Life Cycle Impact Assessment definition study: Background document III

Analysis of midpoint categories

This background document reviews 12 different midpoint categories. For each midpoint category, it start by describing the impact category and the related impact pathways and by carrying out a short and non exhaustive review of the state of the art. Specific scientific and practical challenges are then considered together with existing bases and resources to address these challenges. This finally leads to proposed actions toward recommended practice

4.1 Ozone depletion

Ruedi Mueller-Wenk

a) Description and State of the art

Impact pathway: A number of persistent gaseous compounds released to the air may produce a growth of clorine and bromine concentrations in the stratosphere, causing a reduction of the stratospheric ozone concentrations, with a time lag of many years. This reduction of stratospheric ozone is unequally distributed over the globe, with a tendency to be less important in equatorial regions and more important in polar regions and mid-latitudes. The consequence is an increase of solar radiation, particularly UVB, on earth's surface. Increased UVB radiation over long periods (years or decades) is known to have a detrimental influence on human health.

LCI results: At the level of LCI results, several dozens of compounds released to the air exist, with a known effect of reducing stratospheric ozone concentration. These compounds are mostly man-made, and characterised by high chemical stability (years or decades) and by inclusion of F, Br and Cl atoms. Main classes of such compounds are CFCs, Halons and HCFCs. Although the global production of these compounds has been reduced substantially, combined with a shift to relatively less detrimental formulations, emissions still continue and may appear in LCIs.

Midpoint impact category ‘ozone depletion’: The impact pathway of the stratospheric ozone depleting compounds is similar, so that is was possible and practical to group them into a midpoint impact category ‘ozon depletion’. The corresponding midpoint indicator expresses the ozone depletion potential of 1 kg of a given compound, relative to the ozone depletion potential of 1 kg of CFC-11. The time-lag between emission and ozone depleting effect varies from substance to substance. An updated set of Ozone Depletion Potentials ODP for the relevant compounds was published by WMO in 1999.

(How far is the fate modelling consistent with other categories ?)

Areas of Protection and Damage Categories addressed:
Human Health: Increased UVB radiation due to ozone depletion may interact with the surface of the human body, if the latter is not adequately protected by clothes or other precautions. A life-long exposition of the human skin to UVB can result in non-letal or letal types of skin cancers, and epidemiological research indicates that ozone depletion is a significant factor contributing to the total of currently observed skin cancers. Similarly, a life-long exposition of the human eye to UVB radiation can cause cataract, leading to blindness if the appropriate eye surgery is not available due to local economic and social situation. In addition to the currently observed damage to human skin and human eye, the long time-lags in the impact pathway has the consequence of building up further cases of skin cancer and cataract in future years, due to past and current emissions.
Natural Environment: Although scientific data are not available, it appears plausible that increased UVB radiation could also cause health implications to animals and plants, because their surface tissues are attacked by vectors of high energy content which are able to destroy structural elements, if this surface tissue is not protected by hairs or similar items. But as a fundamental difference to AoP human health, a decreased well-being of individual animals or plants is not considered as a damage in prevailing LCIA concepts. Even if a lots of animals become sick due to increased UVB radiation, it is still possible that this has no detectable influence on the dynamics of population of the corresponding species. As a provisional decision, it might be stated that ozone depletion has *no* impact link to AoP natural environment.
Man-made Environment: It is known that certain materials, particularly plastics, are attacked by UV radiation. In consequence, an impact from ozone depletion to man-made environment cannot be excluded. However, it appears that in current practice, such damages are not relevant so that it is defendable to omit the corresponding link in the LCIA impact network.

Degree of certainty of quantitative modelling of the impact pathways: Current knowledge appears to be sufficient for a quantitative modelling of the complete impact pathways from LCI results via midpoint impact category ‘ozone depletion’ up to the damage indicator for AoP human health.

b) Specific challenges

It is desirable to improve the scientific knowledge regarding the impact pathways between LCI results and the reduction of stratospheric ozone concentration as a function of time and geographical area.

c) Bases/resources to address these challenges

Scientific knowledge regarding the impact pathways in the context of stratospheric ozone depletion is available at RIVM in the Netherlands and at the MIT in Boston US

Eexperts with widely accepted scientific authority are H. Slaper of RIVM,and Mario Molina, at MIT, Nobel price on the subject of Ozone hole.

d) Proposed actions toward recommended practice

Acceptable propositions for modelling the full network of impact pathways regarding stratospheric ozone depletion are available, e.g. Goedkoop and Spriensma (1999), Steen (1999), Hayashi et al. (2002).

In comparison to other parts of the LCIA impact network with a higher priority, it appears defendable to allocate, within the LC-Initiative, only limited resources for stratospheric ozone depletion.

In consequence, we propose only activities of level 0 (i.e. reviewing ODP-related projects).

4.2 Climate change

Helias Udo de Haes and Reinout Heijungs (adaptation Olivier Jolliet)

a) Description and State of the art

Impact pathway: Greenhouse gases have many types of impact: temperature rise, changes in precipitation, sea level rise, change of ocean currents, storms, hurricanes, and possibly others eventually leading to impacts on human health and on biotic natural resources. All of these types of impacts depend on changes in radiative forcing (expressed as W/m2). So this category offers the opportunity for a science based midpoint indicator, the well known Global Warming Potential (GWP). If weighting is performed at midpoint level due to too high uncertainty in the description of further impact pathways, climate equilibrium can be considered as a life support function to be protected as such: the capacity of the environment to provide the conditions for a long term stable climate on earth. This helps making explicit the values behind such a midpoint indicator.

b) Specific challenges

Two points need to be discussed:

1) the time period
2) the background level.

It is important to aim at a consistent approach which is (or will become) applicable for all impact categories. Therefore at least a comparison should be made with developments in the area of toxicity modelling.

Time period

For toxicity modelling the simplest way is steady state modelling, using multimedia models, which is mathematically equivalent to the integration of the impacts of a pulse over infinite time. So at least for methodological "best practice" reasons infinite time (or steady state modelling) should be included.

Now from a policy standpoint there are good arguments for a shorter period of time. These reasons all deal in one way or the other with uncertainty about the future: the life time of measures and their impacts, possible new technical measures, adaptations of organisms, and time discounting. If this is taken into account, a time period of 100 years is often chosen. For toxicity modelling there are now various approaches to shorten the time period from infinite time to this 100 years. Several methods suggested that for climate change also this 100 years period will be taken. We leave it open which of the two should be the default: the technical infinite time or the political 100 years.

Background level

In toxicity modelling we see a gradual shift from modelling without background levels being taken into account (PEC/NEC ratios), to modelling with background levels included (modelling in terms of PAFs). Now the GWP modelling does already include background levels, based on specific "best guess" scenarios. A problem is that these scenarios are not well known in the LCIA community. On the other hand, one can argue that the thinking in the IPCC is on this point advanced over the thinking in the LCIA community, and that the latter will step by step approach towards IPCC practice. Taken this into account there is little reason to strip the IPCC models from the background levels. So it is suggested that the well known factors will be used.

c) Bases/resources to address these challenges

- Here the work of IPCC is clearly the most relevant. However, several methods and assumption exists and a closer look is necessary to choose the set of indicators
- For damage categories, the Japanese projects provides interesting inputs.

d) proposed activities

In comparison to other parts of the LCIA impact network with a higher priority, it appears defendable to allocate, within the LC-Initiative, only limited resources for climate change as this is covered by IPCC. In consequence, we propose only activities of level 0 (i.e. reviewing IPCC-related projects) and suggest to take profit of national projects to arrive to best suitable proposal on methods and related factors. We therefore suggest to:

- Follow new IPCC developments and analyze the different options offered by the latest results of IPPC
- Ensure consistency with fate & effect modelling in other categories (time horizon, background levels)
- One important activity is to model or at least describe the related damages on ultimate area of protection. Here again, inputs from IPCC and from the Japanese national LCA project could be highly relevant to help interpreting the generated damages.

4.3 Human toxicity

Olivier Jolliet & David Pennington (review: Jane Bare)

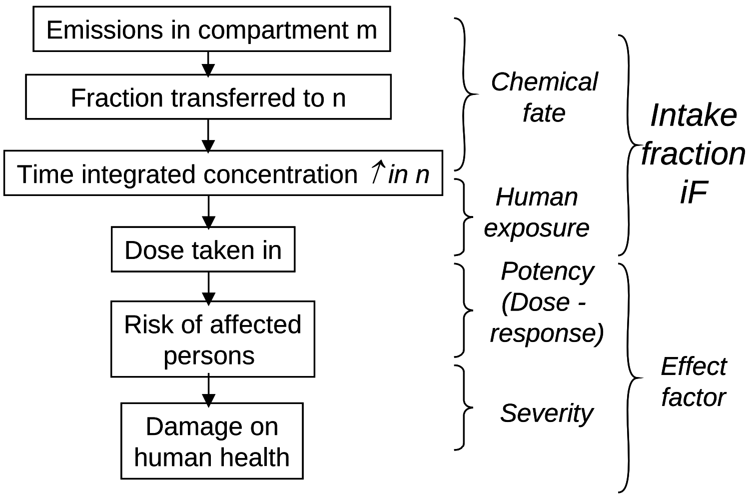
a) Description and state of the art (1 to 2 p. max)

principles and possible methods

Available characterisation factors for toxicological impacts on human health in LCA try to account for chemical fate, human exposure, and toxicological effects (Jolliet et al. 1996, Guinee et al. 1996, Hertwich et al. 1998, Huijbregts 1999, Goedkoop and Spriensma 1999, Udo de Haes et al. 2002):

$$\frac{\text{Effect}}{\text{Emission}} = \frac{\text{Fate}}{\text{Emission}} \cdot \frac{\text{Exposure}}{\text{Fate}} \cdot \frac{\text{Effect}}{\text{Exposure}} \qquad (1)$$

Figure 1 summarizes the different types of information of relevance to human toxicity: fate is composed of transport in the environment on the one hand followed by exposure, leading to a given intake. It is then combined with an effect factor characterizing the potential risks linked to the toxic intakes. In a damage oriented approach, severity of damages could be finally characterized.



Many of the methods developed in the last ten years rely directly on simple adaptations of regulatory-risk orientated methods and data (Guinee et al. 1996, Hertwich et al. 1998, Huijbregts 1999), providing measures such as:

$$\text{Characterisation factor} = [\text{Intake/RfD}]_X \big/ [\text{Intake/RfD}]_{Ref} \qquad (2)$$

where intake is the predicted (marginal) human exposure for a unit emission rate (mg per kg body weight per day) of chemical x, RfD denotes the Reference Dose - a policy-based effect threshold measure adopted in regulatory safety applications -, and the subscript "ref" denotes a reference substance, such as toluene. The results are therefore reported in terms of equivalents of the reference substance, such as toluene equivalents. Pulse emissions in a life cycle inventory are then directly multiplied by such ratios and summed, providing a final estimate of e.g. toluene equivalents per functional unit in an LCA.

Recently, a group of scientists, with both risk assessment and LCA backgrounds, proposed to address fate and exposure at a population level by introducing the intake fraction: the time and space integrated fraction of a mass of chemical released into the environment that will result in human population exposure (Bennett et al. 2002). This is a useful concept for LCA as an the interface between fate & exposure and effect side.

In addition to cumulative risk, a growing number of methods account for differences in the potential consequences of toxicological impacts on human health (Crettaz et al. 2002, Pennington et al. 2002, Udo de Haes et al. 2002, Goedkoop and Spriensma 1999, Hofstetter 1998). Measures like Quality Adjusted Life Years (QALYs) and Disability Adjusted Life Years (DALYs), for example, take into account potential differences in the severity of effects (further discussion of these measures is given in Hammitt (2002), Hofstetter & Hammitt (2002), and Hofstetter (1998). However, on the one hand values are not readily available for most non-cancer effect endpoints at this time. Differences in such effects are currently taken into account, quanitatively using default estimates (Pennington et al. 2002) and qualitatively (Owens 2002), through adaptations of the severity based categories of endpoints proposed by Burke et al. (1996). On the other hand, in risk assessment, the margin of exposure (ratio of dose taken in to Reference doses or acceptable daily intake) approach is based on the fact that we want to avoid any types effect, without summing up across or comparing the different effects. Once, the same RfD or ADI are used in LCA to calculate an overall human toxicity score for different toxics, this could implicitly mean that equal weighting is assumed whatever the severity of the endpoint.

Even using these recent marginal approaches outlined here, and in spite of advances in terms of accounting for differences in emission scenario (location, dispersion, point source, from stacks, in densely populated areas, …), current estimates for toxicological impacts in LCA generally provide preliminary, or screening level, insights only. While the calculation of characterisation factors can allow for the consideration of non-linear low dose response curves, biological thresholds, the influences of the complex mixtures found in the environment, and multiple background exposure concentration levels, the availability of required data remains too limited in practice (Pennington et al. 2002). Assumption of default linear low dose, marginal response relationships based predominantly on chemicals tested in isolation in laboratories or associated estimations remains pragmatically necessary. For truly non-linear dose-response curves with mechanistic thresholds, some of the marginal cumulative risk measures in LCA may only reflect "erosions of margins of exposure" - impacts on the capacity of the world to accommodate such emissions. Acknowledging such high model uncertainties will remain important when interpreting the results of an LCA study.

Scope:

Finally, the scope of this category needs to be discussed further: so far LCIA work on human toxicity mainly concentrated on the impacts of diffuse outdoors emissions. Should other Indoor Air, Consumer Exposure to off-gassing emissions from products, impact of worker health and safety, impact of ionizing and non ionizing radiation. Will these be addressed? Why or why not? When (is?) it appropriate to include these categories? This should all tie in well with the taxonomy discussion which should lead the entire document.

At this level, a few elements can be mentioned: on the one hand, one has to acknowledge that LCA has its limitations and that different tools have to be applied to take different decisions. For example, the ability to deal with acute toxicity is limited as local individual exposure are often not known within a life cycle system.

On the other hand, neglecting significant trade-off could lead to biased decisions and it is interesting to examine the feasibility to include such effects in the assessment of human health impacts:
- In principle the above-described concept of intake fraction is also used in different context to model the impact of indoor emission and the exposure of consumers to off-gassing emissions from products, usually leading to very high intake fraction compared to outdoor emissions.
- If prediction of individual exposure in the work environment is usually not feasible within an LCA, Hofstetter (2002) shows the possibility to address the work environment through statistics per industry sectors. Further details on work environment have been studied by a dedicated SETAC working group (Jensen et al., 2002).

- For ionising radiation, damage factors have been developed by Frischknecht et al. (2000) in terms of yr/kBq, and by Solberg-Johansen (1998). In Goedkoop & Spriensma (1999) the damage level of an early version of Frischknecht et al. (2000) in terms of DALY's have been included.
- For non-ionising radiation, the framework of figure 1 could in principle enable its incorporation once more specialized knowledge will be more mature and become available on the basis of epidemiological studies. Further work is however clearly needed before arriving to operational factors

b) Specific challenges (1/2 p.)

The following scientific challenges are amongst those that exist in the context of regional human health toxicological effects to help advance the current state-of-the-art:

- Develop and/or identify best available practical models and methodologies to calculate best-estimate fate factors (intake fractions), including accurate estimate of exposure pathways, especially through food intake. The question of bioconcentration in plants and animals is of central importance for substances leading to high intake fractions. Present data are based on very few experiments often used outside their validity field (correlations with Kow, etc) and this area clearly requires more investigations.
- The feasibility to identify morbidity endpoints for humans and to extend consequence measures, such as DALYs per incidence, to non-cancer effects.
- Address essentiality and speciation of metals
- The development of simplified methods that can be readily applied for screening with low quality/amounts of data, as well as more advanced models that adopt higher relevance/peer reviewed data to give factors with higher confidence (but which will be less commonly available).
- Quantify uncertainty (model, parameter, and scenario) associated with different estimates (possibly adopting the categories of Hofstetter 1998 as a starting example for parameter uncertainty and including estimates for the screening methods).
- To address the ability to deal with multiple effects which occur from single chemicals. (e.g., the most severe effects vs. the lowest concentrations causing effects).
- To address the combined effects of various mixtures – some common (asphalt mixtures, gasoline mixtures) and some less common.

c) Bases/resources to address these challenges (1/2 to 1 p.)

In addition to individual research projects at different institutes, the EU OMNIITOX project and the US TRACI project are examples of an international initiative with the potential to advance the current state of the art and to establish a best available practice in the context of characterizing toxicological impacts for LCA.

Scientific experts in the domains of chemical fate, human exposure, and toxicological effects are numerous. However, attention should also be given to identify experts that are very familiar with the objectives of life cycle impact assessment and many of the recent developments. The table below provides an associated summary of *some* of the well-known researchers with in-depth methodological knowledge (presented in random order).

d) Proposed actions towards recommended practice at (1 p.)

Within the framework of figure 1, modules could be addressed using models of different kinds, like for standard components in automobile industry which can be easily replaced by plug-in: On the one hand, the LC initiative should encourage scientists to work together to develop best recommended models for different modules, which could then be adapted to regional specificities. On the other hand, due to data and model availability, recommended practice could lead to different models for different situations and substances. In that case the framework provides a modular structure that provides a transparent basis for researchers with specific expertise to develop appropriate models that fit into the framework using the same inputs and outputs.

The following activities could be foreseen

a) Stimulate collaboration between OMNIITOX model development, TRACI development and scientists active worlwide (e.g. end 2003), including:
- Open challenge to improve individual modules (2003-2004)
- Comparison workshop between modules and with other models (beginning 2004)
- Selection of recommended models and calculation of generic factors corresponding to typical emission situations (end 2004).

This could include

- Proposal of a recent open-architecture model/framework for the estimation of toxicological human health characterisation factors – providing modules for the fate of chemicals in different environmental compartments, human exposure pathway models, and toxicological (cancer + non-cancer) effects.
- Peer review of sub-modules of proposed approach by domain experts to identify clear areas for improvement or modification.
- Invitation to specific domain experts, as well as open public invite, for specific proposals to suggest further improvements/additions.

b) Based on the 2002 Montreal ICMM workshop, a specific group of participants could be asked to arrive with a proposal in a document on how to consider essentiality and speciation of metals in LCIA. This could be of interest to metal industry (ICMM) within a case study.

c) Data collection and supply for a wider range of chemicals, with the support of US-EPA (make their own effort known and widely available)

d) Further investigation on the scope of the category regarding indoor emissions, worker health, ionizing and non ionizing radiations. This should all tie in well with the taxonomy discussion which should be carried out on the entire document (see section 3.2).

4.4 Accidents

a) Description and state of the art (1 to 2 p. max)

Finally, the scope of this category needs to be discussed further: As discussed in the second part of section 4.3a, so far very few LCA studies have considered accidents by physical impacts and the discussion on scope of section 4.3 also applies here. Again, on the one hand, one has to acknowledge that LCA has its limitations and that different tools have to be applied to take different decisions and that the prevention of individual accidents is out of the scope of LCIA. On the other hand, neglecting completely damages on human health due to accident over the life cycle of a product could lead to biased decisions.

As a matter of fact, accidents statistics are usually available in term of risks and enable to short cut the fate part of figure 4.3.1 and provide data directly in term of mortality and morbidity. This could then be eventually compared to other damages on human health if there can be modelled up to endpoint.

b) Proposed actions towards recommended practice at (1 p.)

- As a first step: further investigation on the scope of the considered impact on human health and on the need to include accident statistics.

- Eventually elaboration of typical damage factors on human health for screening LCA

4.5 Photochemical Smog

Rita Schenk (review: Jane Bare):

a) Description and state of the art (1 to 2 p. max)

Photochemical smog is caused by the release of both natural and man-made substances into the atmosphere, and their reaction in the presence of sunlight. The most highly studied portion of photochemical smog is the creation of ground-level (or tropospheric) ozone from the interactions of volatile organic substances (VOC's) and oxides of nitrogen. Ozone is a toxic gas which has been shown to cause respiratory distress in people and other mammals, as well as causing reductions in the primary production rates of aquatic and terrestrial plants. Oxone acts through the creation of free radicals, which are implicated in carcinogenesis as well as in the destruction of cellular membranes. Background levels of ozone are approximately 10ppbv. Damage to crops has been observed at 20 ppbv, and to animals at 40ppbv.

Midpoint indicators for smog follow two models: that developed in Northern Europe is based on the calculated photochemical ozone creation potential (POCP). It is expressed in units of ethylene. The POCP is calculated based on different scenarios in Northern Europe. In the United States, Photochemical ozone production is estimated based on the Maximum Incremental Reactivity (MIR), and is measured in units of O_3. MIR is based on laboratory measurements of the maximum amount of ozone that can be produced by given VOC's in an artificial atmosphere that represents the weighted average of U.S. cities. MIR is the indicator used in TRACI.

Both these approaches are midpoint indicators, and speak to both human and ecological health.

b) Specific challenges (1/2 p.)

The POCP approach has the advantage that it provides different scenarios, and the disadvantage that it does not evaluate non-Northern European situations. The MIR approach is a simpler one to use, but its results have not been verified outside of North America. On a more basic level, it is not clear that measuring or estimating the ozone in smog is the best indicator of the overall effects of smog. For example peroxyacetyl nitrate and other photochemically produced substances may cause damage to human health and the environment.

As MIR and POCP approach are based on specific situations, it should also be studied how far this is consistent with the comparative approach required in LCIA: how this relates to other impact categories, also in term of mean versus extreme responses of time horizon ?

c) Bases/resources to address these challenges (1/2 to 1 p.)

- It may be possible to perform the kinds of simulations necessary to test MIR or POCP in other parts of the world.

- Basic studies and atmospheric chemistry are necessary to determine if other substances besides ozone should be studied in the context of smog.

d) Proposed actions towards recommended practice at (1 p.)

- For now, the use of MIR and POCP should continue. However, inquiries to the developers of POCP and MIR should be made to determine if they are able to or willing to expand the coverage of these indicators and if an adaptation to comparative assessment is required. *A priori*, it seems likely that MIR would be the easiest to adjust to other atmospheres, since it does not require extensive site-specific fate and transport modeling.

References

POCP: http://www.ivl.se/rapporter/pdf/B1305.pdf
TRACI & MIR http://www.epa.gov/ord/nrmrl/std/sab/AICHE2002paper.pdf

4.6 'Traffic Noise':

Ruedi Mueller-Wenk

a) Description and State of the art

Impact pathway: Whilst inclusion into LCA of noise from stationary sources seems to be a problem of lower priority, it is an accepted fact that environmental noise emissions from traffic systems (road vehicles, rail vehicles, aircraft) exert a heavy load on an important proportion of most country populations, with noise levels that affect their well-being, so that noise effects from transports should be represented in LCA. In general, health effects of noise are not caused by the emissions of a single vehicle as a separate event, but rather by the continuous noise caused by all vehicles using a certain traffic channel within an extended period of time. This continuous noise is usually measured as the equivalent continuous sound pressure level LAeq,T , summing up the total energy over some time period T, and resulting in a level equivalent to the average sound energy over that period. The higher LAeq,T is, the more damage is exerted on the health of persons living along streets, railroads and airport areas; information is available linking the probability of specific health effects to the magnitude of LAeq,T under which a population lives. The contribution of a single vehicle, respectively a single transportation task, to the LAeq, T can be calculated by generally accepted calculation methods. In consequence, it is possible to allocate tiny fractions of health cases to single transport activities.

A basic problem of traffic noise assessment in LCA is that the exact route of a transport across the network of paths is generally not known, so that it is difficult to say which part of the population is hit by the noise emissions. This problem can be solved by assumptions on the annual increase of traffic over the whole network, and by considering the single transport activity as a tiny fraction of this general traffic increase over this whole network. Are these networks of traffic paths to be seen on regional, country, continental or global level? A practical compromise is to consider street and railroad networks at a country level. Air transport networks are a special case, insofar as the noise problem is concentrated around the airports and their starting and landing corridors, whilst the populations below the routes between the airports are not exposed to high levels of aircraft noise.

LCI results: For street and railroad transports, the relevant information referring to noise at the level of LCI results should consist of the following data elements:
- transport distance in km
- code indicating daytime or nighttime transport
- country street/rail network where transport is executed
- category of vehicle used (category expressing the level of loudness of the vehicle)
- part of the vehicle’s capacity used for the transport

In the case of air transport, the transport distance and country can be omitted, but names of airports used have to be mentioned.

This means that LCI results are not expressed directly in decibels or in another unit of noise emission, but rather by indirect data that is suitable to be converted into units of noise at the level of LCIA.

Midpoint impact category ‘transport noise’: As a practicable midpoint on the cause-impact chain from LCI results to human health effects, the mean Delta-LAeq,T over the whole traffic network used may be selected: All transport tasks executed during a year within the street or rail network of a given country contribute to an imputed increase Delta-LAeq of the continuous sound pressure level averaged over a year and the whole network. This contribution can be calculated on the basis of generally accepted calculation procedures. It is understood that this noise increase Delta-LAeq does not bescribe the time and the place of the physical noise produced by the transport activity, but rather a theoretical equivalent of this physical noise.

Areas of Protection and Damage Categories addressed:
Human Health: An increase Delta-LAeq of the continuous sound pressure level on a given street or rail network (or around an airport with its landing/starting corridors) can be linked to additional cases of sleep disturbances, communication disturbances and other types of health impairments within the population living in the reach of this noise source: 1000 Persons living e.g. under a background noise level of 60 decibels are expected to show additional cases of sleep disturbance, if the noise level is increased to 61 decibels, and information is available to estimate the
number of such additional cases. This information is based partially on social research results, and partially on epidemiological research.

Natural Environment: Transport noise may not only influence the well-being of humans, but also the well-being of animals. However, there is a lack of information confirming a possible influence of noise on the dynamics of population of noise-sensitive species. As a provisional decision, it might be stated that transport noise has *no* impact link to AoP natural environment.

Man-made Environment: Various studies have shown that the market price of appartments and houses is reduced in noisy areas. Although noise certainly influences real estate prices, it is inadequate to say that the Man-made Environment is damaged by transport noise. In fact, it is the well-being of humans that is actually damaged, and the reduction of real estate prices is merely an indirect consequence of this primary damage. To include also such price reductions of real estate into LCA would be a double count.

b) Specific challenges

In comparison to chemical emissions, the inclusion of noise emissions into LCA methods has not got much attention so far, in spite of the incontestable seriousness of the damage of noise to the health of humans. Within the LCA-Initiative, it is an important task to fill this gap
- by studying the available literature on health effects of noise
- by studying the available calculation models connecting vehicle-kilometers with the increase of continuous noise levels
- by evaluating the possible choices of LCI results and midpoint categories.

c) Bases/resources to address these challenges

Experts with widely accepted scientific authority in the fields of noise calculation models and noise-related health effects can be extracted from Berglund B. et al.: Guidelines for Community noise, published on behalf of World Health Organisation Geneva, 2000. As far as noise calculation models is concerned, experts are Dr. Hans Boegli, Dept. of noise prevention BUWAL, Bern CH, and K. Eggenschwiler, Leiter Abt. Akustik/Laermbekaempfung, EMPA, Duebendorf CH. As far as noise-related health damages is concerned, W. Passchier-Vermeer, TNO Leiden NL, C. Maschke, TU Berlin D, B. Griefahn, W. Babisch can be mentioned as experts.

d) Proposed actions toward recommended practice

Actions are proposed at level I:

A proposition for modelling the full network of impact pathways regarding health damages due to road traffic noise has been worked out by Müller-Wenk R.: Attribution to road traffic of the impact of noise on health, BUWAL SRU 339, 2002 Bern CH. This proposition should now be tested on case studies to examine the potential impact of traffic noise on human health compared to other impacts.

Alternative proposals for assessing road, rail and air traffic should be identified or developed, so that an evaluation of available concepts can be made.

4.7 Acidification

Norihiro Itsubo (review: Mark Goedkoop)

a) Description and State of the art

Impact pathway

Substances causing acidification such as sulfur dioxide and nitrogen oxides are diffused while a transportation along an air stream. These substances will be transformed to acidifying substances like sulfuric acid, nitric acid through oxidization and photochemical reactions. These acids finally deposit on the surface of the earth. The type of deposition can be divided into wet-type and dry-type. The amount of dry deposition is comparable to that of wet deposition, although the ratios between these amounts are depending on the region. These depositions may cause undesirable effects on terrestrial and aquatic ecosystem, man-made resources and even human health.

LCI results

Substances generating these acids are sulfur compounds (SO2, H2S, DMS), nitrogen compounds (NO, NO2), ammonia, chlorine, hydrogen chloride. Main acidifying substances are sulfuric acid and nitric acid. Hydrogen chloride and organic acids also contribute acidification occasionally. In addition, ammonia, behave as alkaline originally, can be treated as potential acid, because ammonia will be nitrified by bacterium after the deposition on soil in a short time. Emission sources of these above substances can be divided into artificial source and natural source. Incineration, refinery of metal, chemical industry and agriculture are main sources of the former part. DMS from oceans, ammonia from soil and SO2 from volcano also promote acidification as one of the natural source.

Early LCIA studies like Heijung et al (1992) based on midpoint approach developed a characterization factor evaluating the potential emission of proton from causative substances of acidification. This factor only gives relative information on the emission impact on the basis of sulfur dioxide equivalent. Several later studies (e.g., Potting et al. 1998; Huijbregts 1999) improved the circumstances considering regional sensitivity of ecosystems and atmospheric fate of causative substances. Although it seems that they are the most advanced models reflecting the natural phenomena in midpoint approaches at present, the following problems are still open.

(i) The impact on water living things are not taken into account.

(ii) The scopes of area to be assessed are limited. Some methodologies cover European, Japan and U.S. They can not deal with the impact on the other regions.

(iii) Some significant substances (ex. Ammonia, hydrogen chloride and hydrogen fluoride) are excluded in the scope of most models.

Recent studies (e.g.,Goedkoop and Spriensma (2000); Steen (1999); Hayashi et al (2002)) estimate concrete damage due to acidification. However, the subjects measuring the damage are independent of studies. Goedkoop and Spriensma focused on the impact on the terrestrial plant. Hayashi et al (2002) considered to measure the damage on plant growth and fishery. Steen took the loss of biodiversity into account in addition to the above subjects. In addition, endpoint approaches have also not solved the problems noted in the previous paragraph yet.

Area of Protection and Damage Categories addressed

Human Health

If ground water is acidified, the concentration of nitric acid and aluminum ion might be increased. These increases may cause cyanosis and Alzheimer’s disease. The studies that measure the quantitative relationship are insufficient. In addition, acidified ground water will promote the dissolution of metal on the surface of water pipe. This may also cause health impact. But this impact is not considered as serious as the other aspects comparatively. At present no studies regarding health impacts from acidification are performed in LCIA field.

Natural Environment
Terrestrial plants, aquatic living things and soil microbes may be affected by the deposition of acidifying substances.
The deposition of acidifying substances will promote the acidification of soil with the outflow of cation. These phenomena lead to the exudation of aluminum and heavy metals which prevent the growth of plant and cause a shortage of nourishment in plant. Several LCIA methodologies have taken the impact on terrestrial plant into account in their models.
Decrease of PH level influences on the inhabitant of fresh water fish. Tolerances of the decrease of PH are independent of species. Especially, wandering fish are considered to reveal high sensitivity against acid. In contrast, the tolerance of benthos for acid revealed higher comparatively. Very few LCIA study take the impact on aquatic living things so far, although this impact is considered as critical importance.
Acidification of soil also affect on the soil ecosystem. This hinders microbe decomposing organic matter and nitrifying strongly. The knowledge regarding the relationship acidification with soil microbes and the following impact on plants is insufficient. At present, there is no research consider this effect.

Man-made Environment
Like terrestrial plants, the growth of crops may be affected by acidification. But in the case of crops, the contribution of indirect impacts caused by soil acidification through the long time are seen as small comparatively, because the life time of crops is very short (one year more or less) than that of forest. Most of studies estimating the impact on crops caused by direct deposition of acidifying substances indicated that the decrease of crops is not critical within the present level.
Materials exposed acidifying substances might be damaged. The speeds of deterioration are independent of materials. Especially, steel and some building stone like marble are sensitive. The reduction of quality of materials causes the increase of maintenance cost and the loss of fortune.

b) Specific challenges
For midpoint approaches, there are international collaborative study like RAINS and EMEP fortunately. It seems effective way to start from these results and try to apply them to the assessment for another region. In order to apply them, background information such as critical load for each region have to be collected. Considerable time is required to investigate them. Ammonia and hydrogen chloride those are seen as important contributors should be treated in this category.

For endpoint approaches, a consideration of the damages on aquatic life and soil organism are insufficient. Damage on material and crops also has to be taken into account as one of the major impacts. ExternE has already considered assessing the impact on material. LCA national project of Japan take the impact on aquatic life and crops into account in the program. But these above considerations should be revised continuously.

c) Bases/resources to address these challenges
We should follow or take into account the results of international collaborative studies such as EMEP and RAINS. The contributions from the experts of these programs would be very helpful to proceed.

d) Proposal actions toward recommended practice

Actions are proposed at level I:

There are many activities internationally that can be applied to tackle with these problems. Researches to solve the above problems are required based on these contributions.

4.8 Eutrophication

Norihiro Itsubo (review: Mary Stewart)

a) Description and State of the art

<u>Impact pathway</u>

Airborne substances involving nitrogen and waterborne substances containing nitrogen and phosphorus may promote eutrophication in land and water area. The subjects suffering from eutrophication can be divided into aquatic and terrestrial life.

For the impact on aquatic life, the increases of nutrient to water area contribute to generate phytoplankton. The generation of large amount of phytoplankton in a short time may increase the risk of the emergence of red tide and also cause to increase the consumption of oxygen for decomposition of carcass of phytoplankton (organic substances). These phenomena may cause serious damage on fishery and biodiversity finally.

Additional organic compounds make the transparency of sea worse. A decline of transparency may hinder the photosynthesis of seaweed bed. This difficulty of production may also influence the food web of ecosystem.

For the impact on terrestrial life, the surplus of nitrogen may collapse the balance of nourishment in plant. This may result in the reduction of plant productivity and the impact on tree can be seen as the damage on forest and biodiversity.

<u>LCI results</u>

The substances including nitrogen and phosphorus are considered as causative substance of eutrophication. Nitrogen and phosphorus are essential for living things to survive, but the excess exposure of these substances cause undesirable phenomena for ecosystem. COD is also taken as a kind of causative substance in eutrophication, because the amount of organism that influences the concentration of oxygen is affected by the inflow of COD.

Animal husbandry, agriculture and food industry are considered as main sources of these above causative substances.

<u>Midpoint and endpoint impact category</u>

Researches of LCIA in eutrophication can be classified into three groups. The studies belong to the first group (e.g., Heijung et al (1992)) are based on the red-field ratio that denotes the representative composition of microorganism. Later studies (e.g. Heibregts (1999)) that add the result of fate models to red-field ratio can be classified into second group. Recent studies belonging to the third group are based on the damage modeling (e.g. Goedkoop and Spriensma (2000), Hirosaki et al (2002), Steen (1999)).

The types of advantages are independent of the groups. If we use a method in the first group, it is possible to cover many of substances in LCIA. When a method of the second group is applied, the deposition rate of air pollution can be considered. This inclusion may contribute to improve the quality of the result of LCIA. The application of the methodology in third group enables it to compare with the contribution of another impact categories.

b) Specific challenges

It should be noted that there is a specific characteristics in eutrophication. Taking a definite amount of nutrient is essential for life, but if they are provided too much, the damage may emerge. It is quite difficult to consider the balance of negative and positive effects in LCIA.
In addition, eutrophication appears at very local scale such as inland sea, lake and marsh. In order to reflect the characteristics of local area, huge information have to be collected at least.

For midpoint approaches, how to reflect the differences of the sensitivity of each area and how to generate the representative value from the localized information should be discussed. Several studies including fate model have already been developed. This deals with the transportations from air to water and soil. The transfer from soil to water has not been discussed yet sufficiently.

For endpoint approaches, the consideration of damage on aquatic life and fishery is insufficient. Damage on forest and biodiversity also have to be taken into account as one of the major impacts in eutrophication.

c) Bases/resources to address these challenges

Several studies measuring the impact of eutrophication exist in a national level. These activities might be basic information to tackle with the challenges described previously.

d) Proposal actions toward recommended practice

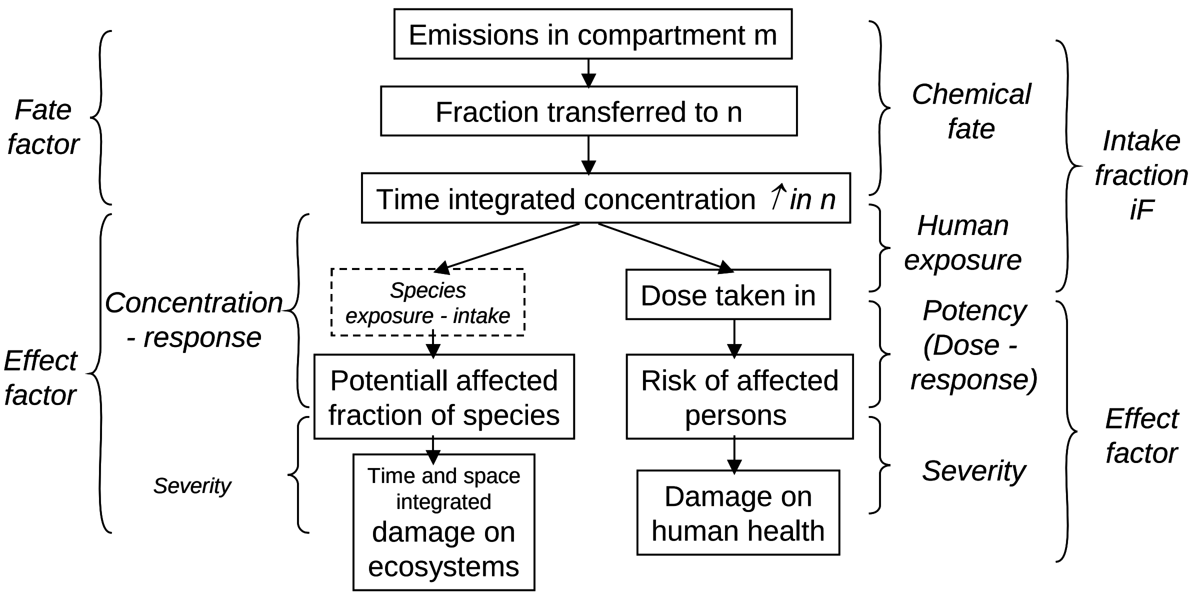
Actions are proposed at level II:
Unlike the circumstance of acidification, there is little international collaborative study available for LCIA. This makes it difficult to address the specific challenges compared to acidification. Further efforts to collect background information are required. A few years are required to address these problems described in b) specific challenges at least.

4.9 Ecotoxicity

Olivier Jolliet & David Pennington (review: Rita Schenk)

a) Description and state of the art (1 to 2 p. max)

In many respects, ecotoxicity is treated similarly to human toxicity including both fate and effect, with however some noticeable difference. First, we are generally interested in effect. Secondly, the same fate model is applied as for human toxicity, but the interface between fate and effect is at the level of concentration for ecotoxicity (figure 4.9.1). Exposure is generally implicitly taken into account in the effect factor. The fate factor enables to relate emissions to a concentration increase in the environment. It is directly linked to the equivalent residence time of the substance in the environment (the time and space integrated concentration per mass input of chemical released into the environment). It is then combined with an effect factor characterizing the risks at species level rather than on individuals eventually leading to a potentially affected or disappeared fraction of species and to a preliminary indicator of damage on ecosystems.



Hauschild et al. (2002) as well as Pennington et al. (2003) provide a good summarised review of existing knowledge in the field. Similarly to measures for human health, Guinee et al. (1996), Hertwich et al. 1998 and Huijbregts (1999), for example, provided characterisation factors in the context of ecotoxicological affects associated with chronic exposures to chemicals using established regulatory risk measures. Many of the methods developed in the last ten years rely directly on simple adaptations of regulatory-risk orientated methods and data (Guinee et al. 1996, Hertwich et al. 1998, Huijbregts 1999), providing measures such as:

$$Characterisation\ factor = {[PEC/PNEC]_X}\Big/{[PEC/PNEC]_{Ref}} \quad (2)$$

where PEC is the predicted environmental concentration over the predicted no effect concentration and PNEC an estimate of the predicted no effect concentration based on most sensitive species. In practice, the endpoint most often chosen is mortality, and thus the "no effect" level most often represents the singly generation no-mortality level. In risk assessment, the use of most sensitive species is based on the principle of avoiding any types effect, without summing up across the different effects or species. This approach has the virtue of identifying “safe” levels of contaminants in the environment, but poorly distinguishes between different levels of “unsafe” levels, thus making additions of impacts between chemicals problematic. Alternative measures have therefore been proposed for comparative assessment: Goedkoop and Spriensma (1999) proposed factors in the context of PAFs (Potentially Affected Fraction of species, Klepper O, van de Meent D. 1997), reflecting the marginal change in PAF per unit emission for background effect level assumptions of 10 to 50% PAF. This method draws on the concepts of concentration addition in mixtures and species sensitivity distributions (Posthuma et al. ….Hamers et al. … , Escher B., Hermens J.L.M., 2002). Huijbregts et al. (in SSD book) illustrated extensions of these concepts to also account for response addition in mixtures. Pennington et al. (submitted to ET&C) provided a review of these concepts, suggesting that model and scenario uncertainties will be high, but differences between methods in current practice will be primarily associated with the data sources and methods used to estimate the median multi-species effect level (HC50). A marginal risk-based effect measure, such as $\Delta PAFmixture = 0.5\times \Sigma\Delta C/HC50$, the change in the Potentially Affected Fraction of species that experiences an increase in stress for a change in contaminant concentration could be of interest. Payet et al. (2003) proposed to calculate this median and its uncertainty using bootstrapping to calculate the median and its uncertainty on the basis of chronic EC50 (concentration affecting 50% of the test species), as a measure of comparative damages.

As polluting a small lake versus polluting all the lakes in Europe at the same level of risk is not considered equivalent, for example, measures for toxicological effects in LCA are multiplied by surface area in Goedkoop and Spriensma (1999). An alternative is to multiply by the volume of water affected for aquatic impacts. The resultant factors for toxicological effects on aquatic (water column) ecosystems are interpreted as the marginal change in the volume of water that is exposed, over a certain period of time, to a particular level of risk – risk being measured in terms of the fraction of species experiencing a potential increase in stress above a certain effect level such as the No Observed Effect Concentration (NOEC) or EC50. Most methods keep separate freshwater and marine environments as both fate and effect factors differ under marine conditions.

Risk-based measurement endpoints for species assemblages, such as the PAF, reflect the number of species affected above a certain effect level. How different exposure above the different effect levels may affect the population, the structure, the biodiversity, and the function of an ecosystem remains unclear. Toxicological indicators that attempt to reflect the change in the so-called Potentially Disappeared Fraction (PDF) of species (or changes in biodiversity) as a measurement endpoint might have higher relevance for some decision makers, although this has to be established, but could improve cross-comparability in relation to other categories of environmental stress, such as land-use.

The difficulty with all these risk-based estimates of impacts is the paucity of data on the toxicological responses of species. In general the species tested are biased towards animal species, and microorganisms such as fungi and bacteria are seldom evaluated, even though these groups represent by far the majority of the biomass.

b) Specific challenges (1/2 p.)

The following scientific challenges are especially relevant to ecotoxicological effects to help advance the current state-of-the-art (for fate, challenges are mostly the same as for human health):

- Develop methods valid for comparative risk assessment of chemicals
- Address bioavailability and speciation of metals and of persistent substances, in freswater and marine aquatic environment
- Enable an accurate estimation effect factors in terrestrial ecosystems looking at bioavailable fractions (e.g. total soluble, etc.).
- Model the food chain in terrestrial and aquatic ecosystems
- Develop simplified methods that can be readily applied for screening with low quality/amounts of data, as well as more advanced models that adopt higher relevance/peer reviewed data to give factors with higher confidence (but which will be less commonly available).
- Quantify uncertainty (model, parameter, and scenario) associated with different estimates.

Practical challenges:

- Data availability and reliability of LCI results
- Data availability for terrestrial ecotoxicological test has to be strongly improved

c) Bases/resources to address these challenges (1/2 to 1 p.)

In addition to individual research projects at different institutes, the EU OMNIITOX project and the US TRACI project are examples of an international initiative with the potential to advance the current state of the art and to establish a best available practice in the context of characterizing toxicological impacts for LCA.

Scientific experts in the domains of chemical fate and ecotoxicological effects are numerous. However, attention should also be given to identify experts that are very familiar with the comparative objectives of life cycle impact assessment and many of the recent developments.

d) Proposed actions towards recommended practice at (1 p.)

Within the framework of figure 1, modules could be addressed using models of different kinds, like for standard components in automobile industry which can be easily replaced by plug-in: On the one hand, the LC initiative should encourage scientists to work together to develop best recommended models for different modules, which could then be adapted to regional specificities. On the other hand, due to data and model availability, recommended practice could lead to different models for different situations and substances, still integrated in the same framework (e.g. for organic substances, metals and primary and secondary particles).

The following activities could be foreseen, in parallel to human toxicity for fate modelling:
a) Stimulate collaboration between OMNIITOX model development, TRACI development and scientists active worlwide (e.g. end 2003), including:
- Open challenge to improve individual modules (2003-2004)
- Comparison workshop between modules and with other models (beginning 2004)
- Selection of recommended models and calculation of generic factors corresponding to typical emission situations (end 2004)

This could include

- Proposal of a recent open-architecture model/framework for the estimation of ecotoxicological characterisation factors – providing modules for the fate of chemicals in aquatic freshwater and marine environments

- Peer review of sub-modules of proposed approach by domain experts to identify clear areas for improvement or modification.
- Invitation to specific domain experts, as well as open public invite, for specific proposals to suggest further improvements/additions.

b) Based on the 2002 Montreal ICMM workshop, a specific group of participants could be asked to arrive with a proposal in a document on how to consider bioavailability and speciation of metals for ecotoxicity assessment in LCA. This could be of interest to metal industry (ICMM) within a case study.

c) Data collection and supply for a wider range of chemicals, with the support of US-EPA (make their own effort known and widely available)

4.10 Land Use/Habitat Conservation/Biodiversity

Rita Schenk (review: Alan Brent, Bo Weidema and Ruedi Mueller-Wenk)

a) Description and state of the art (1 to 2 p. max)

There are many studies that show that terrestrial species extinction is primarily driven by loss of habitat[1]. Conversion of natural habits for the purpose of agriculture, silviculture, the expansion of urban areas and industrial uses such as mining all displace natural ecosystems. For the most part, species formerly living in these areas are either displaced to sub-optimal habitat or else face local extinction. For this reason, the land use indicator is primarily a proxy for biodiversity. The factors that appear to be important in preserving species populations include the total area of each ecosystem type, the size, shape and interconnectedness (or fragmentation) of the ecosystem patches, and the integrity of the land/water interface.

Although there is significant research indicating that activities such as trawling and aquaculture destroy habitat under water in much the same way that clear cutting and agriculture affects terrestrial ecosystems, the situation in the oceans is somewhat different from that on land. There over-fishing seems to be at least as much a source of species extinction as habitat destruction.

There are been a wide range of indicators of habitat conservation, most of which has been developed in the context of conservation biology. Layton, Guynn and Guynn (2002)[2] recently reviewed the scientific literature to identify all published indicators for species diversity. Although their focus was on forest ecosystems, their survey covered all ecosystems, aquatic as well as terrestrial. They identified 155 publications that suggested indicators, and concluded that there were “no universally accepted or rigorously validated metrics”.

That being the case, indicators must then fall back upon the consensus of expert opinion. The United Nations Environmental Program tracks habitat degradation and loss, percentage of species that are red-listed, average population size of wildlife populations, and area of protected land. The World Wildlife Fund for Nature (WWF) has taken the approach of identifying all the world’s ecoregions and seeking to conserve examples of each. In the United States, there are two primary efforts evaluating the state of the Nation’s ecosystems: one by

[1] UNEP 2002. GEO-3

[2] Layton, P., S.T. Guynn and D.C. Guynn. 2002. Wildlife and Biodiversity Metrics in Forest Certification Systems. Final Report, National Council for Air and Stream Improvement

the National Academy of Sciences[3] and a second by the Heinz Center[4] Both these efforts identified dozens of indicators rather than the few that are preferred.

The LCA community has recognized the need for Land use indicators, and several attempts have been made to develop a land use indicator. The Ecoindicator 99 system has developed a relationship between area of land used and the extinction of higher plant species. This approach can be considered to be an endpoint indicator, since it relates to loss of biodiversity itself. Unfortunately, it is a method suitable only to certain part s of Europe.

The efforts of Weidema and Lindeier[5] *et al.* within SETAC Europe have produced a series of indicators which are based on area multiplied by factors related to scarcity of ecosystems, by a time of use and recovery rate, by ecosystem vulnerability and ecosystem quality. This complex midpoint indicator system is based on a comparison to a baseline, and there is no agreement as to the appropriate baseline.

In South Africa, Land use indicators have been developed based on ecoregions defined by vegetation types in separate water basins[6]. This system is a midpoint indicator system based on the biogeography and policy of South Africa.

In the United States, land use indicators have been developed by a consensus process led by IERE and the Defenders of wildlife[7]. A set of midpoint indicators were developed. Two of them are based on satellite data for land cover (proportion of land in natural use, fragmentation of land in natural use), while a third (proportion of species threatened or endangered) is based on the Natural Heritage data base, which is only available in North America. The U.S EPA has also developed a land use indicator, which is based on the number of endangered species per county[8].

These land use indicator approaches are summarized in the table below.

Basis of Indicator	**UNEP**	**WWF**	**SETAC Europe**	**Eco-Indicator 99**	**US EPA**	**Brent, S.Africa**	**IERE/ Defenders**
Area of land	x		x	x	x	x	x
Occupation by natural vegetation	x					x	x
Ecoregions	x	x				x	
Endangered/red-listed species	x				x		x
Species extinction				x			

[3] National Research Council 1999. Ecological Indicators for the Nation.
[4] State of the Nation's Ecosystems. 2002 John H.Heinz Center for Science, Economics and the Environment.
[5] Physical impacts of land use in product life cycle assessment. Final report of the EURENVIRONLCAGAPS. sub-project on land use. Bo P. Weidema with contributions from Erwin Lindeijer. http://www.lca.dk/publ/gaps9.pdf
[6] Alan Brent 2002. Developing Country-Specific Impact Procedures: Human Health And Ecosystem Quality As Criteria For Resource Quality And Availability. InLCA 2002. http://www.lcacenter.org/lca-lcm/session-methods.html#brent
[7] http://www.biodiversitypartners.org/im/05.html
[8] TRACI. 2002. www.epa.gov.

Basis of Indicator	UNEP	WWF	SETAC Europe	Eco-Indicator 99	US EPA	Brent, S.Africa	IERE/ Defenders
Ecosystem vulnerability			x				
Ecosystem fragmentation	x						x
Ecosystem Quality			x				
Occupation/ recovery time			x				
Ecosystem scarcity			x				
Invasive Species	x						x

b) Specific challenges (1/2 p.)

As noted above, although many of these indicators are based on scientific knowledge about the relationship of landuse and biodiversity, few if any of them can truly be said to have been tested in any scientifically rigorous fashion. Part of the problem is that biodiversity itself is not always a clear concept when looked at in detail. For example, zoological and botanical gardens have very high species diversity, but no one is suggesting that the world should resemble a zoo. On the other hand, there is a growing consensus that conservation of ecoregions is a much better way to conserve biodiversity than efforts aimed at a particular species or list of species[1]. This supports the concept that land cover should be used as a primary indicator of terrestrial biodiversity.

Relatively little has been done to evaluate biodiversity indicators in aquatic systems. This is unfortunate, since by some estimates 20% of all freshwater teleosts are endangered, and about 80% of marine fish stocks are considered to be either over fished or significantly degraded.

c) Bases/resources to address these challenges (1/2 to 1 p.)

The conservation community has already spent a great deal of effort to evaluate appropriate indicators of habitat conservation. These efforts have been noted by UNEP and others, and to the greatest extent practicable, it makes sense to follow the lead of conservation biologists and managers world-wide.

d) Proposed actions towards recommended practice at (1 p.)

- At a minimum, one can use the area used by a product system as an indicator of the land use impacts.
- At the secondary level, land use inventory data should be identified as to its location (latitude and longitude). There are many sources of satellite based information about the different habitats around the globe so that knowing the location of the land use is enough for both current weighting schemes and any future weighting schemes to be applied
- More work needs to be done to reach some consensus about appropriate indicators: fewer is better than more. A workshop may be an appropriate way to approach this issue. Aquatic indicators are not well developed, and a great deal more effort needs to be put into this area of research.

- Indicators need to be tested against different definitions of biodiversity to assure that they are effective indicators of the impact category.

4.11 Dispersal of invasive species & GMO

Bo Weidema

a) Description and state of the art (1 to 2 p. max)

Increased dispersal of invasive species, alien to the local ecosystems, may happen as a result of intentional introductions or as an unintentional side-effect of creating new corridors or dispersal vectors. The largest impact is due to transport vectors, such as ballast water of freighters, soil sticking to trucks and souvenirs brought home by tourists or business travellers. Intentional introductions is mainly relevant for agri-, silvi- and aquaculture. The dispersal of genes introduced via genetically modified organisms is generally a more limited problem due to stricter legal approval procedures, but its potential impact can be modelled in the same way as dispersal of natural species.

The resulting direct impact in the affected area is *altered species composition and population volumes*, a midpoint already in use for physical impacts from land use (see chapter [..]). The suggested indicators for this midpoint are primary production and biodiversity-weighted area.

The concern for biodiversity is not the impact on the overall species richness (which may increase, be stable, or decrease as a result of the introduction), but that some species will be favoured at the expense of others. Thus, the change in the biodiversity indicator should reflect the relative number of native species negatively affected by the introduction. As for physical impacts of land use, the biodiversity indicator should ideally reflect the number indigenous and endemic species, rather than the overall species number. However, current data on biodiversity at the global level does not allow this distinction.

The actual impact of the introduction of an invasive species on the two midpoint indicators has to be assessed on a case-to-case basis, because of the large variation in invasiveness characteristics between species and invasibility characteristics of the receiving environments.

The problem of dispersal of invasive species have not hitherto been described systematically in the context of life cycle impact assessment. Thus, initial efforts should focus on:

- describing a generic model that can be applied to the different vectors of introduction,
- collecting data and quantifying the relationships in the model.

An initial model may be provided in analogy to models used for the spreading of diseases. The main elements in a model would be:

- Pressure (dose), which depends on the vector (e.g. ballast water, truck transport, passenger transport), and may depend on the originating environment (differences in numbers and types of organisms susceptible to the vector).
- Invasiveness of the species, which for plants is related to “weediness” characteristics. Invasiveness may be expressed as the probability that a species will establish itself in a favourable environment as a function of the dose.
- Invasibility of the receiving environment, expressed in terms of area and relative number of native species vulnerable to the type of invasive species in question.

Each element in the model needs to be quantified. The model parameters should be specific to each vector and the model needs to be geographically subdivided, both in terms of originating

environment and receiving environment. For some parts of the model, data are available, but needs to be gathered in a form suitable for this specific purpose.
The further modelling from the midpoint indicator to the damage indicators is similar to that described under physical impacts from land use (chapter [..]). Thus, the required activities would be identical with respect to the quality assessment of the receiving environments. These activities have therefore not been included in this section. As noted above, an important refinement in the data basis would be to have the global biodiversity data in a form that distinguishes the indigenous and endemic species from the overall species number. Data for this are available at a local level, but needs to be aggregated and harmonised at the global level.

b) Resource persons and institutions

Europe: Professor Ingo Kowarik, Technical University Berlin (http://www.tu-berlin.de/~oekosys/kowarik.htm) and Inger Weidema, Denmark (http://www.sns.dk/natur/nnis/)
Dr Igor Nikolic, CML.

USA: Professor Richard Mack, Washington state University (http://www.sci.wsu.edu/sbs/faculty.php3?pageID=6&id=58&groupID=1)
Global: GISP - Global Invasive Species Programme (http://jasper.stanford.edu/gisp/home.htm)

c) Suggested activities

Short to middle term activities (within 2 years) would include:

- Workshop to identify important model parameters and ensure agreement on model.
- Literature study to identify sources of data and cases where quantification has been attempted of the factors that enter into the model.
- Initial quantification of the model and the uncertainty on each of its parameters, in order to provide initial characterisation factors and priorities for further refinement.

Middle term activities (2-4 years) would be:

- Testing of the initial model on a number of case studies.
- Further refinement of the data basis.

12. Use of natural resources

Mary Stewart and Bo Weidema

In this section a general proposal on the way to handle different types of natural resources, including water, minerals, energy carriers, soil and biotic resources is presented first. Secondly, more detailed considerations are provided for subcategories water use, minerals, soil erosion and soil salination and dessication are presented.

12A) General proposal for natural resources

Introduction and general concepts

There are a number of concepts that are common to impact assessment of all groups of functional resources, be they biotic (wild or domesticated plants and animals) or abiotic (metallic or non-metallic minerals, energy minerals, water or soil). These common concepts are explained in this section, before entering into specific issues for each of the abovementioned groups of resources. In so doing we develop a consistent framework for all natural resource indicators into which existing LCIA models can be integrated. The value of this framework is that it recognises the systemic similarities inherent in resource depletion impact categories, while retaining sufficient flexibility to incorporate existing work on this impact category(s). In addition, it makes it possible to guide selection of different LCIA models (which represent the different value sets of the developers) in a consistent manner.

We deal in this chapter mainly with the functional values of natural resources as opposed to intrinsic or existence values. Most resources have only functional value to humans, i.e. they are valuable because they enable us to achieve other goals that have intrinsic value, such as human welfare, human health, or existence values of the natural environment.

A few resources have intrinsic value to humans; these are mainly unique landscapes and unique archaeological sites. Because of their very different nature from functional resources, we deal with these separately in this section.

In some situations, use of natural resources may indirectly have an impact on other damage categories with intrinsic value. For example, the use of scarce freshwater may reduce the availability of freshwater for human use and for example, lead to disease. This is independent of the assessment of the impact of freshwater use on the freshwater resource itself, i.e. it is an additional impact pathway, which should be followed in addition to the functional assessment outlined in this chapter. In the treatment of the individual resource groups, we will point out where such impact pathways towards intrinsic damage categories can be found.

Figure 1 shows the relevant flows to and from a product system (i.e. the flows recorded in the LCI result) for any resource (i.e Figure 1 is a generic description; for individual resource groups, some of the flows may be irrelevant, as described in the separate sections on each resource type).

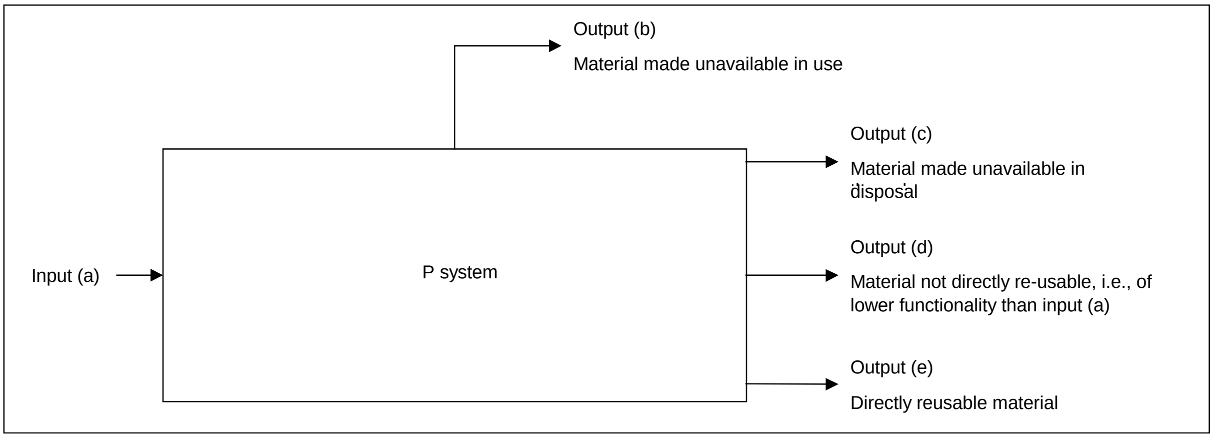


Figure 1. *Flows to and from the product system to be considered for functional resource use*

The value in taking this broad-based view of the system is that it focuses attention on the final destiny of the resources used in servicing the desires of society. As has been noted above (and is explored elegantly in the work of Lindjier et al, 2003 – HELP don't know how to reference chapter 2 of the book), the majority of resources have value only when they are made available for use in products desired by society. For this reason focus seems to focus, to some extent, on the physical process of extracting resources to make them available for use. However, as is noted throughout this section, resources are atomic materials, they are valued for a functionality which relates to their atomic (or in the case of water molecular) nature. As such they cannot be destroyed (the case of water is considered explicitly in this context in Section 12B), they can only be dissipated through use and/or disposal. This places the emphasis for the definition of this impact category on the ultimate form of the resource leaving the system and its remaining potential to deliver the functionality for which it is desired; as opposed to focussing on resource extraction.

At this point there is value in reviewing existing resource depletion impact categories as they have been developed for abiotic resources. The review of Lindjier et al (???) contains a detailed exploration of existing resource depletion impact categories. They refer to the work of Finnveden (1996) which classifies these models according to four generic types:

1. Aggregation of energy and materials on an energy and mass basis; this suggested that the total weight of the ore be considered (as opposed to merely the mass of the contained metal)
2. Aggregation based on measures of known deposits, D, and current consumption, U; different authors have suggested different characterisation factors (for details in which authors suggested specific characterisation factors see the work of Lindjier et al ???):
   a. Q = 1/D.
   b. Q = U/D
   c. Q = 1/D*U/D
3. Aggregation based on interventions from future, hypothetical processes. Pedersen (1991), a scenarios-based approach. This suggests a characterisation for reversibly, used abiotic resources based on the environmental burdens associated with a recovery process that brings the resource back to its original state. Müller-Wenk (1991) uses a similar approach and suggests the additional energy requirement in the future as an indicator for the severity of the depletion impact (i.e., that resource depletion be quantified using an indication of the additional energy required to extract lower grade resources). Eco-Indicator 99 adopts this methodology.

4. Aggregation based on considerations of exergy or entropy. Finnveden suggested an exergy-based method (1996).

This overview is presented here for convenience, the integration of these approaches into the framework suggested in this chapter is discussed below. As an initial statement, the work of Lindjier et al (???) states that methods of type 1 do not necessarily meet the requirements of defining resource depletion. This is also the opinion of the authors of this chapter. This set of models will not be considered further.

Further, while Lindjier et al (???) refer to the complexities associated with defining D for models of type 2 there is still value in discussing this point further. Complexities associated with quantifying D relate to two sets of considerations:

- The first is the difference between a resource and a reserve, according to various national codes of practice for resource valuation (see for example the JORC code of the Minerals Council of Australia) a resource is “a reserve which is deemed economically viable for exploitation by a competent person”. There is significant international debate on resource and reserve classification at present (though it in not foreseen that a single international code for resource categorisation will result). The content of this debate would be of interest should this model type be considered for further development.
- The increasing trend in the minerals industry to process ore bodies which contain more than one product metal (lead-copper-zinc; zinc-cadmium; gold-copper), typically this means that the company is able to process ores whose grades are significantly lower than would traditionally be exploited; formulating a methodology for quantifying D in this context would not be a trivial exercise.

The uncertainties inherent in approaches of type 2 were identified by Lindjier et al (???), these complexities merely serve to increase the uncertainty of the results. Impact categories which require a quantification of D are extremely difficult to inform adequately. Further, because our focus is not on resource extraction but on the potential for abiotic resources to deliver the functionality for which they are desired we do not review the quantification of D directly while still incorporating a consideration of limited future supply of abiotic resources.

It should also be noted that, for the same reasons as were offered by Lindjier et al (???) we do not offer further comment on competition for future resources.

With reference to Figure 1, input (a) is the amount of the resource used by the system as reported in the LCI. This amount includes only virgin material, since recycled material from the technosphere will not be an inventory item in a terminated product system (outflows of material to recycling will be used as inputs of other processes within the product system, either directly or through system expansion). The quantity (a) is typically the value U referred to in impact models of type 2.

Outputs (b+c) are resources made unavailable during use or waste treatment (e.g. dissipated or irreversibly fixed in composites). In this context "unavailable" is defined to be a concentration or a chemical or physical form that renders the material unavailable for any foreseeable future use by society.

Output (d) is the amount of resource output, which is available for reuse, but is of a lower quality (functionality) than input (a). The relevant definition of quality and/or functionality depends on the type of resource, as described below for each resource type.

Output (e) includes only the material that is of the same (or higher) quality (or functionality) as input (a). This does not include material that is recycled within the system (which is already accounted for in the inventory); however, it does include that material which is directly available for recycling, but which is currently not recycled for some reason (e.g. economic or regulatory). The additional quality of output (e) compared to input (a) is a benefit delivered by the system, which could be quantified in terms of the potential savings in concentrating a primary input (a) to the concentration of output (e), which eventually will be realised when output (e) is taken into the economy again. This "benefit" associated with a production system is not usually considered in LCA. For this reason we merely state that the potential exists for such a societal benefit to be considered and discuss this no further in this section.

As the product system is integrated over time, there will be no change in stock within the product system, which implies:
a = b + c + d + e

All such flows are (or should be) reported in the LCI result in mass units with a quality/functionality specification (e.g. concentration).

For the impact assessment, what is of interest is the further consequence (impact pathway) of this change of input (a) into outputs (b+c+d+e). This depends essentially on the future availability of the input (a) and the technologies that will be available to provide this input at its current quality. This is consistent with impact assessment approaches type 3.

The borderline between outputs (b+c) and output (d), we call the ***ultimate quality limit.*** It can be determined theoretically as the upper bound of the variation in the steady-state background resulting from formation or re-deposition (for topsoil and minerals, respectively), which may be natural or accelerated by human activities. It follows from this definition that the ultimate quality limit will have to be determined individually for each mineral resource. The ultimate quality limit is used to differentiate between the material which is still available for current or future use by society and that which has been dissipated through use and/or disposal. Thus resource depletion impact is then evaluated relative only to that material which can no longer deliver the functionality for which it is desired.
Provided the "virgin" resource input (a) has a decreasing quality/functionality over time, the output streams (d) and (e) will come into service as resources at the point in time when this becomes more economical than utilising input (a). This depends essentially on the quality/functionality of these output flows. The resources lost as outputs (b+c) will not come into play in this way, but when the "virgin" resource input (a) has a decreasing quality/functionality over time, the current loss that these outputs represent will nevertheless require that an alternative technology will have to be used at the time when the quality of input (a) has been reduced to the ultimate limit. Both the technology applied to utilise the output streams (d) and (e) as resources and the alternative technology applied when reaching the ultimate quality limit are referred to here as the "***backup technology***" for these output flows. It follows from this definition that different output qualities may have different backup technologies, and that each backup technology comes into play at a different point in time. This is consistent with models of type 3.

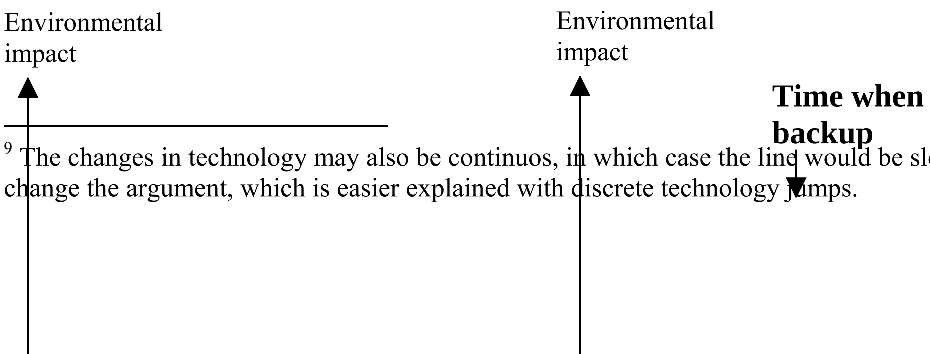
In attempting to determine the environmental impact from future backup technologies, we distinguish three different development scenarios, depicted in figures 2 (α, β, ε and γ).

In figure 2 (α), the technology to provide the current quality of input (a) has an increasing environmental impact over time (the thick line; each jump representing a change in technology[9]). A typical example of this is when high quality mineral ores are depleted and ores of lower quality are exploited, requiring more effort (energy) and maybe greater use of land, water and auxiliary chemicals and materials. In this situation, the current use of a quantity of input (a) will imply that the resources of this quality will be used up at an earlier time than if we had not used this quantity, and thus that resort must be made to the lower quality ores and the associated technology at this earlier date. This is represented in the figure by the dotted lines. The hatched areas represent the resulting increase in environmental impact. It can be seen that the hatched areas can be "stacked" to show that the overall additional environmental impact is equal to the additional environmental impact at the time when the backup technology is applied.

In figure 2 (β), the technology to provide the current quality of input (a) has a decreasing environmental impact over time. An example of this may be energy technologies, where future technologies in general are expected to be more environmentally benign than current technologies. In this situation, the future technologies and the timing of their introduction would not be affected by the current use of input (a), and there would thus not be any future additional impacts caused by this current resource use.

In figure 2 (ε), the technology to provide the current quality of input (a) has first an increase in environmental impact, and then a decrease. An example of this may be fossil fuels, where there may be a depletion of easily accessible reserves leading to an initial increase in extraction efforts, which is eventually superseded by more efficient alternative energy technologies. Here, the additional future environmental effect of current use of input (a) is still represented by the sum of the hatched areas, following the same reasoning as in figure 2 (α), also when the backup technology is applied at the later time when the technology is more benign than the current. Thus, the additional environmental impact caused by the current use of input (a) is that of the technology with the largest environmental impact prior to the time that the backup technology is applied.

In figure 2 (γ), the technology to provide the current quality of input (a) has first a decrease in environmental impact, and then an increase. An example of this could be the more efficient technologies now introduced in minerals extraction, which more than counteract the current depletion of stocks, but which does not preclude the fact that stocks will eventually be depleted, potentially leading to technologies that are less environmentally benign. When the backup technology is applied before time t_2 (i.e. for high quality output flows) no additional future environmental impact is incurred, but when the backup technology is applied after time t_2 (for low quality outputs and for dissipated material) the additional future impact must be calculated in the same way as for the situation in figure 2 (α).



[9] The changes in technology may also be continuos, in which case the line would be sloping. This does not change the argument, which is easier explained with discrete technology jumps.

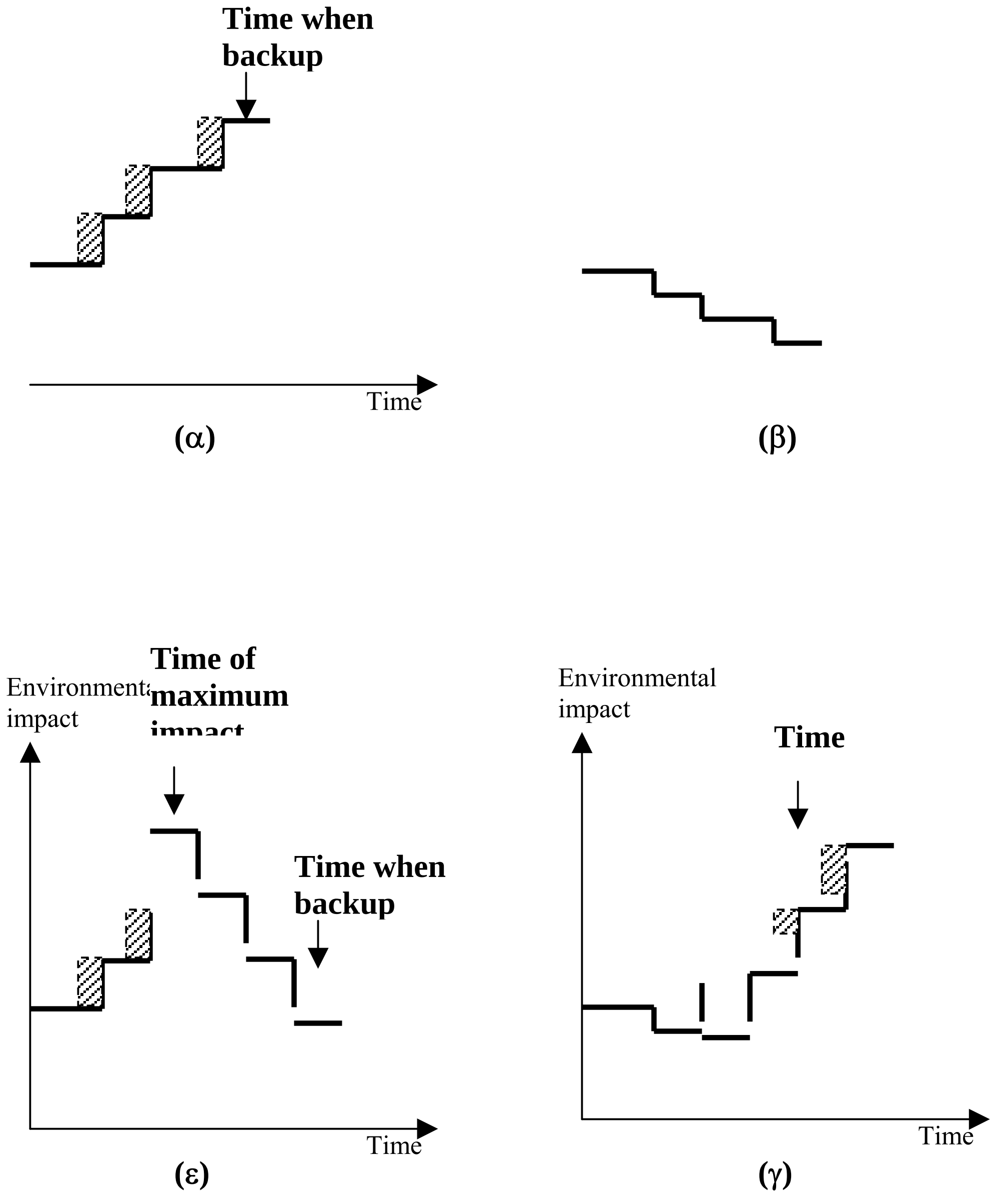


Figure 2. *Environmental impact of the technology to provide the current quality of input (a) as a function of time and the additional impact caused by present use; (α): When technology impacts increase over time; (β): When technology impacts decrease over time; (ε): When technology impacts increase and later decrease; (γ): When technology impacts decrease and later increase.*

At this point it should be noted that the only elements that require definition within an LCIA model are the **ultimate quality limit** and the **backup technologies**; the quality of the input and output flows should be recorded in the LCI.

There has already been significant debate on quantities that are essentially energy requirements for backup technologies for the depletion of metallic resources (Originally suggested by Pedersen Weidema (1991) and Steen and Ryding (1992), with operational contributions from Steen (1999), Müller-Wenk (1999), Goedkoop and Spriensma (1999) and Weidema (2000)). At this stage it is not necessarily possible to determine which is the best approach to be adopted, however, what can be stated about the energy requirement for backup technologies is that:

- The lower limit for the energy requirement for the backup technology (the least amount of effort) is the difference in the entropies of output (d) and the current input (a); this is the thermodynamic limit, which cannot be improved upon within the current understanding of physics. This is consistent with the entropy approach of Finnveden (1996). Considerations of exergy (as included in other type 4 models) would increase the amount of energy required.
- The upper limit for the energy requirement for the backup technology is the energy requirement of existing technology to convert the output (d) to the current input (a); this statement being made with the (robust) assumption that any future technology developments will only improve the efficiency of technologies (i.e. technological efficiency will not decrease in future).

Thus, while it may not be possible to identify the actual backup technology explicitly, it is possible to place it within bounds.

In this section we have introduced a generic framework into which existing

Below, we discuss specific issues for each abiotic resource category.

Metallic Minerals

The functionality delivered by metals within the industrial economy is relative to both the concentration of the metal and its form (wire, plate, pipe, etc). As a first assessment however, we look at the functionality of metals as a result of concentration only.

Using copper as an example, copper ores are typically mined at 2% and refined to 99.99% before being used in the production of desired end-products. It is assumed that the effects of mining activities will be captured through other impact categories. Only 1% of copper is used dissipatively (in chemicals and pesticides), a relatively small percentage of copper is alloyed to deliver brass, and the majority of copper is used as 99.99% copper in products. The overall concentration of copper in different products is a function of the amount of copper used in the product. Over and above the 1% of copper in dissipative uses, copper also dissipate *during* use (for example from roof tiles), and copper can be disposed of dissipatively. These effects are all captured as an eco-toxicity effect in LCA.

In attempting to define the ultimate quality limit, the proposal has been made (Steen and Ryding 1992) that this be some multiple of the background concentration for the metal. In reality, a specific limit needs to be defined for each metal considered.

Mining of virgin ores (input (a)) will continue to the point that ore grades decrease below that of solid waste deposits (output (d)) at which point input (a) will be replaced by inputs from stockpiled outputs (d). This is already the case in the South African gold industry where mine dumps are routinely re-mined for their gold content. This will be supported more by economic considerations (and specifically consideration of supply and demand and resulting pricing structures, which are a function of resource availability) than by physical resource depletion.

Non-metallic minerals

Some non-metallic minerals deliver their desired functionality as a result of their shape and form. Thus, if these are broken down in used (for example marble is shattered when a building is demolished) then the material can no longer deliver the function for which it is exploited.

The depletion of non-metallic minerals is of greater concern than metallic minerals, as metallic minerals can generally be recovered, limited only by consideration of energy inputs, while non-metallic minerals are desired for their form which is often destroyed in use or disposal. Thus, for the majority of non-metallic minerals it is not sensible to reconstitute the material properties, which implies that the backup technologies will not be recycling (as for metals) but rather the production of an artificial substitute material (e.g. terrazzo instead of marble). Exceptions to this rule may occur.

It can be assumed that for the majority of non-metallic minerals, output (e) will not exist since the effort required to deliver a recyclable output (e) will be so high that the output will be recycled directly, in which case it will be included in the inventory.

It should be possible to define the ultimate quality limit as a particle size for each non-metallic mineral smaller than which it is not longer possible to exploit the function of the material. This particle size would need to be defined individually for each non-metallic mineral.

The resources depleted (or functionality lost) through changing input (a), for example a slab of marble, into output (d), e.g., marble chips from a demolition site, is related to the difference in particle size between the two flows, which might be used as a first order assessment of functionality lost.

Energy Minerals

Energy minerals are easier to discuss when considered as two distinct categories – fossil or carbon based fuels, and nuclear fuels. Including nuclear fuels as energy minerals and not as metallic minerals is a subjective choice, which could be debated at a later date.

Focussing first on fossil fuels, these are generally dissipated in use – output (b) – contributing to climate change, photochemical oxidant formation, human toxicity. Wether there will be an additional environmental impact from future energy technologies is currently an open question. In general, future energy technologies are expected to be cleaner than the present as we move towards a solar economy. However, there may be a temporary resort to lower grade fossil fuels and nuclear fuels that may temporarily involve additional impacts. These impacts should be included in the impact assessment following the logic described by figure 2 (ε). In addition, energy content itself is dissipated in a non renewable way and it has to be studied if and how changes in non renewable energy stocks have to be included.

While the nuclear fuel minerals are not dissipated as such (as nuclear fuels are metallic and thus the same argument as presented for metallic minerals can be applied), their energy content is dissipated in much the same way as for fossil fuels. This implies that models used to inform the backup technology will be identical to that for fossil fuels.

Water

Water can be found in different input (a) qualities and different output qualities (d + e). Water is an output (d) if it has a lower quality than input (a); and an output (e) if it is of the same or higher quality as input (a).

These available water qualities should be used to determine the benefits to the system of supplying output (e), and the backup technologies required for outputs (b) and (d), respectively.

The backup technology is thus the technology that will be used to return output (b) or (d) to quality (a) when such a supply is expected to take place (i.e. in areas of water scarcity). Desalinisation of seawater may be used as the ultimate backup technology in areas of water scarcity, for replacing water quality lost through a system that uses input (a) and has output (b).

In the summary for water resources approaches for developing this impact category further are presented, they are not duplicated here. This section also includes comments on the contribution of water usage to intrinsic damage categories. It is worth noting that, unlike minerals, water does deliver functionality to natural and human systems, which may affect intrinsic indicators significantly.

Soil

Soil is similar to water in that a number of different soil qualities can be defined (based to a significant extent on productivity).

Soil can be dissipated (output (b + c)), which is included as dust in some cases in LCIs. Note should be taken that some soil lost through erosion may be redeposited on agricultural lands, in which case only the net dissipation should be included in the further impact assessment.

During land use, soil quality may be depleted (output (d)) or improved (output (e)). Soil depletion will require the application of backup technologies to provide the same productivity as for the original soil input (a). Backup technologies may either be soil maintenance activities that bring back the original productivity, and/or alternative means of producing the same products (e.g. on a larger area of lower quality soils) until original soil quality has been restored. In the latter case, temporary reductions in global food output may result, affecting intrinsic damage categories. As is the case with water, soils deliver functionality to natural and human systems, which can have significant effects on intrinsic damage indicators.

An ultimate quality limit can be defined, i.e. the limit at which it is unlikely that a depleted soil will be recovered for agricultural use. The ultimate backup technology for soils that are made unavailable may be soil-less agriculture (hydroponics and production of single-cell protein).

Biotic resources

By biotic resources, we mean plants and animals that have a functional value to humans as opposed to an intrinsic or existence value. Thus, we deal here with stocks of wild plants and animals that are harvested for human use, as well as the production outputs of agri-, silvi- and aqua-culture.

Harvesting of biotic resources in excess of their natural surplus can lead to both temporary and permanent reduction in their production capacity. The production capacity of biotic resources may also be affected as part of other impact pathways (of emissions etc.).

Temporary reductions in production capacity of biotic resources can be dealt with in the same way as depletion of other functional resources, by applying backup technologies to provide the same productivity as before the change. Backup technologies may either be maintenance activities for the populations in question (such as improving breeding and growth conditions) that bring back the original productivity, and/or alternative means of producing equivalent products (e.g. utilising larger areas to provide the same yield or utilising stocks that demand more harvesting efforts) until original productivity has been restored. In the latter case, temporary reductions in global food output may result, affecting intrinsic damage categories. As is the case with soil and water, biotic resources deliver functionality to natural and human systems, which can have significant effects on intrinsic damage indicators.

Permanent reduction in production capacity of biotic resources, i.e. irreversible effects of non-sustainable utilisation, is an impact pathway towards the intrinsic impact indicator "biodiversity." Permanent impacts on wild species can be modelled in parallel to other biodiversity impacts, such as those caused by physical impacts of land use (see section 10). The importance of a permanent impact on domesticated species may depend on the current existence or non-existence of the natural ancestors to the domesticated species, i.e. the degree of irreversibility of the loss. In case of reversibility, the impact may be modelled through the use of backup technologies provided to restore the lost species. In case of irreversibility, the loss may be valued as being more severe than the loss of a wild species, since domesticated species are often of special concern to humans, both as species type and for the cultural aspects of domestication. Thus, the loss of domesticated species should be kept as a separate impact category and not aggregated with other categories of biodiversity.

Unique landscapes and archaeological sites

As mentioned in the introduction to this section, unique landscapes and archaeological sites have intrinsic value to humans, rather than functional value. Therefore, they place very different requirements on the impact assessment, which cannot follow the above-described schema for functional resources. The impacts on unique landscapes and unique archaeological sites are fundamentally related to landscape transformation, whether this transformation is one from a natural state into human use, from one human use to another, or a relaxation from human use. Thus, this impact category might in fact better be grouped under the heading of physical impacts of land use (see section 10).

Specifically because of their uniqueness, the value of unique landscapes and unique archaeological sites cannot be determined in terms of a general indicator, but must be treated on a case-by-case basis. However, an indicator may be developed for disruption of unknown archaeological sites (i.e. possibly but not necessarily unique), since this can be related to increases in ploughing depth, introduction of deep-rooted plants, and other activities that disturb or remove soil layers that were previously undisturbed. Thus, an indicator may be based on the thickness of soil layer disturbed. This indicator should be multiplied by the area, and weighted by a factor determined by archaeologists and historians, expressing the probability of occurrence of archaeological remains in different area types (and soil depths). Predictive models for this purpose are in development (see *e.g.* Dalla Bona 1994). The possibility for a meaningful classification of area types depends also on the ability of the life cycle inventory to identify the location of specific activities within such classes.

Bases/resources to address these challenges

To save space these have been tabulated.

Metallic Minerals	Potential experts to include in the development of this impact category should be drawn from the ICMM (John Atherton) and the various industry associates who are increasingly actively involved in LCA (Bruce McLean, Scott Baker, Alain Dubreuil, Mary Stewart). Experts who have been involved in the development of the impact category within LCA are Bengt Steen, Bo Weidema and Ruedi Müller-Wenk. Potential funding for this impact category might be sourced through the ICMM as the mining

	and minerals processing industry appears to be focussing its attention on the ICMM to deliver these results. Also worth highlighting is the newly formed Co-operative Research Centre for Sustainable Minerals Processing, which will be formally constituted in Australia in 2003. The Green Lead project should be followed up, though their funding sources are not clear at present.
Non-metallic Minerals	To date, little attention has been paid to non-metallic minerals in LCA and experts are not easy to identify. Attention has been focussed on the mining of non-metallic minerals in Europe and experts might be drawn from there. Rio Tinto has invested some time in LCAs of borax and talc, and comment on this impact category might be sought from them.
Energy Minerals – Fossil Fuels	Energy is one of the oldest areas where scenarios have been applied. Expertise from the World Energy Council should be sought. From the LCA field, Tomas Ekvall is among the persons that work much in this field. SETAC-Europe has also recently established a working group under the leadership of Wolfgang Krewitt.
Energy Minerals – Nuclear	Bente Solbjerg-Johansen; Rolf Frischknecht
Water	Research activities are extensive in most countries, especially in eco-regions where water is naturally limited or where biodiversity is under threat. Databases of water availability and quality are generally in the public domain. Resources at the global level include the GLOREM project at the Potsdam Institute for Climate Impact Research, The WHO and UNICEF Joint Monitoring Programme for Water Supply and Sanitation, and the World Water Council.
Soil	Experts from the LCA community include Bo Weidema and Llorenc Mila i Canals who should be consulted. Further, Sven Lundie from the University of New South Wales in Australia has also stated his interest in the development of this impact category.
Biotic resources	It should be a fairly easy task to identify conservation biologists and agriculturalists with relevant knowledge on productivity and backup technologies within each of the relevant species groups (fish, mammals, plants, etc.). The area has not been in focus of LCIA development.
Unique landscapes and archaeological sites	Dalla Bona

Proposed actions towards recommended practice

In this table the following key has been used:

(a) – Short term activities to initiate the effort and set the problem properly (workshop, etc)
(b) – Short to middle term activities leading to recommended characterization factors within two years
(c) – Middle term activities leading to (additional) characterization factors within four years
(d) – Exploration activities and feasibility studies

General	- Workshop to discuss agreement on the relevance of Abiotic Resource “Depletion” Impact categories and on the proposed model, which represents a uniform framework for assessing the impacts associated with

	the depletion of abiotic and biotic resources and. - Once specific challenges have been addressed: Initial quantification of the model parameters and the uncertainty on each of its parameters, in order to provide initial characterisation factors and priorities for further refinement.
Metallic Minerals	This approach requires debate before it can be formalised. Debate should focus on both the generic model presented above, and the specifics as they relate to metallic minerals (a). Once consensus has been reached on the relevance of still including resource depletion of metallic minerals in LCIA it may be necessary to convene experts to identify limit (X), and the backup technologies for specific metals (b). It must be recognised that X is a function of the metal, no single value can be defined. Metals other than those which are of significance to the developed world should also be considered.
Non-metallic Minerals	The next step in the development of this element of abiotic resource depletion would be the convening of a committee of experts to review the methodology presented in chapter 12A (d). Only once an expert committee has been convened and some debate has taken place will it be possible to determine where future work should focus. Potential funding sources do not come to mind immediately, but, as attention has been focussed in Europe (for example mines in England) this might be where to look. Most of the work on the mines in Europe has focussed on closure considerations.
Energy Minerals – Fossil Fuels	Earlier attempts to categorise energy resources in LCIA, which describe the depletion of these resources as a percentage of known resources and reserves does not align with the theoretical model presented here. Consensus should be sought on the applicability of the generic model to this impact category (a). It is felt that there is value in first reaching agreement on the model as it represents a uniform approach to modelling abiotic and biotic resource depletion according to a consistent framework. It will then be necessary to gain consensus on the preferred calculation of backup technology for each fuel type (b).
Energy Minerals – Nuclear	It is proposed that further action on the development of an indicator relating to the depletion of nuclear fuels should be reviewed only once consensus has been reached on the depletion of fossil fuels and of metallic minerals[d].
Water	Some propositions have been made to characterise and weight water usage. However, these may be limited and further approaches should be proposed and reviewed within the LCIA community. It may also be required to define focussed regions at a global level. This should start with a level (a) workshop.
Soil	Further actions on this impact category should include consideration of the proposals made by Mark Goedkoop on salinisation and erosion. The first step should be to conduct a literature review, which would form the basis of a uniform set of soil quality indicators, which are applicable on a global basis. This review should include a consideration of soil qualities in different global regions (d). A panel of experts should be convened to determine the basis for developing backup technology arguments for soil quality (a).

Biotic resources	Literature study to identify sources of data for describing backup technologies for biotic resources, possibly differentiated per geographical region, also identifying pathways towards intrinsic impact categories. It is likely that sub-surveys should be performed for trees, wild fish, wild mammals, other wild animals, wild plants, and domesticated plants and animals.
Unique landscapes and archaeological sites	No specific activities are foreseen in a first period, until the scope is clearly defined in the taxonomy workshop (see section 3.2).

A further note, the Green Lead project presents a significant opportunity for a case study within the Life Cycle Initiative for the following reasons:

- Global partners have already been highlighted and a communication structure is in place
- It has an industry focus
- It has a product focus
- It has elements of LCI, LCIA and LCM

Potential funding

The Cordis website www.cordis.lu/fp6 on the new sixth framework, and presents a very interesting call for financing research on the "new" impact categories. The INCO programme is realty focussed on international collaboration with developing countries, so not only between EU countries. I sued this programme also in my failed attempt to make a Latin American Eco-indicator, If you click on the link Areas and instruments addressed within this call, you will find that under INCO-DEV-1 2 , there is a thematic area on Managing resources, with the text pasted below. I think it would be a very good funding possibility to bring together experts from all over the work and to coordinate and exchange research.

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Addendum

The table below has been developed to summarise the arguments developed above. This table gives an indication of what requires further development for each abiotic resource investigated, and highlights the difference between resources that deliver a function in the natural and human environment, and those that only have function once they have been processed. In this context, we highlight the intrinsic value to be protected (human health and the abiotic environment in the form of landscapes, cultural heritage, etc) and the functional values that these resources deliver (manmade capital, buildings etc).

Resource	Valued for	Suggested Units of Measure in LCI	Limit (X) Limit of availability	Effect of Dissipation	Backup technologies (Z)	Other comments
Metallic minerals	Metallic qualities (heat transfer, mass transfer, etc) – function of concentration	Mass flow and Concentration	Function of background concentration	Eco-toxicity	Minimum is entropy, maximum is current technology	Depletion not significant on a global basis
Non-metallic minerals	Structural qualities - function of shape	Mass flow and Particle size	Particle size	Dust	Substitute technology	Non-metallic minerals are ultimately depletable as they are valued for their form which is often lost during use/disposal
Energy carriers – fossil fuels	Chemical composition	Mass flow and Energy Content	All fossil fuels are dissipated	Global Warming	Substitute technology	Fossil fuels are depleted through use
Energy carriers – nuclear	Metallo-chemical composition	Mass flow and Concentration	No nuclear fuels are dissipated	Radioactivity	Substitute technology	Nuclear fuels should be modelled as a combination of metallic minerals and fossil fuels
Water*	Quality, ability to support life as a result; recreation	Mass flow and Purity (concentration of impurities)	Only dissipated through reaction	None	Energy required to return quality	Differences in regional importance of water needs to be captured; both for availability and quality. Possible impact on human health through water scarcity.
Soils*	Quality, ability to support life as a result	Quantity used (volume or mass) and Productivity	Any soil leaving the system	Effects of dust (on climate, health, buildings etc.)	None defined as yet	Regional soil differences need to be captured; specifically for quality. Possible impact on human health through starvation and mal-nutrition.

* The ability to include regionalisation of effects is highlighted as being of significance for these impact categories

12B) Water resource depletion Alan Brent

Water resource use **Alan Brent (review: Bo Weidema)**

Water resource depletion Alan Brent

a) Description and State of the art

Impact pathway: Water as a resource is typically divided into freshwater and marine or coastal water systems [1]. The impacts on the sustainability of these two resource groups are typically addressed separately. In both cases impacts are defined in terms of quality and quantity impacts. The usage of water resource may be characterised as an impact on both the quality and quantity, i.e. the reduction in the availability of water of a certain predetermined quality.

Freshwater systems are further segregated into groundwater and surface water supplies. These supplies are managed at a local level, i.e. in water catchments. Within the catchments surface and groundwater supplies must be available for agricultural, industrial and urban drinking purposes. Furthermore, the natural environment or ecosystems require a minimum amount at a certain quality level for the continued existence of terrestrial and aqueous species. The water balances that are available for the water catchments are therefore a function of [2]:

- the maximum surface and groundwater yield, which in turn depends on the precipitation, evaporation, runoff rates, etc. of the catchments,
- the extraction of surface and groundwater reserves for human and ecosystem consumption, and
- the transfer of water reserves between catchments where the maximum yields are inadequate.

The quality of the water resources in a specific area is determined by natural and human interventions, e.g. acidity, salinity, toxicity, etc. The impact of extractions of water from catchments are consequently dependent on the need and the current burdens in a region. For example, if surface water supplies are limited and groundwater reserves are high in natural salinity, the extraction of water of drinking water quality for agricultural or industrial purposes will have a higher impact compared to regions where ample water resources of good drinking quality are available.

With respect to marine or coastal water systems, the use of water resources has a lesser impact. However, the character of specific local ecosystems should be considered, e.g. estuaries [1]. Many of these ecosystems are rather fragile and a significant extraction of water could result in the transformation of the quality of available water, e.g. an increase in the salinity. Conversely, considering such site-specific impacts in a LCIA framework would be problematic. This is true for the impact pathway of freshwater usage as well.

LCI results: At the level of LCI results, the mass of water extracted on an annual basis for a specific activity must be stipulated in terms of:

- Freshwater systems, with distinction of surface and groundwater supplies.
- Delicate coastal marine water systems.

Furthermore, the quality of the water that is used should be incorporated into the LCI results, i.e. water available for [3]:

- Drinking purposes and recreational use.
- Agricultural activities through irrigation.
- Agricultural activities through aquacultures.
- Industrial use purposes.
- Natural ecosystems.

<u>Midpoint impact category 'water resource depletion':</u> The impact mechanisms for extraction of water can be considered to have a common base (reduction in the availability of water to maintain the natural and human activities in a region) thus the potential remains to group these as the midpoint impact category "water resource depletion". The midpoint indicator should reflect the degree of scarcity of water of a certain quality per region and the technological and economic accessibility of the resources. Subjective weighting may be required that could consider the cost to improve the quality and availability of the resources, social value of the resources, preferences of local government in a specific eco-region, etc. [4]

<u>Areas of Protection and Damage Categories addressed:</u>
<u>Human Health</u>: In order to ensure a reasonable state of human health, communities require the availability of an easily accessibly supply of water that provides safe water to meet the community needs. Household water needs are rather region-specific and community members are typically questioned about their daily water use [5]. However, the minimum water need can be calculated by assuming that the average person requires 25 litres per day for drinking, cooking and personal hygiene. More water will be required for laundry. To ensure that the water is potable, the water resources must be protected or the water must be treated before use. In either case, minimum guidelines define the quality standard that must be maintained of the water supply [3, 5].
<u>Natural Environment</u>: The water requirements of natural ecosystems are highly variable. In most cases region-specific aquatic species are used to determine the amounts and quality of water that must be available to ensure the continued existence of the species. The quality of the available resources are typically defined in terms of [3]:

- Constituent-specific criteria.
- Criteria for complex mixtures.
- Biological criteria, although these are still in development
-

In some dry regions, aquatic species are of limited numbers. In these cases the amount of water that is necessary to maintain the terrestrial species (plants and animals) in an eco-region is stipulated [1].
<u>Man-made Environment</u>: Surface and groundwater supplies are required in sufficient amounts to sustain the agricultural, urban, industrial and recreational activities in a region. The quality of the supply is again ensured through the protection of the resources or through the treatment of available resources. The quantities may be variable, but a minimum amount could be calculated to sustain economic growth in a region.

b) Specific challenges

The current knowledge appears to be sufficient to weight the impact pathways from LCI results to the midpoint impact category 'water resource depletion'. However, modelling up to the damage indicator for the AoPs may be problematic. It is desirable to improve the scientific knowledge regarding the impact pathways between LCI results, i.e. the reduction of water supplies as a function of time and geographical area, and the AoPs. The definite challenge with this category lies in the region specificity:

- Water resources availability is geographically variable, i.e. between countries, and between catchments or eco-regions.
- Water resources availability is time variant, i.e. impacts may be seasonal dependent.

c) Bases/resources to address these challenges

At global level water is viewed as a limited resource. Government, industry and research activities are extensive in most countries, especially in eco-regions where water is naturally limited or where biodiversity is under threat. Databases of water availability and quality are generally in the public domain.

d) Proposed actions toward recommended practice

Some propositions have been made to characterise and weight water usage. However, these may be limited and further approaches should be proposed and reviewed within the LCIA community. It may also be required to define focussed regions at a global level.

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12C) Energy extractions

Bo Weidema (review: Claudia Peña)
See general introductory paper for natural resources (12A)

12D) Mineral Extraction Category

Claudia Peña (review: Mary Stewart)

a) Description and State of the Art:

<u>Impact Category</u>:
Due to their own nature as naturally occurring elements, metals are infinitely recyclable – limited only by energy considerations. Even for those metals to which the concept of scarcity could be applied in the near future, there exists the potential that they can be recycled from the significant stock already present in the industrial economy (1).

Thus it should be recognised that the impact associated with resource extraction should not focus on the point of extraction, but rather on those activities which allow metals to leave the industrial economy in such a form as to render them unavailable for future use. Then attention should be focussed on dissipative use and disposal, perhaps quantifying the energy which would be required to make dissipated material available to the industrial economy.

However, because even for recycling with the level of technology available nowadays, fresh metal (of primary production) is needed to control impurities. Then another important issue for this impact category is the future access to resources, this immediately focuses attention directly on environmental and social-economic factors. Developments that may limit the future viability of minerals exploitation include (2).

The potential does exist for technologies to develop in line with the decline in ore grades, specifically with respect to efficiency, there is every chance that technologies developed to exploit lower grade ores will potentially require the same (or even less) energy per ton of product. But attention has to be paid to the fact that the impact associated to a metal unit is increasing as the resources of high law ore are depleted. It actually means that the marginal impact (for each extra metal unit) is increasing, and this seems to be an important point. Based on the actual performance of the metallurgic industry, to maintain equal levels of productivity with lower grade minerals, necessarily the energy consumption increases (longer leaching process, crushing, milling and flotation step, etc

Another important point is the fact that not all impurities contained in ore are valuable from the economic point of view, and must be confined in a stable form (that means more process treatment, more energy and sometimes, more mass) and dispose in a certain area of land.

<u>LCI results</u>:
From an environmental perspective (2):
- extraction of the lower-grade ores may result in an increased generation of waste,
- decrease in the availability of metals could imply the transportation of goods over greater distances to markets, raising the environmental impact of transportation.

<u>Midpoint impact category “resource depletion: minerals”:</u>
The impact mechanisms for extraction of minerals can be considered to have a common base (accumulation of greater amount of wastes as minerals become low-graded, increasing of transportation impacts) thus the potential remains to group these as the midpoint impact category “resource depletion: minerals”. The midpoint indicator should reflect the degree of scarcity of the particular metal per region and the technological and economic accessibility. Subjective weighting may be required that could consider cost to improve the quality and availability of the resources, social value of the resources, preferences of local government in a specific eco-region (3).

<u>Areas of Protection and Damage Categories addressed:</u>
Natural Resource:
(from Chap. 4 The need for and availability f Minerals. MMSD Draft Report - March 2002).
Society today is highly dependent on the use of most metals and minerals for transmission, mobility and transportation, information and communication, food supply, health delivery, etc. Minerals use and production is also essential (especially for developing countries), in terms of employment and incomes generation.

<u>The case of non-metallic ores</u> should be analyzed in more details. In many cases, recycling is not possible and industrial minerals should be considered as single use resources just as energetic ores.

<u>The concept of "average rock</u>" from which any metal or elements could potentially be extracted is a geological nonsense. Geological processes selectively dissolve, transport and precipitate the different elements and every rock will present different concentrations for the different elements. Some particular rocks are then more suitable for the recovery of the different metals, even if they are no considered as mineral resources or reserves. However, the mineralogical and chemical complexity of these rocks will require the development of new processes, probably with a higher energy consumption and a greater waste production.

Despite many years of debate between the pessimists and the optimists, there are still uncertainties regarding the long-term availability of mineral commodities. There are too many unknowns, but is broadly agreed that the world is unlikely to face shortages of commercially important mineral commodities at a global level in the next half century.

Natural Environment:
As ore grade decline, new mines could be opened in sites less desirable from social and environmental perspectives. This could be especially relevant for developing countries in which the economy is still highly dependent on natural resource exploitation: the bulk of mining activities in the world take place in developing countries. Besides, as ores become more inaccessible the consumption of energy and water required to produce the desired metals may also increase, affecting eco-systems (terrestrial and aquatic), changing natural volumes of water-bodies and potentially increasing their levels of contamination. Major energy consumption may imply increasing CO_2 emission and consequently mining activity's contribution to greenhouse effect.

Human Health:
As ore grades decline, the impurities present in ores can increase and along with this, potential emissions to the environment (air, soil, water) of toxic substances or by-products (for example, pyrothermal-processing of copper sulphide ores can potentially release SO_2, dust containing Cu, Zn, As, Bi, Sb, etc.) which can have a direct affect on human health if they are not managed correctly (for example, As is carcinogenic). There is scientific evidence that the number of cases of myocardial infarction increases with the level of particulate material releases to the atmosphere, specifically near smelting plants (US EPA in the City of Provo, USA, 1998.)

Man-made Environment:
As ore grade decline, waste disposal could increases affecting land that could be otherwise used, for example in eco-systems development or farming. Surface water could be affected by increasing the probability of levels of contamination and lowering the volumes left for agriculture or other human urban/rural/recreation activities.

Water is part of the natural environment (rivers, ocean, lakes, etc.). But, water can also be considered as a good that is affected by human decisions (economical and socio-political), such as how to use and manage water disposals' volumes. Thus, water management, which is decisions dependent, changes the natural environment in one suitable for human activities, playing an important role in the functionality of the man-made environment.

b) Specific Challenges:
Development of adequate midpoint indicator(s), based on more precise calculations and focussing attention on the dissipation of the resource, and not necessarily its extraction. Care should be taken to ensure that any re-defined resource depletion impact category does not incorporate any double accounting.

The current trend in the minerals industry is to exploit complex ore bodies which can contain in excess of five desired minerals, all work on the Resource Depletion impact category has, to date, assumed that all minerals present as single minerals in ore bodies.

Sulphur and Iron are desired metals in some industries, but present as carry through contaminants in the majority of metallic minerals processing, thus, in some cases they are a desired product, and in other instances they are an undesired co-product, the Resource Depletion impact category needs to ensure that effects associated with co-production of products as a function of ore quality is captured.

c) Bases/resources to address these challenges
Direct engagement with the mining, minerals processing and metals production industry; involvement of engineers and scientific experts in fate model, technological limitations/possibilities, and technical and environmental cost of extracting minerals from "average" rock (there is a potential point of time in the future at which there is no naturally occurring mineral concentration beyond background concentration (1)).

d) Proposed actions to address these challenges

- Determine whether this impact category is seen as a priority within the UNEP SETAC Initiative
- Engaging the mining, minerals processing and metals industry in active debate (for example through the ICMM and industry affiliates such as ISSI, NiDI, ICA and others)
- Ensuring that the voice of the developing world whose economies depend on these industries have a significant voice in these debates
- Determine whether Resource Depletion will continue to be based on Resource Extraction, or whether it will be modelled relative to Resource Dissipation
- Determine an acceptable base-line for the chosen scenario
- Develop models for different metals, not only those which are of significance in the developed world
- Develop methodologies for addressing complexities associated with complex ore bodies, as well as co-products.

References:

(1) Draft Report Theme 2: Impact assessment for metal mining. Workshop on LCA and Metals, Montreal April 2002.
(2) Part II Current Trends and Actors. Chapter 4 "The need for and availability f Minerals". MMSD Draft Report - March 2002.
(3) Developing country-specific impact procedures: Human Health and ecosystem quality as criteria for resource quality and availability. Dr. Alan Brent, Chair: Life Cycle Engineering, University of Pretoria.

12E) Erosion and landslides*

Marc Goedkoop, Llorenç Milà i Canals (review: Helias Udo de Haes,)

a) Description and state of the art

Erosion relates to a number of different mechanisms that all result in the unwanted displacement of soil and soil nutrients trough wind or water run off. Generally it is associated to agricultural practices or the use of military terrains, but also the new development of infrastructure, like road construction, urban area's and the damaging of natural area's can be associated to the phenomena.

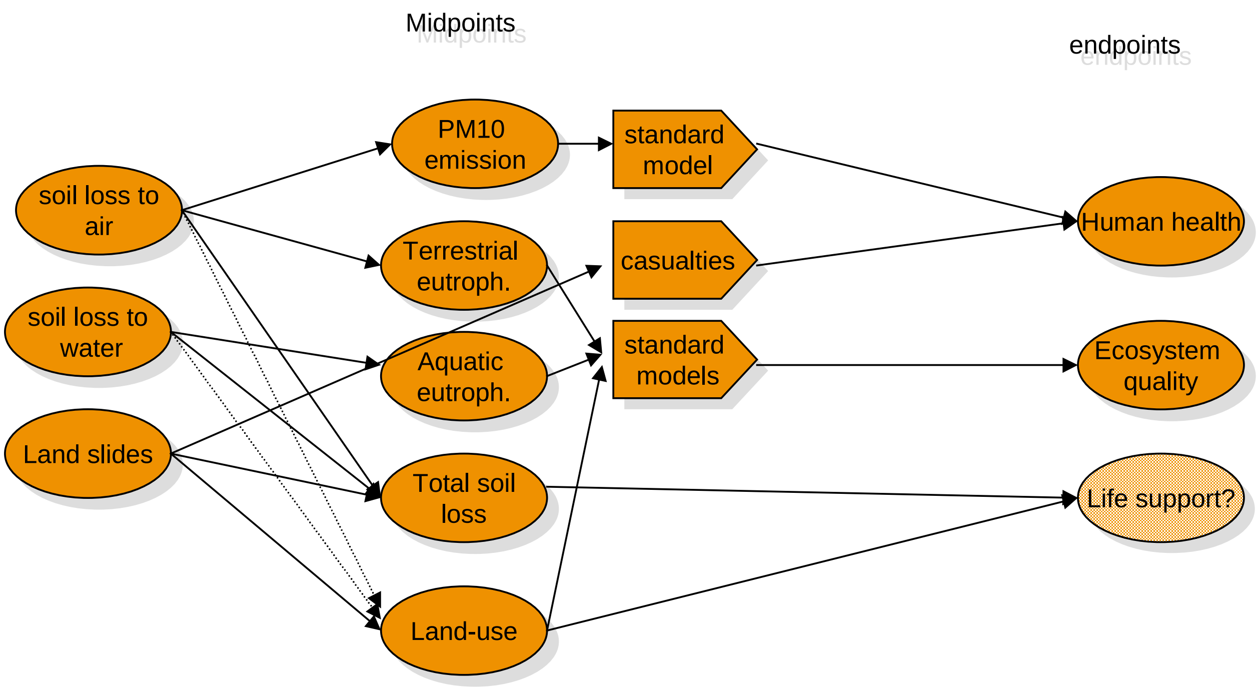
Erosion is not a problem in all parts of the world; for instance in the northern part of Europe there are very few problems. Wet and sufficiently flat area's suffer little from erosion, but dry, windswept and hilly area's can be very seriously affected.

We propose to introduce three LCI parameters:

1. Soil losses to air (kg), relating to wind erosion
2. Soils losses to water (kg) relating to the relatively gradual loss, so without sudden landslides
3. Landslides (kg), expressed as the average mass of land per event times the frequency of occurrence

The third category may prove difficult to apply (see also below under specific challenges), but for the time being we include it.

The use of mass as the LCI parameter deviates from a more common unit to express erosion (kg/m2/yr), because mass be linked to a functional unit, like growing 1 kg of coffee beans. However,, often the data can be extracted from the common erosion parameter, if we know the coffee yield per hectare per year, we can calculate the mass by dividing the normal erosion parameter by the yield.



We propose to introduce one new midpoint, defined as the total soil loss, expressed as Kg, disregarding the type of soil or the mechanism, although in princi0ple it is simple to split the midpoint into two category indicators for wind and water. Furthermore, erosion relates to a number of already existing midpoints and endpoints, see figure below:

1. Wind erosion can contribute to the PM10 category, relating to human tox, and to terrestrial eutrophication as the blown away soil can be rich in nutrients.
2. Soil losses to water can contribute significantly to aquatic eutrophication
3. Landslides can have a direct link to a midpoint or endpoint defined as causalities, if this is to be included in the framework. Landslides can also seriously affect the land use category

The total soil loss category indicator cannot directly be related to the endpoint human health or ecosystem quality, but in principle it can be related to the area of protection Life support

b) Specific challenges

The impacts of erosion depend very much on site specific conditions, like soil type, average rainfall and evaporation, wind speed, slope and vegetation. By use of the eroded mass as the LCI parameter, part of the modelling problems is moved to the LCI part of LCA this problem is moved to the LCI part of LCA. The LCI experts will need to gather data on the seriousness of the erosion; the LCIA experts will describe the impacts.

In order to keep this new impact category manageable both for LCI and LCIA practionners, we propose to develop LCI and LCIA parameters for a limited set of archetypical conditions, that are characterized by the factors like wind, rainfall, slope, etc. The benefit of this approach is that many agricultural products will in practice only grow in one or two of these archetypical conditions. So in an LCA for Coffee, one will need to study only a limited subset of these conditions to develop default LCI and LCIA parameters. This approach also has the advantage that one can start with relative coarse models and refine later.

c) Bases/resources to address these challenges

Llorenç Milà i Canals, MSc has made a literature overview of the erosion issue as part of his upcoming thesis (ref>). An early version has been submitted to the WIA report.

On internet a number of interesting projects are going on:

An international Soil erosion network with 43 m3mbers from 20 countries http://mwnta.nmw.ac.uk/GCTEFocus3/networks/erosion.htm, and an European COST network http://soilerosion.net/cost623/ are currently joing forces to organize two dedicated erosion conferences in 2003: http://soilerosion.net/model-eval-2003/

Other possibly interesting sources are: US department of Agriculture has studied the issue of wind erosuion, and also links erosion to air quality. Cranfield University coordinates a European Soil Erosion Model project, wich involves many experts: http://www.silsoe.cranfield.ac.uk/nsri/research/erosion/eurosem.htm

d) Proposed actions towards recommended practice

Organize a workshop with experts

Check literature on the relevance of the link with PM10

Participate in the two erosion conferences in 2003

Build a scratch model of one or two archetypical conditions that can be used as a basis for further discussion and refinement

12F) Soil salinisation and dessication

Marc Goedkoop (review: Mary Stewart)

Please note that there is a specific section for water extraction as a resource. In this section only ecological impacts are addressed

a) Description and state of the art

Salination and dessication are two new, impact categories relating to the impacts from increased salt concentrations in soil and water. We propose to distinguish between 2 different sub types of salination

- Salts contained in irrigation water, in agricultural areas
- Salts from acid drainage (mining), usually in natural areas

Of course there are also other mechanisms that can potentially increase the salt concentration, like emissions from other industrial activities and natural causes, such as floodings by sea water, salt contained in wind blowing from the sea and natural salt sources

Dessication refers to the impacts from lowering groundwater tables due to water extraction, or changes in the infrastructure (like changing the flow of rivers, making hard surfaces which prevent rainwater from entering the soil etc.) Also the use of surface water can influence dessication, for instance by extracting water from a river it may cause problems downstream The impacts from dessication can also be related to salination, as in some area's salination problems are caused by the lowering of groundwater tables. However, dessication also has other impacts on ecosystems in terms of species diversity as well as on the productivity of agricultural systems.

Later research will have to show whether it is useful to make different impact categories for the two types of salination and for dessication.

In the case of salination through Irrigation we propose to use as an LCI parameter, the mass of salts transported to the irrigation water (usually the concentration of the salts times the amount needed for a certain yield or surface). When relevant, salt that is absorbed by the harvested crops may be subtracted. The LCI parameter should specify each salt independently. Note that the salts are usually from a natural source, or from a mixture of natural and industrial sources, so in this impact category we introduce a new phenomena, the impacts of natural sources, through an artificial irrigation system. Normallys, we would not count the natural emissions, but the irrigation system creates an unnatural concentration
If the irrigation water contains toxic substances (even from a natural source); it seems justified to include the toxic effects, as irrigation is used to provide crops. However, this is a field for further research

In the case of salination from mining, or acid mine drainage, the LCI parameter is the total mass of the emissions per type of salt. A characterisation factor should include the differences in ionic strength. Also here the origin of the emission is partially natural, but through the mining processes, artificially high concentrations are created.

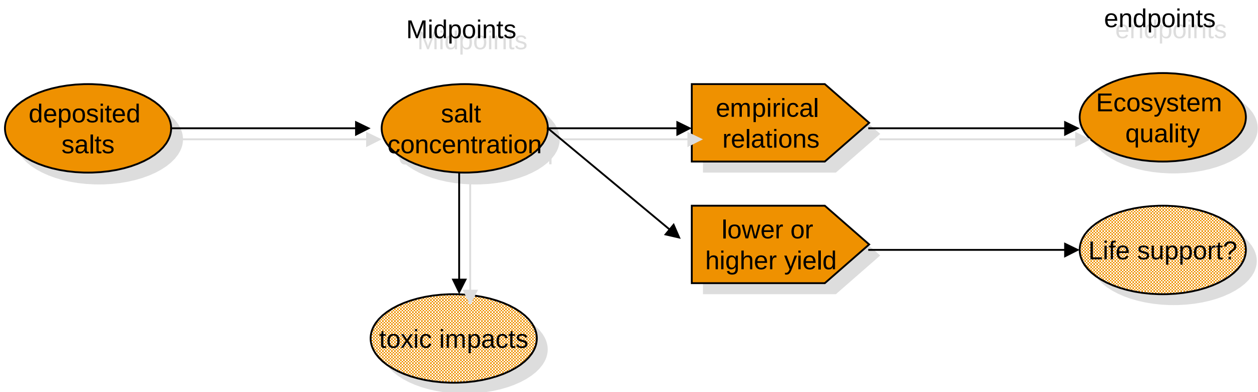
For Dessication we propose as an LCI parameter the total amount of water withdrawn from the soil and the total amount of water being prevented from entering the soil, for instance due to changes of the soil surface.

Pathways

The toxic effect of the salt emissions can be treated as the other toxic impact categories, although some additional fate and exposure modelling is needed for two different cases:

- The mine is located in a uninhabited area
- The mine is situated very close to populated area's (in developing countries even mines in uninhabited area's draw a big influx of people seeking for employment. These often live near or even on the tailings)

The damaging impact of salts on ecosystems in mostly relevant for mines in natural area's. Salt drainage form agricultural to natural area's may have little significant effects. The impact of salts to ecosystems can be modelled with a similar mechanism as the pathway for ecotoxic substances, and with empirical models.
The impact of salination through irrigation on life support is a difficult issue. On the short term irrigation has a very positive impact on the life support system, on the longer term the salination will reduce the productivity of the irrigated lands, but it is questionable if the lower productivity will become lower than in the case of no irrigation at all.
Depending on how the land-use impact category is modelled; salination will also have impacts on land-issue. For instance the restoration time will be increased, and the species diversity in the irrigated land will first increase and later decrease.
Salination has also links to erosion; however we propose not to model this link, and keep erosion as a separate impact category with its own LCI parameters. Dessication will also contribute to erosion an especially to the endpoint ecosystem quality. In some very dry area's it may also have significant effects on human health, but it is unclear if this link should be established.



b) Specific challenges

The impacts of salination depend very much on site specific conditions, like soil type, average rainfall and evaporation, wind speed and vegetation. One important factor is the amount of salt that is deposited. By making this the LCI parameter, this problem is moved to the LCI part of LCA. The LCI experts will need to gather data on the salts deposited; the LCIA experts will describe the impacts.
In order to keep this new impact category manageable both for LCI and LCIA practionners, we propose to develop LCI and LCIA parameters for a limited set of archetypical conditions, that are characterized by the factors like wind, rainfall, slope, population density etc. The benefit of this approach is that many agricultural products and will in practice only grow in one or two of these archetypical conditions. So in an LCA for Coffee, one will need to study only a limited subset of these conditions to develop default LCI and LCIA parameters. This approach also has the advantage that one can start with relative coarse models and refine later. Similarly we can develop LCI and LCIA default parameters for different conditions in which mines are located. . Similarly, it may be possible to link such conditions to different types of ores, as some ore types (oxides) create much lower acid mine drainage compared to others (like S), and in case the ore concentration is low (gold) the potential emission is even bigger. Furthermore we can distinguish between management practices, like: well managed, restoration planned, to badly managed, no restoration, and different levels in between. The Green Mining initiative could be a useful framework.

c) Bases/resources to address these challenges

There are a number of initiatives in the mining sector to study, model and manage acid mine drainage, like the MEND project. Most of these initiatives seem to be managed by or via the ICMM. There are already many links between the life cycle initiative and this sector.

Salination through irrigation is studied by the International Society for Horticultural Science (ISHS, see http://www.ishs.org/) One of the models used is the Integrated Modelling Approach for Irrigation Water Management using saline and non-saline water: the SALTMED model, see http://www.actahort.org/books/573/573_15.htm

Research on dessication seems scattered, but UNEPs water portal http://freshwater.unep.net/ on internet gives a god overview of institutes and experts. Also UNEPs Vital Water website as a good overview http://www.unep.org/vitalwater/index.htm.

d) Proposed actions towards recommended practice at

Organize a workshop with experts from the ICMM and the ISHS, to review this proposal, and decide whether this impact category should be split.

For desiccation we propose to consult experts within UNEP and its associated groups to develop future actions.

12G) Biotic resource use**

Bo Weidema

See general introductory paper for natural resources (section 12A)

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