants, and results in the creation and distribution of massive material flows, some of which are irrecoverable. These processes are in turn associated with substantial water, soil, air and ecosystem contamination that has ecotoxilogical and other adverse effects, including the crippling of ecosystem functions.

The table below lists some of the effects of raw material use on the structure and functions of ecosystems.

Table 7-1: Effects of raw material use on the structure and functions of ecosystems

Cause	Area of protection affected	Effect
Preparatory and support measures for extraction • Elimination of physical and cultural assets • Elimination of vegetation • Cleanup, transport and interim storage of soil and ground cover • Water table reduction • Aquifer exposure • Waterbody engineering and other waterbody uses *Raw material extraction* • Wet/dry sand and gravel extraction • Bedrock (blasting) • Clay and other materials *Raw material processing, storage and transport; product manufacturing*	• Ecosystems • Flora, fauna and their habitats • Soil • Groundwater and surface water bodies • Air and climate quality • Landscape • Physical and cultural assets	• Disappearance of and damage to flora and fauna • Soil loss and damage • Topographic relief changes; dimensional loss • Erosion • Changes in mesoclimate • Water balance/water quality change and degradation • Structural landscape changes • Noise • Vibrations • Traffic related pollution • Air pollution

Source: GÜNNEWIG, D. ET. AL. (1997): Entscheidungsgrundlagen für die weitere Nutzung in der Gipskarstlandschaft Südharz/Kyffhäuser unter besonderer Berücksichtigung des Bodenschutzes, Abschlußbericht zum F+E-Vorhaben 107 02 010/02, UBA-TEXTE 39/98, Berlin

It is safe to assume that as resource use increases, the extent of the effects on ecosystem structure and functions will increase in the long term. For example, the extraction and use of raw materials and fossile fuels is likely to result in more “ecological rucksack,” i.e. increased amounts of overburden and waste, higher levels of energy and material consumption, and a rising rate of emissions per usage unit, as well as in absolute terms. The quality of the resources available in the coming years will probably decline. For example, the use of raw materials with lower concentrations of exploitable elements or elements that are worth extracting results in larger environmental loads in the form of greater proportions of displaced overburden, or an increase in the amount of water table decline per ton of brown coal extracted and so on. Inasmuch as the environment’s ability to absorb input is limited, it is likely that resource use will exacerbate ecological damage.

These effects on the “ecosystem structure and functions” area of protection are classified under other impact categories such as structural landscape changes in the “land use” category.

7.1.2 The “human health” area of protection

7.1.2.1 Mechanisms of action

Resource use can be directly associated with human health problems. For example, raw material extraction may generate noise pollution, as well toxic substances such as mercury and cyanide (during gold extraction). Raw material extraction can also result in the partial displacement of human settlements and the extirpation of recreational areas. If a sense of wellness is included in the health equation, then resource use can also be regarded as being psychologically deleterious by virtue of effects such as the loss of landscape features and the consequences thereof (also see the section on the “land use” impact category).

The use of non-renewable resources can also have a deleterious effect on the quality and quantity of assets that are vital for human survival such as suitable soil for food production. This results in quantity and quality deficits for these resources at the local and regional level.

7.1.3 The “resources” area of protection

Declining raw material and fossile fuel stocks constitute a worldwide environmental problem.47 The principle of resource conservation (in this case, raw materials) is rooted in the concept of sustainable development, the aim being to ensure that future generations have an equal opportunity to make their way in the world.

The manner in which non-renewable resources are used should be assessed in a differentiated manner, in light of the limited availability of these resources.

h) *Destructive resource use*
Resources are destroyed via chemical transformation processes such as burning oil for energy production. In such cases, the exploitable properties of

[47] Also see MÜLLER-WENK, R., (1998): Depletion of abiotic resources weighted on base of “virtual” impacts of lower grade deposits used in future, IWÖ-Diskussionsbeitrag Nr. 57, Universität St. Gallen

the raw material, i.e. its suitability for energy production via combustion as a fossile fuel, are destroyed.

i) *Non-destructive, dissipative resource use*
In this type of use, instead of being destroyed, resources are converted and broken down, or are widely dispersed, and their spatial distribution pattern is altered. After having been localized centrally at the beginning of the usage chain, these resources are transformed into products or waste that are widely dispersed in the technosphere and biosphere, and can only be recycled at considerable expense (e.g. in cases where materials with very low concentrations of raw materials such as copper are distributed in the environment).[48] Hence the recyclability of dispersed resources is largely determined by the efficiency of waste and recycling technologies.

Classification systems have been proposed in the professional literature for various non-renewable resources in respect to the role they play in sustainable development. Such proposals rank metals as a more valuable material in terms of long term availability than bulk construction materials such as sand and gravel, on the grounds that metal is available solely in discrete repositories that were created via accretion and whose exploration and extraction entails substantial energy use. Bulk materials such as sand and gravel, on the other hand, are frequently transformation products of bedrock.

7.1.3.1 Reversibility, irreversibility and duration

The removal and use of finite resources reduces the available stock of these resources and thus limits their availability for future generations. The effects of removing and using such resources are irreversible insofar as they cannot be recovered and their function is irreplaceable.

The duration of the effect of resource use on the “resource” area of protection should be assessed in accordance with the raw material and application domain involved.

destructive resource use (see section 7.1.3(a))

The effect of destructive resource use is irreversible, insofar as fossil fuels are concerned. Once such raw materials have been converted into energy, they are no longer available for renewed use and their function must be replaced by other energy sources.

non-destructive/dissipative resource use (see section 7.1.3(b))

The duration of the effect of resource use that converts the resource and then disperses it into the technosphere and biosphere (rather than destroying it) is determined by the nature of the recovery technology applied. In view of the technologies available today, the effect of using most such resources remains irreversible for all practical purposes. The extraction and use of finite resources

[48] MÜLLER-WENK, R., (1997): Safeguard Subject and Damage Functions as Core Elements of Life-Cycle Impact Assessment, IWÖ-Diskussionsbeitrag Nr. 42, Universität St. Gallen

reduce the available amounts of these resources and limit their use options for future generations.

Example: In the German state of Lower Saxony, the gypsum deposits needed for building construction throughout Germany will be completely depleted within the next three to four decades.[49] As a result, gypsum will have to be extracted in other regions of Germany or imported; or a material that can replace the function of gypsum will have to be found, e.g. gypsum obtained from flue gas desulphurization facilities, or from construction debris recycling.

7.1.3.2 Spatial extent

The spatial extent of the effects of resource use on the "resource" area of protection can be local, regional or global depending on the type of resource involved, and the type and scope of resource/fuel use.

7.2 Basis for determining distance to target

Resource conservation has been a high priority environmental policy objective for many years now. It is also a cornerstone of recycling and waste management statutes, and is a key issue in the literature and discourse of sustainability.

No comprehensive, clearly defined, quantifiable and/or geographically specific target values concerning resource conservation levels that could form the basis for distance to target estimates are currently available. However, the following general rule of thumb formulated by a 1994 German parliamentary commission on sustainable resource use[50] is currently regarded as applicable:

Non-renewable resources should only be used insofar as (a) they can be replaced by physically and functionally equivalent renewable resources; or (b) the productivity of both renewable and non-renewable resources can be increased.

In view of the difference between destructive and non-destructive/dissipative raw material use, differing approaches should be applied to distance to target assessments for these parameters.

destructive resource use (see section 7.1.3(a))

The table below shows the worldwide reserves of non-renewable destructively used resources and the extraction rates thereof for 1991 and 1992, i.e. the empirical amount of these resources that is currently available for future generations (i.e. number of years of use), assuming that current usage levels are maintained. More than 90 percent of the world's energy production activities center

[49] NIEDERSÄCHSISCHES LANDESAMT FÜR ÖKOLOGIE (1997): Stoffstrommanagement Gips als Beitrag zum nachhaltigen Ressourcenschutz in Niedersachsen, Vorstudie, Hildesheim

[50] ENQUETE-KOMMISSION (1994): Enquete-Kommission *Schutz des Menschen und der Umwelt* des Deutschen Bundestages (ed.): Die Industriegesellschaft gestalten. Perspektiven für einen nachhaltigen Umgang mit Stoff- und Materialströmen, Economica-Verlag, Bonn

around fossil fuel use.[51] *Each year*, the amount of coal, petroleum and natural gas consumed worldwide represents a *500,000 year* natural "production" process.[52]

Inasmuch as the proportion of renewable energy use relative to conventional forms will increase only slightly in the coming years, it will be necessary to conserve destructively used raw materials for the coming generations for as long as possible, owing to the physical scarcity of these resources.

Table 7-2: Worldwide reserves/extraction of non-renewable resources, and the consequent remaining years of use

Resource	Reserves (in megaton oil equivalent)	Extraction (in megaton oil equivalent)	Reserves/extraction ratio (remaining years of use)
Brown coal	202,000	530 (1992)	381
Hard coal	386,000	2350 (1992)	164
Oil	135,000	3130 (1991)	43
Natural gas	113,000	1820 (1991)	62
All fossil fuels	836,000	7830	107

Source: FRISCHKNECHT, R. in Müller-Wenk, R. 1997: Safeguard Subject and Damage Functions as Core Elements of Life-Cycle Impact Assessment, IWÖ-Diskussionsbeitrag Nr. 42, Universität St. Gallen

Energy use per unit of GDP (gross domestic product) has declined sharply in Germany in recent years, and energy productivity has risen accordingly. On the other hand, although work productivity in the former West Germany more than tripled between 1960 and 1990, energy productivity increased by "only" 36 percent during this period.[53] The usual response to an increase in energy use efficiency is to overcompensate by ramping up production and consumption levels. In keeping with this principle, primary energy consumption increased by 94 percent in Germany between 1960 and 1993.

In determining distance to target values, in addition to the aforementioned data concerning current energy resource consumption trends, policy objectives can also be used, which are formulated in this report as environmental action objectives. In its 1998 draft environmental policy action program, the Federal Ministry for the Environment called for the doubling of energy productivity by 2002

[51] International Energy Agency World Energy Outlook, 1995, Edition Paris 1995, in: MÜLLER-WENK, (1997): Safeguard Subject and Damage Functions as Core Elements of Life-Cycle Impact Assessment, IWÖ-Diskussionsbeitrag Nr. 42, Universität St. Gallen

[52] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit: Nachhaltige Entwicklung in Deutschland. Entwurf eines umweltpolitischen Schwerpunktprogramms, Bonn

[53] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit: Nachhaltige Entwicklung in Deutschland. Entwurf eines umweltpolitischen Schwerpunktprogramms, Bonn

relative to 1990 levels.[54] Energy productivity indicates the amount of GDP (in 1991 prices) "produced" using one year's worth of primary energy consumption. Improved energy efficiency has also been endorsed by the EU, OECD and UN. Of particular significance in this regard is the "sustainable energy future" strategy that is slated for adoption at the 2000 meeting of the UN's Commission for Sustainable Development, for which the participating countries will be preparing implementation programs and timelines.

nondestructive, dissipative resource use (see section 7.1.3(b))

As with energy resource use trends, raw material productivity associated with dissipative energy resource use increased by 90 percent in Germany from 1960 to 1990;[55] but during this same period, consumption of dissipative raw materials increased owing to the sharp rise in Germany's GDP.

Dissipative use of non-renewable resources is non-extirpative and thus the resources are available for future use. However, they are so drastically altered that the recycling costs associated with the recovery of these materials and obtaining the consequent environmental benefits are prohibitively high in many cases.

The MÜLLER-WENK method (1998)[56] should be used as a basis for future assessments of dissipatively used raw materials.

Using models as a starting point, this method determines, for various raw materials, which environmental interventions are entailed by the greater technological effort required for obtaining these materials from relatively low concentration deposits using currently available technologies. Factored into this assessment as well are calculations of future raw material mineral content, supplementary energy use requirements resulting from exploration of and extraction from low concentration mineral deposits, and the ensuing additional environmental interventions attributable to supplementary energy requirements. These virtual environmental interventions are used as a basis for determining the scope of the environmental impact that is likely to associated with current resource use in the coming years.

Non-energetic raw materials such as metal ore are available in such large quantities in the earth's crust that we need have no concerns about exhausting these resources. That being said, it is also safe to assume that the accessible deposits of these minerals that have elevated concentrations of useable material will decline over the next one to ten centuries. This means that future generations will be faced with greater extraction efforts resulting from the use of mineral deposits with lower concentrations of useable ore. This development will also become relevant even if steady technological advances are made in the extraction

[54] ibid.
[55] ibid.
[56] MÜLLER-WENK, R., Depletion of abiotic resources weighted on base of "virtual" impacts of lower grade deposits used in future, IWÖ-Diskussionsbeitrag Nr. 57, Universität St. Gallen

of dissipatively used raw materials in such a way that the use of low-concentration ore also becomes economically feasible These higher use costs will also engender more severe environmental impacts (see the section entitled “the ‘ecological structure and function’ area of protection”).

Inasmuch as MÜLLER-WENK’S calculations suggest that the “virtual environmentally relevant interventions” associated with the amounts of dissipatively used resources generally found in life cycle assessments account for only a minor portion of the overall results of these assessments, we recommend that dissipatively used resources be omitted from life cycle assessments until such time as a viable method has been developed.

8. The “stratospheric ozone depletion” impact category

8.1 Classification system for the “ecological severity” criterion

8.1.1 The “ecosystem functions and structures” area of protection

8.1.1.1 Mechanism of action

The rapid, annually iterative depletion of the ozone layer over the Antarctic was discovered in the mid 1980s. Toward the end of the polar night in the Antarctic spring in September/October, total ozone values decrease to up to about 70 percent relative to mean values from 1956 to 1978, i.e. the period prior to discovery of the ozone hole. And unfortunately, the geographical and temporal reach of ozone layer destruction now extends far beyond the Antarctic and the Antarctic spring, for it is now observed year round, albeit in a less severe form, up to the 50th parallel in the Southern Hemisphere (southern tip of South America). Ozone depletion has also been observed over the Northern Hemisphere. Measurements of the ozone layer show that total ozone content over continental Europe has been on the decline since the early 1970s. This decline accelerated during the 1980s and is now occurring at a rate of 5 percent per decade, with ozone loss being two to three times higher in winter than in summer.

This development is directly attributable to the worldwide increase in emissions of chlorofluorocarbons (CFC) compounds and of halons containing atomic chlorine and bromine. HCFC compounds[57] are also ozone depleting, but to a far lesser degree.

One of ozone’s properties is its ability to absorb almost all UV-B solar radiation (i.e. in the 280-320 nanometer wavelength range). Hence, the less stratospheric ozone there is, the greater the increase in UV-B intensity at ground level.

Inasmuch as high quality (i.e. spectrally resolved) measurements of UV-B radiation at ground level only became available recently, the available data does not allow any valid conclusions to be drawn concerning long term ground level UV-B radiation trends up to the present. That being said, more recent measurements realized in cloudless skies show that low ozone column density is in fact associated with higher ground level UV-B radiation, a phenomenon that confirms model-based calculations. Thus for example, when the ozone hole makes its appearance during the Antarctic spring, ground-level UV-B readings in the Antarctic and the southernmost regions of South America are substantially higher. Elevated UV-B radiation was also observed in the Northern Hemisphere during low ozone periods in 1992 and 1993.

Elevated UV-B radiation can provoke a broad range of adverse effects in plants, animals and humans, although the susceptibilities associated with various species and the development stages thereof are extremely diverse.

[57] HCFCs are compounds containing hydrogen (in addition to halogens such as chlorine and fluorine), whereas CFCs are fully halogenated and contain no hydrogen.

Elevated UV-B radiation can be harmful to phytoplankton, which live in the uppermost reaches of the ocean and are the most important element in the maritime food chain. This in turn has a deleterious effect on commercial fishing (and hence the world food supply) as well as on carbon dioxide exchange between the atmosphere and bottom water.

Elevated UV-B radiation can also trigger growth disorders, cell damage and mutations in higher plants, resulting in crop damage and reducing agricultural production.

8.1.1.2 Reversibility, irreversibility and duration

Ozone depletion could be halted by a worldwide ban on the production and use of CFC compounds. Restoration of a natural stratospheric trace substance balance would allow for regeneration of the ozone layer and a return to pre-ozone hole substance concentrations. Hence ozone depletion can be reversed, albeit slowly. Implementation of such measures would result in ozone layer restoration by the mid 21st century at the earliest.

> Ozone depletion is mainly attributable to stratospheric chlorine content, which is currently some five times higher than what would be observed under natural conditions. Anthropogenic emissions of bromine-containing substances have resulted in an approximately 200 percent increase in stratospheric bromine content. Despite CFC limits and the ban on halon production mandated by the Montreal Protocol and related agreements, stratospheric chlorine concentrations are expected to continue rising until the year 2000 (up to approximately 5 ppbv; 1 ppbv = 1 volume unit per billion (= 10^9) air volume units). This evolution is attributable to two factors: the slow transport of CFC and halon compounds into the stratosphere; and steady emissions of products containing CFC compounds. Hence ozone depletion is likely to get worse before it gets better. Stratospheric chlorine concentrations are expected to decline to 2 ppbv or less by the mid 21st century, thus eliminating currently observed levels of ozone depletion attributable to reactive chlorine.

However, since ozone has a radiation effect (albeit a slow one) in both the ultraviolet and infrared spectra, ozone depletion in conjunction with temperature differences can provoke changes in atmospheric circulation. It is unclear whether or not such changes are reversible. However, at a minimum these changes are likely to induce irreversible shifts in atmospheric circulation patterns, which will in turn provoke climate change.

Despite any countermeasures that may be implemented, ozone depletion attributable to the slow transport of CFC and halon compounds into the stratosphere is likely to increase in the coming years and decades.

8.1.1.3 Spatial reach

Regions over which the ozone layer is thinnest tend to experience elevated UV-B radiation. However, this does not necessarily entail a linear correlation between stratospheric ozone concentrations and UV-B radiation intensity, since for example clouds, atmospheric aerosols, and tropospheric ozone can also interact with UV-B radiation. But be this as it may, ozone depletion is a problem of global scope.

8.1.2 The “human health” area of protection

8.1.2.1 Mechanism of action

j) *Short term effects*

Exposure to UV-B radiation can provoke acute human health disorders such as sunburn, as well as snow blindness (acute damage to the cornea), which affects skiers or mountain climbers. UV-B radiation can also trigger photoallergic reactions in users of cosmetic products or sunscreen.

b) Long term effects

The nature and scope of the long term effects of UV-B radiation are mainly determined by radiation dose and wavelength, as well as individual sensitivity. The most clinically significant long term effects are premature skin aging, skin tumors, eye disease, and immune system disorders.

- *Skin tumors*
  It has been scientifically proven that UV-B radiation can provoke malignant skin tumors, but it has yet to be determined whether lifetime exposure dose is also a decisive cause of skin cancer. It is currently believed that the risk of skin cancer is greatest for children who frequently experienced sunburn. Malignant skin tumors range from basal cell and epithelial cell cancers, which are less malignant, to highly malignant melanomas.
  The incidence of skin cancer has risen sharply worldwide. The melanoma rate in the US increased 3 - 4 percent per year from 1974 to 1986, with the highest rate being recorded in Australia. Dermatologists attribute this evolution mainly to improvident leisure time behavior. Inasmuch as exposure time multiplied by intensity is the decisive variable for skin cancer, it is safe to assume that continued ozone depletion will lead to further increases in skin cancer rates.
- *Eye diseases*
  A positive correlation between UV-B radiation exposure and eye diseases such as cataracts has been scientifically proven. Studies in equatorial regions have established a correlation between exposure to elevated UV-B radiation and eye diseases.
- *Immunological effects*
  Exposure to UV-B radiation has a deleterious effect on T cell formation and other immunological functions. However, only preliminary data concerning the effects of UV-B radiation on the immune system are available. If studies confirm that the UV-B radiation does in fact weaken the human immune system, infectious diseases may become more widespread and/or frequent.

8.1.2.2 Reversibility, irreversibility and duration

The acute disorders ascribable to UV-B radiation are generally reversible. The long term effects of exposure to elevated UV-B radiation can be either reversible, or (as in the case of malignant tumors) irreversible.

8.1.2.3 Spatial reach

See section 2.1.1.3.

8.2 Basis for determining distance to target

Ozone depletion can only be reversed by banning the manufacture and use of CFCs, HCFCs, and halons. The 1987 signing of the Montreal Protocol laid the cornerstone for an exemplary international ozone protection program that has resulted in a ban (as at 1 January 1996) on the production of fully halogenated CFC compounds in industrialized countries.

However, the use of CFCs in laboratories and in certain medical sprays is still permitted.

On the other hand, CFC use and emissions are currently regulated by national laws to a limited extent only, and CFC manufacture and use (sanctioned by the Montreal Protocol) have even risen in some developing countries.

Contrary to the provisions of the Montreal Protocol, fully halogenated CFC compounds are still being manufactured, used and to some extent exported in the former Eastern bloc countries. Such practices must be ended as soon as possible in these countries if we are to achieve ozone layer regeneration within the foreseeable future.

An important milestone toward a definitive end to CFC use in developing counties was reached in 1995 at the seventh Montreal Protocol meeting in Vienna, where 1 January 2010 (i.e. ten years following the signing of the Vienna Convention for the Protection of the Ozone Layer) was set as the definitive deadline for a ban on CFC and halon production. The developing countries also agreed to abide by treaty regulations concerning a ban on partially halogenated HCFCs.

Stratospheric chlorine concentrations can be used as a benchmark for compliance with Protocol targets. The uncritical values that were observed prior to the advent of ozone depletion are less then 2 ppbv;[58] it now appears that these values will be achieved sometime during the second half of the 21st century. Total current chlorine content from all source gases is approximately 3.8 ppbv in the troposphere, but only 3.3 ppbv in the stratosphere. Scientists estimate that as a result of chlorine transport from the troposphere, stratospheric chlorine will increase to more than 4 ppbv.

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[58] The target value for stratospheric bromide concentration is 15 pptv or less (1 pptv = 1 volume unit per trillion ($=10^{12}$) air volume units)

9. "Global warming" impact category

9.1 Classification system for the "ecological severity" criterion

9.1.1 The "ecosystem functions and structures" area of protection

9.1.1.1 Mechanism of action

Primary effects

Elevated concentrations of greenhouse gases derange the energy balance of the earth's atmospheric system, resulting in increased temperatures in the lower layers of the atmosphere, thus provoking further climate change.

Model based calculations indicate that mean ground-level air temperature will have risen by 2° C in 2100 relative to 1990 levels (best estimate). The projected temperature increase varies between 1° C and 3.5° C depending on modelled climate system sensitivity to various input values and future changes in aerosol concentrations. This temperature rise would result in a 50 cm increase in mean sea levels by 2100, with estimates ranging from 15 to 95 cm. It is also safe to assume that global warming will result in a greater number of extremely hot days and a smaller number of extremely cold days. Global warming is also likely to alter precipitation distribution patterns as well as the frequency and intensity of draughts and floods. The currently available data does not allow for projections of the frequency or geographical distribution of violent storms. However in view of the non-linear nature of the mechanisms that come into play here, they are likely to provoke large scale and rapid climate change.

Secondary effects

The composition and geographical distribution of many ecosystems are likely to change, depending upon how various species react to climate change, which will also reduce species diversity. Establishment of a new equilibrium may take centuries for some ecosystems after climate change has reached a new equilibrium.

Forests: Mathematical models indicate that a 1° C long-term increase in global mean ground level temperatures would be sufficient to alter regional climatic conditions to the point where the growth and regeneration capacities of many forests would be impaired. The rate of change is a decisive parameter with regard to such mechanisms, since in many areas this factor will substantially alter forest functions and composition. For example, changes in temperature patterns and water availability would translate into major changes in entire vegetation types in an average of one third of the world's existing forestal areas. Rapid climate change relative to the speed of forest species growth, propagation and recolonization is an extremely likely prospect. There may also be major changes in forest species composition, characterized by the disappearance of entire forest types and the possible emergence of new forest species compositions and ecosystems. Despite a possible net overall increase in primary ecosystem productivity, the existing forest biomass may actually become less productive owing to more frequent and widespread pest and pathogen infestations, and more frequent and extensive forest fires.

Farmland, pastureland and meadows: Although mean temperature increases will probably not bring about any substantial change in tropical meadow productivity and species composition, these elements will be altered by changes in the amount and annual distribution of precipitation and by increased evapotranspiration. Elevated atmospheric carbon dioxide concentrations may alter the carbon/nitrogen ratio, and hence the nutritional value, of the forage consumed by herbivorous organisms. Shifts in temperature and precipitation patterns in pastureland areas in temperate zones may result in longer or shorter growth periods and may relocate the transitional zones between grasslands, trees and bushland.

Any number of adaptation scenarios are in the offing for the agricultural ecosystems of the temperate zones of Europe and North America. The situation in subtropical and tropical regions is likely to be critical, as it is likely to be characterized by major climate change on one hand and a lack of resources for counteracting these problems, owing to the prevailing poverty in these regions.

Mountainous regions: It has been predicted that the altitude of the vegetation line will increase. In addition, some species that live on mountaintops owing to the climate conditions that prevail there may die out owing to the disappearance of their habitats or a reduced spectrum of migration options. The shrinkage of mountain glaciers, permafrost and snow cover that is expected to be brought about by global warming will impact hydrological systems and ground stability. Indigenous populations in many developing countries may no longer be able to access food, energy and other mountain resources.

Lakes, rivers and wetlands: Inland aquatic ecosystems will feel the effects of climate change engendered by altered water temperatures, discharge systems and water tables. The most severe biological effect of global warming on higher-latitude lakes and rivers will be elevated biological productivity, whereas in lower latitudes the greatest impact will be on the boundaries of the life-worlds of cold and cool water species, which will be most at risk of extinction. Temperature increases in relatively large and deep lakes in temperate zones would increase the productivity of these waterbodies, whereas the warming of some shallow lakes and rivers could increase the risk of oxygen deprivation. Increased variability in inflow and discharge patterns, and above all an increase in the frequency and duration of large scale flooding and draught, could degrade water quality, and reduce biological river productivity and habitat quality. Water tables will decline most acutely in lakes and rivers in dry evaporation areas and in basins with small catchment areas. Altered temperature and precipitation patterns will probably change the geographical distribution of wetlands.

Coastal areas: Climate change and rising oceans levels, or changes in storm patterns or storm tides could bring about the following changes: coastline and coastal habitat erosion; elevated salt concentrations in estuaries and fresh water repositories; altered tidal ranges in rivers and bays; changes in sediment and nutrient transport patterns and in the distribution of chemical and microbiological debris in coastal areas; and increased coastal flooding. Some coastal ecosystems such as salt lakes, mangrove ecosystems, coastal wetlands, coral reefs and river deltas are particularly vulnerable. Changes in these ecosystems would have extremely deleterious effects on fresh water stocks and species diversity. These effects would in turn bring about changes in coastal water and inland waterbody functions, in addition to the existing effects of anthropogenic pollution, physical changes, and material inputs.

Oceans: In addition to bringing about a rise in mean ocean levels, climate change may also alter ocean circulation and vertical mixing patterns and shrink ocean ice sheets. This in turn could adversely affect the food supply, biological productivity, the functions and structures of ocean ecosystems, as well as their heat and carbon storage capacities. These changes would have major climate related repercussions and would massively impact coastal areas.

9.1.1.2 Reversibility, irreversibility and duration

Once triggered, a specific climate change mechanism is highly unlikely to be reversible on account of the relatively long retention times of most greenhouse gases. Species extinction that is either triggered or promoted by climate change is a wholly irreversible process in every instance.

The chain of events entailing *elevated greenhouse gases in the atmosphere → climate change → effects on ecosystems* is subject to time lags ranging from 50 to 100 years. The full effects of this cycle will not appear until a new equilibrium is reached, which scientists predict will take centuries.

9.1.1.3 Spatial reach

Climate change and the effects thereof are expected to have a global reach, but with regional differences in the scope, and to some extent the direction of change.

9.1.2 The "human health" area of protection

9.1.2.1 Mechanism of action

In numerous regions climate change will probably have a broad spectrum of primarily adverse effects on human health and will be a direct cause of significant numbers of deaths. The direct effects of climate change on human health potentially include increased death rates, as well as an increased incidence of disease (particularly cardiovascular and pulmonary disorders) owing to heat waves, which are expected to increase in intensity and duration. Rising temperatures in colder regions may reduce the incidence of deaths caused by cold. An increase in extreme weather events would increase the incidence of death, injury, and mental disturbances, and would result in a large number of persons being exposed to contaminated water. The potential secondary effects of climate change include an increase in infectious diseases (e.g. malaria, dengue fever, yellow fever, and certain types of meningitis) resulting from geographical propagation and the longer seasonal lifetime of the relevant vector organisms. The incidence of non-vectored infectious diseases such as salmonella, cholera and giaridiasis could to some extent rise as the result of temperature increases and more frequent flooding. Additional indirect effects of climate change include respiratory disease and allergies attributable to a climate-driven increase in certain air pollutants, pollens and fungal spores.

All things considered, air pollution and severe weather events will increase the risk of death and disease. Food supplies could be adversely affected in some regions by the negative impact of climate change on food production and fishing. Limited fresh water resources will also have a detrimental effect on human health. Additional problems could result from large scale migrations.

9.1.2.2 Reversibility, irreversibility and duration

The observations made in section 1.1.1.2 apply to the reversibility of climate change as well. Chronic disorders are usually irreversible, whereas acute disease tends to be reversible.

9.1.2.3 Spatial reach

The health effects of climate change will affect the health of human beings throughout the globe, albeit to varying degrees depending upon the level of natural, technical and social resources available in various societies and regions.

9.2 Basis for determining distance to target

The objective here is defined in the United Nations Framework Convention on Climate Change as "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." This objective will force policymakers to face up to the challenge of defining greenhouse gas concentrations that will promote the achievement of specific environmental quality and climate protection goals. Research on the stabilization of greenhouse gas concentrations is currently ongoing. The main factors for determining the impact of climate change on ecosystems are the scope of the effects in various regions and above all the rate at which such change is occurring or has occurred. It is generally presumed that ecosystem adaptability to temperature change is limited to a maximum of 0.1° C per decade.

The only metric currently available for determining distance to target for climate change is the projected rate of such change over the course of the next 100 years. Temperatures are expected to rise at a rate of approximately 0.2° C per decade (best estimate)[59] if no countermeasures are taken.

[59] The rate of temperature change in more recent times (e.g. over the past century) is an unsuitable metric, owing to the time lag between cause and effect.

The OECD and former Eastern bloc/Soviet Union countries have agreed to reduce their greenhouse gas emissions by 2000 to 1990 levels. The following figures for 1990 - 1995 provide a clear picture of the current carbon dioxide emission trend:[60]

OECD:	+ 4 %	of which:
Japan:	+ 12 %	
Australia:	+ 8 %	
EU: - 2 %		
Former Eastern bloc/Soviet Union:	- 31 %	

(for data on absolute emissions, see table 9-1.)

During this same period (1990-1995), Germany reduced its carbon dioxide emissions by 13 percent, i.e. from 1014 to 885 million tons.

The 1997 Kyoto Protocol calls for the industrialized nations to implement a 5 percent reduction in emissions of the six most important greenhouse gases by 2008 - 2012. However, in order for these nations to fulfill the goals of the UN Framework Convention on Climate Change, they will need to reduce their greenhouse emissions, relative to 1990 levels, by 11, 23, and 43, and 77 percent by 2005, 2010, 2020, and 2050 respectively. Moreover, inasmuch as the Kyoto targets alone are not nearly sufficient, they represent a first step only.

Carbon dioxide emission estimates for the EU for 1990 - 2000 are based on the assumption that these emissions will rise by 5 percent during this period.[61] However, it should be noted that atmospheric greenhouse gas levels will rise for decades to come even if emissions are stabilized, owing to the lengthy lifecycles of these concentrations.

60 Carbon accounts for approximately half of the anthropogenic greenhouse effect.

61 Source: European Environment Agency, Denmark.

Table 9-1: Energy related carbon dioxide emissions (in millions of tons)

	1990	1991	1992	1993	1994	1995	Difference (+/-)[3]
North Amercia[1] Latin America[2] EU 15 Former Soviet Union/Eastern bloc Middle East Africa Asia Pacific region (total) Asia Pacific region (excluding Japan, Australia and New Zealand)	5933 1052 3480 4807 649 671 5606 4129	5867 997 3480 4671 682 686 5724 4209	5973 1019 3454 4290 715 678 6002 4459	6090 1056 3392 3916 792 693 6211 4635	6208 1115 3384 3513 851 719 6732 5122	6270 1137 3425 3337 876 755 7036 5394	+ 337 + 85 - 55 - 1470 + 227 + 84 + 1430 + 1265
Total OECD[1] Former Soviet Union/Eastern bloc[4] Developing countries[2]	11128 4807 6505	11125 4671 6574	11227 4290 6871	11568 3916 6937	11458 3513 7803	11605 3337 8162	+ 447 - 1470 + 1657
Total world	22440	22370	22388	22421	22774	23104	+ 664

[1] excluding Mexico
[2] including Mexico
[3] Increase (+) and decrease (-) in annual emissions from 1990 to 1995

adapted from: World Energy Council: Press Release (4 July 1996)

10. “Acidification” impact category

10.1 Classification system for the “ecological severity” criterion

10.1.1 The “ecosystem functions and structures” area of protection

10.1.1.1 Mechanism of action

The mechanism of action of acidification can be summarized as follows, albeit very reductively: After being emitted into the atmosphere (primarily via power plants, vehicular traffic, and intensive livestock raising) and transported distances ranging up to thousands of miles, acids and acidifiers (mainly oxidized sulfur compounds (SOx), oxidized nitrogen compounds (NOx), and reduced nitrogen compounds (NHx)) are deposited in ecosystems such as forests and lakes.

The resulting soil and waterbody acidification has a number of adverse effects on flora (e.g. root, leaf and needle damage), fauna such as fish, and ecosystems in general (e. g. elevated leaching of key nutrients).

The secondary effects observed in such situations include permanent changes in species composition (e.g. lake fish and forest ground cover), genetic variability in the remaining species, decreased resistance to anthropogenic and natural (e.g. climatic or biotic) stress factors, and ultimately system breakdown (fish death in lakes, forest death). Groundwater and other receptor systems adjoining these ecosystems can also be damaged by mechanisms such as elevated nitrate input and heavy-metal mobilization.

These latter effects should not be regarded as isolated events, but should instead be viewed in terms of their interplay with the consequences of eutrophication (in particular) as well as global warming, increased carbon dioxide concentration and ozone depletion. Most of these environmental problems heighten the effects of acid inputs by destabilizing ecosystems even further.

10.1.1.2 Reversibility, irreversibility and duration

Critical acid loads are defined in such a way that once this threshold is reached, the soil has no buffering capacity beyond its capacity to buffer long term inputs of basic cations via deposition and weathering. Substantial changes in soil characteristics irreversibly and relatively quickly diminish the soil’s effective medium term capacity to buffer inputs via mechanisms such as exchangeable basic cations. Only effective long term processes are factored into critical load calculations since the capacity of solely medium term active buffer mechanisms to forestall soil acidification is limited, and otherwise unduly high critical loads values would be obtained for soil with high medium term buffer capacity.

If actual input does not reach the critical load threshold over the long term, acidification as defined above is basically reversible. However, this recovery process can take anywhere from *several decades to several centuries*, including for deposition rates that fall short of critical load, depending on the acidification and soil properties involved.

Acidification damage is reversible to a limited extent only (e.g. some leaves and needles recover), but most such damage is irreversible (elevated nutrient leaching, species loss, gene pool reduction for the remaining species, system collapse).

The buffering systems described produce an effect time lag whose length can vary, depending on ecosystem properties, from several years to several decades.

10.1.1.3 Spatial reach

Anthropogenic acidification is a phenomenon that occurs at both the regional and (European) continental level. Hence the problem cannot be studied from the German perspective alone, since a substantial majority of Germany’s acidifier emissions are deposited beyond the country’s borders and vice versa, with Germany’s substance specific “exports” in this domain exceeding its “imports.” For example, 78 percent of Germany’s sulfur emissions, 84 percent of its NO_X emissions, and 45 percent of its ammonium emissions are “exported,” whereas 40 percent of the country’s sulfur dioxide, 55 percent of its NOy emissions and 28 percent of its ammonium emissions originate outside Germany. Hence acidification should be analyzed from a European perspective.

Although the territorial reach of acidification is both regional and continental, the actual ratio between deposition and critical load varies considerably from a territorial standpoint. Deposition und Critical Load. Some areas are characterized by massively high critical load exceedances, while in others such acidification as there is falls short of the critical load threshold.

10.1.2 The “human health” area of protection

The “human health” area of protection is only affected indirectly by acidification, in that long term soil and waterbody acidification can provoke the release of heavy metals.

10.2 10.2. Basis for determining distance to target

The generally recognized criterion for the risk of acidification related damage is critical load exceedance via atmospheric deposition of acidifiers.

The main obstacle to quantifying distance to target lies in the substantial spatial variability of susceptibility (critical load) and deposition (see above). The target proposed in the present study is that recommended by the UN ECE Convention on Long-Range Transboundary Air Pollution – namely 95th percentile critical load exceedance (i.e. damage potential, see above).

The damage potential for Europe is quantified using the UN ECE “deposition minus critical load” formula, where the unit of this critical load exceedance is kg/acidification/ha/year. However, this formula is unsuitable, since distance to target is used to rank various impact categories and thus a dimensionless variable is needed. In our view (contrary to the ECE approach), such a variable can be obtained using the quotients of deposition and critical load. The 95th percentile for the forest area Deposition (1993)/Critical Load quotients in Germany is 8.5, which means that current acid deposition exceeds the critical load by a factor of 8.5.

At present, critical loads for acid are exceeded in approximately 90 percent of Germany’s forest soil. Although this figure will decrease overall as the result of emission reductions, particularly sulfur dioxide, the status of the most severely affected areas will remain essentially unchanged (particularly Northern and Eastern Germany) until 2010 if emissions of oxidized and reduced nitrogen (which are mainly attributable to vehicular traffic and intensive livestock raising) are not reduced beyond currently planned levels. It should be noted that the emission reduction obligations of Germany and other European states pursuant to the UN ECE Convention on Long-Range Transboundary Air Pollution, which are based on critical loads as well as economic and other relevant factors, do not even come close to achieving critical load levels. The only change will be in the *extent* to which these levels are exceeded. This means that acidification of the affected soil and waterbodies above natural levels will continue, with the consequences described above.

Annex 2

Federal Environmental Agency recommendations for impact category priority ranking in life cycle assessment valuations

As mentioned in the methodological section, the Federal Environmental Agency has defined priority rankings for the various impact categories. The decisions in this regard were based on recommendations made by two working groups (“Life cycle assessment valuations” and a life cycle assessment working group) and were elaborated using the panel methods described above.

The Federal Environmental Agency plans to initially apply the impact category rankings to the following life cycle assessments that are currently in their valuation phase: graphics paper; packaging for mineral water, soft drinks, juice and wine; and used oil recycling methods.

As indicated in section 2.2.2 of the methodology section, five impact category priority rankings were defined ranging from A (top priority) to E (lowest priority).

The impact category priority rankings were defined for life cycle assessments in the narrow sense, i.e. LCA that do <u>not</u> refer or pertain to emissions or raw material extraction in any specific geographical region. The priority rankings presented here should be altered for life cycle assessment studies pertaining to specific locales, since such studies (which constitute the less common case) can include more exact data regarding territory-specific emissions and raw material extraction and the ecological damage that could potentially be incurred in such territories.

A: Priority rankings based on the “ecological severity” assessment criterion:
(see section 2.2.3 in the main section)

11. “Direct human toxicity” impact category

12. “Direct ecosystem damage” impact category

The priorities of these impact categories could not be ranked in their entirety due to the fact that no methodological model is currently available for their characterization. Hence the interpretation here is limited to an analysis of the individual inventory analyses results.

13. The “aquatic eutrophication” impact category

- The overfertilization of lakes and other inland waterbodies occasioned by elevated nutrient inputs is highly detrimental to aquatic ecosystem functions and structures such as biotic community diversity and composition. However, this mechanism has very little direct effect on the “human health” area of protection (i.e. on drinking water use and swimming water quality).
- All hierarchical levels of aquatic ecosystems are affected by eutrophication.

- Most effects of eutrophication on aquatic ecosystems should be regarded as being irreversible.
- Although eutrophication is an omnipresent phenomenon, it has the most severe impact on coastal and inland waters, particularly coastal water habitats, which are especially important areas of protection by virtue of their ecological functions.
- Inasmuch as the cause and effect relationships that come into play here are highly complex, forecasts regarding the ecological effects of eutrophication are fraught with high uncertainty.

Ecological severity: B

14. The “terrestrial eutrophication” impact category

- Soil eutrophication has an extremely deleterious effect on terrestrial ecosystem structures, functions, and biodiversity.
- All hierarchical levels of aquatic ecosystems are affected by eutrophication.
- Although some effects of eutrophication are reversible over the long term, the effects of eutrophication on ecosystem biodiversity are irreversible for the most part.
- Terrestrial eutrophication is a pan-European phenomenon, but the regional scope of its qualitative ecosystem effects varies.
- Inasmuch as the cause and effect relationships that come into play here are highly complex, forecasts regarding the ecological effects of eutrophication are fraught with high uncertainty.

Ecological severity: B

15. The “land use” impact category

- Land use has substantial detrimental effects on ecosystem structures and functions.
- The ecological effects associated with land use have an impact on all hierarchical levels of ecosystems.
- Most such ecosystem effects are irreversible or are only reversible over the long term.
- Land use is a worldwide problem. Although the effects of land use on ecosystems can vary greatly from one locale to another, effects such as species composition changes and species extinction should be regarded as global biodiversity changes. For example, an island species becoming extinct is not a problem specific to one island, but is rather a global problem since it impinges upon the biodiversity of the entire living world.
- The cause and effect relationships between land use and the consequent structural and functional changes in ecosystems are extremely complex. Hence the extent of the ecological damage attributable to land use cannot be prognosticated satisfactorily, and any such prognostications are fraught with high uncertainty.

Ecological severity: A

The following priority ranking should be applied if empirical data is available concerning the extent of land use:

- Near-natural areas that fall into **naturalness class I** exhibit no adverse ecological effects and thus are not subject to an ecological threat. The relevant ecological characteristic of such areas is that they are not used for anthropogenic purposes. These are areas that are subject to ecological protection or that have been taken out of use. Insofar as any human activity reduces the proportion of an area that is designated as "naturalness class I," an ecological severity ranking of A is allocated to that area.
- The ecological severity of **naturalness class II** is ranked as negligible since shifting the naturalness class allocation to naturalness class II (e.g. natural forest) has been defined as a target environmental status.
- The ecological severity of **naturalness classes III, IV,** and **V** are given **D**, **C**, and **B** rankings respectively, since the lower the naturalness ranking of an area (i.e. as ordinal naturalness class numbers ascend), the greater the decline in ecosystem self regulation capacities and functionality, in species populations and ecosystem viability, and the smaller the chance of reversing adverse ecological effects.

16. "Photochemical oxidant formation/summer smog" impact category:

- Summer smog adversely affects ecosystem structures and functions, as well as human health.
- Inasmuch as cause and effect relationships underlying smog formation have been relatively well described, they can be prognosticated with reasonable accuracy.
- Summer smog mainly exerts its effects at the lower hierarchical levels of ecosystems, which means that individuals (e.g. human beings) or populations (crop plants, crop damage) are harmed, but ecosystem structures and functions as a whole remain virtually untouched.
- Most effects of summer smog on areas of protection are reversible.
- Summer smog has no direct effect on future generations; only the generation that is actually exposed is affected.
- The effects of summer smog range primarily from regional to trans-regional and are seasonal in nature.

Ecological severity: D

17. "Resource use" impact category

- Raw material extraction for fossil fuel mainly affects the "resource" area of protection.

- Resource use can be regarded as irreversible by virtue of the fact that the re-formation rate of fossil fuels is negligible relative to the extraction rate of these materials.
- There is no severity time lag, and thus no uncertainty regarding resource use, i.e. since consumption and use are identical, no cause and effect relationship is needed.
- Resource use is a problem of global scope.

Ecological severity: C

18. “Stratospheric ozone depletion” impact category

- The increase in UV-B radiation intensity engendered by ozone depletion has serious deleterious effects on ecosystem functions and structures, as well as on human health.
- Most of the effects of ozone depletion occur at the lower hierarchical levels of ecosystems.
- Some effects are reversible, albeit with a substantial time lag, whereas others are irreversible.
- The effects of ozone depletion occur at the global level. Substantial effects are currently being observed in the polar regions. However, in view of the time lag to which such effects are subject, their spatial reach is bound to increase.

Ecological severity: A

19. “Global warming” impact category

- It is safe to assume that the climate change brought on by global warming will have a catastrophic impact on ecosystem functions and structures, as well as on human health.
- In view of the extreme complexity of the cause and effect relationships that come into play, as well as the lengthy time lag of the onset of the relevant effects, any forecasts of the nature and scope of the effects of global warming are inevitably fraught with very high uncertainty.
- The effects of global warming occur at all hierarchical levels of ecosystems.
- Virtually all effects of global warming are irreversible.
- The effects of global warming occur at the global level.

Ecological severity: A

20. “Acidification” impact category

- Soil and waterbody acidification and the associated secondary effects impinge acutely on the structures and functions of both aquatic and terrestrial ecosystems; the secondary effects may also pose a human health hazard.
- The effects of acidification mainly occur at the middle hierarchical levels of ecosystems.

- A substantial number of the effects of acidification are irreversible.
- Although acidification is a global problem, the scope of its regional effects varies widely.
- The cause and effect relationships associated with acidification are highly complex, but have been relatively well described; thus the consequent uncertainties are limited in scope.

Ecological severity: B

B: Priority rankings based on the distance to target criterion:
(see section 2.2.4 in the main section for assessment criteria)

21. "Direct human toxicity" impact category and

22. "Direct ecosystem damage" impact category

The priorities of these impact categories could not be ranked in their entirety due to the fact that no methodological model is currently available for their characterization. Hence the interpretation here is limited to an assessment of the individual inventory analyses results.

23. The "aquatic eutrophication" impact category

- The environmental quality objectives for the achievement of waterbody quality class II in flowing waters are exceeded at 80 percent of German flowing waterbody monitoring sites. In addition, more stringent quality objectives are needed to protect the North Sea.
- The quality of Germany's flowing waterbodies has improved in recent years. CSB inputs is on the decline.
- Overall emissions of P compounds are on the decline.
- Reductions of the N and P compound inputs that provoke aquatic eutrophication are governed by international obligations within the framework of OSPARCOM, HELCOM, river protection commissions and so on.
- Although emissions can be reduced to some extent via technical measures, for the most part they can only be eliminated by changing agricultural policies; and so presumably such emission reductions would be difficult to implement.

Distance to target: C

24. "Terrestrial eutrophication" impact category

- Critical loads for forest eutrophication are exceeded in 95 percent of Germany's forestal areas, and are exceeded in nearly 100 percent of more fragile ecosystems such as moors and heaths.
- In 5 percent of Germany's forestal areas, inputs currently exceed critical load values by a magnitude of more than 4.5; the exceedance for the remaining areas is less than 4.5.
- Emissions of some eutrophying substances are declining slightly. NO_X emissions are expected to decline moderately by 2010, whereas ammonium emissions are likely to remain at current levels unless current agricultural and environmental policies are reformed.
- ECE, EU and other international agreements have been reached for NO_X emission reductions, but not for ammonium.

- Emissions can be partially reduced through the use of technical measures; but any substantive reduction would necessitate reforms in agricultural, transportation and economic policies.

Distance to target: B

25. "Land use" impact category

- Only about 7 percent of Germany's territory is currently designated as priority nature protection areas, which means that the environmental quality objective of extending this protection to 15 percent of the country's territory has only been half achieved.
- The degree of land use in Germany is currently remaining at a steady level and to some extent is decreasingly slightly.
- If land use is to be reduced significantly, far reaching reforms in social, transportation, agricultural and economic policies will be needed.

Distance to target: B

- ***managed forests***:
  The distance to target for Germany's managed forests is ranked as A owing to the fact that naturalness class II has been achieved in only 5 percent of these areas.
- ***wilderness areas and non-exploited forestal areas:***
  The distance to target for Germany's naturalness class I forestal areas is currently C due to the fact that the target status (10 percent wilderness/non-exploited forest areas) has been half achieved.

26. "Photochemical oxidant formation/summer smog" impact category:

- The critical levels that have been defined for ozone related vegetation damage are currently exceeded by a factor of approximately 3 virtually everywhere in Europe.
- Even if optimal smog reduction technology were applied, a Europe-wide reduction in the critical level for vegetation damage would be out of reach.
- VOC and NO_X emissions are decreasingly slightly.
- In order for the "human health protection" environmental quality objective to be reached, emissions of the precursor substances NO_X and VOC would have to be reduced by 70-80 percent of their mid 1980s levels.
- Precursor substance emissions can be reduced only in part through technical measures; the lion's share of these emissions can only be reduced by reforming transportation, agricultural and economic policies.

Distance to target: B

27. “Resource use” impact category

- Current fossil fuel use is highly incompatible with the objective of sustainable resource use.
- Fossil fuel use is continuing to rise.
- If fossil fuel use is to be reduced significantly, far reaching reforms in social, transportation, agricultural and economic policies will be needed worldwide.

Distance to target: B

28. “Stratospheric ozone depletion” impact category

- Global ozone depletion is on the rise despite substantial worldwide reductions of the offending emissions (CFCs and halons)
- These emissions are still on the decline.
- CFC and halon emission reductions are governed by international agreements such as the Montreal Protocol, which unfortunately has not been signed by all nations (e.g. China, which is a major producer of these substances).
- HCFC compounds – likewise a source of ozone depletion, albeit to a lesser degree – will continue in use, in some cases as a substitute for CFCs. HCFC production and emissions are on the rise.
- Although substitutes for ozone depleting substances are within reach from a technical standpoint, greater international efforts are needed in this domain.

Distance to target: D

29. “Global warming” impact category

- According to scientists, in order for the environmental quality objective of a maximum 0.1 °C/decade temperature rise to be achieved, national carbon dioxide emissions will have to be reduced by approximately 80 percent relative to 1990 levels.
- Carbon dioxide emissions are on the rise worldwide.
- In order to reach the aforementioned quality objective, far reaching reforms in social, energy, transportation, agricultural and economic policy will be needed.

Distance to target: A

30. “Acidification” impact category

- The critical loads for acidification are currently exceeded in approximately 80 percent of all forestal areas in Germany.
- The current load in 5 percent of all German forestal areas is a minimum of 8.5 times higher than the critical load value; the load factor is lower than this in the remainder of the country’s forestal areas.

- Sulfur dioxide, ammonium and NO_X emissions will have to be reduced by approximately 20 percent relative to current levels in order to reach critical loads throughout Germany.
- Acidifier emissions are on the decline. Sulfur dioxide emissions are expected to decline substantially by 2010; a reduction in NO_X emissions is also anticipated, but to a lesser degree. On the other hand, ammonium emissions are unlikely to decline if current agricultural practices remain unchanged.
- Reductions in acidifier emissions (except for ammonium) have been defined in international agreements such as those concluded by the ECE and EU.
- Emissions can be partially reduced through the use of technical measures; but any substantive reduction would necessitate reforms in agricultural, transportation and economic policies.

Distance to target: B