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Swiss Centre for Life Cycle Inventories

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Implementation of Life Cycle Impact Assessment Methods

Data v2.0 (2007)

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Summary

The ecoinvent database offers life cycle inventory (LCI) and life cycle impact assessment (LCIA) results. The following LCIA methods are implemented in the ecoinvent data v2.0:

- CML 2001
- Cumulative energy demand
- Cumulative exergy demand
- Eco-indicator 99
- Ecological footprint
- Ecological scarcity 1997
- Ecosystem damage potential - EDP
- EDIP'97 and 2003 - Environmental Design of Industrial Products
- EPS 2000 - environmental priority strategies in product development
  (will be provided with ecoinvent data v2.1)
- IMPACT 2002+
- IPCC 2001 (climate change)
- TRACI
- Selected Life Cycle Inventory indicators

There is a range of methodological problems and questions while linking the LCIA methods with the elementary flows of a database. This lead to different results in the past, even if the same LCIA method was applied on the same inventory results.

The aim of this report is to avoid such discrepancies. In the first part of this report the general assumptions for the implementation of impact assessment methods on the ecoinvent life cycle invenory data are described. For that purpose, general and harmonised rules were developed how to deal with a certain problem.

The second part of this report contains a detailed description of the implementation of the above mentioned methods. Please refer to the original publications for a general description and the scientific background of the methods. It is strongly recommended to read the original publications before using the LCIA results from the ecoinvent database.

It is recommended to follow these implementation guidelines also while using other or new LCIA methods, which are so far not implemented in ecoinvent data.

Table of Contents

Part I:
General Assumptions

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Citation:

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1 Introduction

The ecoinvent database offers life cycle inventory (LCI) and life cycle impact assessment (LCIA) results. LCIA methods do normally assign a factor to single elementary flows in an inventory table. There are different types of factors, which are shortly described in Tab. 1-1. In this report all types of these factors are meant by the short term "factor".

Tab. 1-1 Type of factors provided by LCIA methods

Factor name	Description
Characterisation factor	The importance of single flows in relation to a specific basic flow is characterised with a factor, e.g. global warming potential of greenhouse gases in relation to CO_2.
Normalized factor	Another factor, e.g. a characterisation factor, is normalized by division through the total sum of the characterised flows in a certain area and within a certain time.
Weighted (…) factor	A weighting is applied to the characterised or normalised results from different categories in order to calculate a final score.
Damage factor	The possible damage due to an emission is described with a factor. This can include a modelling for the environmental fate, a characterisation of the substances and a final weighting.

There are a range of methodological problems while linking the LCIA methods with the elementary flows of a database. Major problems are:

- substance names of elementary flows in the LCIA method and in the database do not match
- elementary flows in the database are not considered by the method
- factors in the method do not have a corresponding flow in the database
- modelling in LCIA and in the database overlaps or does not match

In the past the methodological problems have lead to different results even if the same LCIA method has been applied to the same inventory results. Therefore implementation reports for the assignment of LCIA methods to inventory results have also been published earlier (e.g. Förster et al. 1998; Jungbluth & Frischknecht 2000).

The aim of this report is to avoid confusion and to develop clear guidelines for the use of LCIA factors with cumulative results from the ecoinvent database. Therefore general rules for the assignment of factors to the elementary flows reported in the ecoinvent database have been developed. These general rules are described in this part. It is recommended to consider these rules also while using other or own LCIA methods with the ecoinvent data.

Tab. 1-2 shows an overview for the impact assessment methods implemented in the database ecoinvent. Their implementation is described in part II of the report. For a general description and the scientific background of the methods please refer to the original publications. It is strongly recommended to read the original publications before using the LCIA results.

Tab. 1-2 Impact assessment methods implemented in the database ecoinvent

Method	Background publication
CML 2001	(Guinée et al. 2001a; b)
Cumulative energy demand (CED)	Own concept
Cumulative exergy demand (CExD)	(Boesch et al. 2007)
Eco-indicator 99	(Goedkoop & Spriensma 2000a; b)
Ecological Footprint	Huijbregts et al. 2006
Ecological scarcity 1997	(Brand et al. 1998)
Ecological Damage Potential (EDP)	(Köllner & Scholz 2007a; b)
EDIP - Environmental Design of Industrial Products 1997	(Hauschild & Wenzel 1997), DK LCA Center 2007
EDIP - Environmental Design of Industrial Products 2003	(Hauschild & Potting 2005)
EPS - environmental priority strategies in product development	(Steen 1999)
IMPACT 2002+	(Jolliet et al. 2003)
IPCC 2001 (Global Warming Potential)	(Albritton & Meira-Filho 2001; IPCC 2001)
TRACI	(Bare 2004; Bare J. C. et al. 2007)
Selected LCI indicators	ecoinvent final reports

CML Centre of Environmental Science

IPCC Intergovernmental Panel on Climate Change

The general assignment rules cannot solve all implementation problems. For each of the methods you will find a detailed description of the specific implementation in part II of this report. After a short introduction these chapters will give some hints on the specific aspect for the use of the method. Then the assignment rules for this method are explained as well as the problems that could not be solved by the general assignment rules and which are dealt with in a specific way.

2 General assignments for the implementation

This chapter describes the general assignment rules for the implementation of LCIA methods in ecoinvent. A summarizing Tab. 2-2 with the general rules can be found at the end of this chapter.

Elementary flows[1] in ecoinvent are identified by a flow name (e.g. "Carbon dioxide, fossil"), a category and a subcategory. Tab. 2-1 shows the categories and subcategories, which are used in the ecoinvent database. Categories describe the different environmental compartments like soil and water. Subcategories further distinguish relevant subcompartments within these compartments. The following text refers to these categories and subcategories.

Tab. 2-1 Categories and subcategories for elementary flows in ecoinvent

Category	SubCategory	Definition	Assigned in general to
air	low population density	Emissions in areas without settlements or protected areas in the direct surrounding	Resource extraction, forestry, agriculture, hydro energy, wind power, landfills, waste water treatment, long-distance transports, shipping
air	low population density, long-term	Emissions which take place in the future, 100 years after the start of the process.	Emissions from disposals after more than 100 years.
air	lower stratosphere + upper troposphere	Emissions from air planes and space shuttles.	Air transport cruises.
air	high population density	Emissions near settlements or protected areas which affect directly people or animals due to the local situation. Most important for particles.	Industry, power plants, manufacturing, households, municipal waste incineration, local traffic, construction processes.
air	unspecified		Only used if no specific information available.
resource	in air	Resources in air, e.g. Argon.	
resource	biotic	Biogenic Resource, e.g. wood	
resource	in ground	Resource in soil e.g. ores, but also for landfill volume	
resource	land	Land occupation and transformation	
resource	in water	Resource in water, e.g. magnesium	
soil	agricultural	Emission to soil which are used for the production of food and fodder	Agriculture
soil	forestry	Emission to soils used for plant production (forest, renewable raw materials) which do not enter the human food chain directly.	Forestry
soil	industrial	Emission to soils used for industry, manufacturing, waste management and infrastructure.	Industry, waste management, build up land.
soil	unspecified		Only used if no specific information available.

[1] Elementary flows are flows of pollutants and resources between technosphere and nature.

Category	SubCategory	Definition	Assigned in general to
water	ground-	Ground water which will get in contact with the biosphere after some time.	
water	ground-, long-term	Emissions which take place in the future, 100 years after the start of the process.	Long-term emissions from landfills
water	lake	Lakes with fresh water	
water	ocean	Ocean, sea and salty lakes.	Offshore works, ship transports.
water	river	Rivers	Disposal of effluents.
water	river, long-term*)	Emissions which take place in the future, 100 years after the start of the process.	Long-term emissions from landfills
water	fossil-*)	Salty ground water that does not get into contact with the biosphere.	Re-injection of formation water from oil- and gas extraction
water	unspecified		Only used if no specific information available.

*) Not used in ecoinvent data v2.0

2.1 General rules

If a factor is available for the elementary flow in the specific category and subcategory there is no assignment problem at all. For all other main cases for the assignment of factors to elementary flows we will now describe the applied procedure. In cases, where the assignment of factors to exchanges in ecoinvent was not unequivocal, we also asked for help from the method developers.

2.1.1 Factor “unspecified” for a particular compartment (category) available

It is assumed that the unspecified factor, which is available for an elementary flow in a particular environmental compartment (category), can be used for all subcategories of the elementary flow in this category. It has to be checked if any restrictions on the use of the factor have been introduced by the developers of the method.

2.1.2 Factor available only for a specific subcategory

In this case a factor is available only for one specific subcategory, e.g. a factor is given for emissions to river but not for the emission to the ocean. It can be assumed that such a restriction for the subcategory has been introduced by the developers of the method with a specific reason. Emissions of chloride to rivers are for example an environmental problem while an emission to the ocean will normally not be very dangerous for organisms because the natural concentration of chloride is quite high and will not be changed by man made emissions.

This case is highly relevant for water emissions. We decided to apply the same factor for persistent (e.g. chemical elements like Hg) ground water emissions as for emissions to rivers, because these emissions will enter the biosphere after some time. For other ground water emissions such as degradable organic compounds no factor from other subcategories is implemented. A factor for rivers is not used for emissions to salt water (ocean and fossil).

For air emissions it has to be checked whether the factor describes a local effect, where the subcategories are important or if it describes a global effect (so far there are no examples known for a factor only given for one subcategory).

For emissions to soil it has to be considered that factors for agricultural soil usually consider human exposure via food intake. Thus this factor can not be used for other soil types.

The modelling in the impact assessment method is valid only for the subcategory considered. Further on it has to be considered that some subcategories might have been explicitly excluded from the modelling. The method Eco-indicator 99, for example, does not provide factors for heavy metal emissions to agricultural soil because these impacts are already included in the modelling for the damage category "land use". Thus the assignment is often difficult and relevant errors are possible. Factors for others than the claimed subcategories shall only be assigned with a positive feedback from method developers.

2.1.3 Assessment for long-term emissions

Introduction

Some processes such as landfills have very long emission periods, i.e. they release only a part of the pollutants today, but are likely to continue to do so in the future. Emissions that are emitted after 100 years after waste placement are classified as "long-term" in ecoinvent[2]. Therefore specific subcategories have been introduced in the ecoinvent database. These emissions are modelled for the disposal of different types of wastes like uranium tailings or waste in landfills[3]. In the ecoinvent inventory it is assumed that after 100 years the active landfill aftercare ends. The subsequent long-term emissions have normally no (e.g. heavy metals) or a very low degradability (e.g. radioactive emissions). Thus they remain potentially harmful over a very long timescale. There was a consensus within the group of administrators that these emissions should be included in the inventory and that it should be possible to make a differentiation between present and future emissions.

Until now most of the impact assessment methods have not specified how to deal with this type of emission. In the past some people valuated them just like short-term emissions. Thus the question for our project was:

Shall we assign the damage factors provided by the LCIA method for today emission without changes also to long-term emissions?

The question if long-term emissions should be assessed with the factors investigated in the LCIA methods for today's emissions and how to assign damage factors to this type of emissions in the database led to intense discussions among the ecoinvent administrators. There was a consensus between the people involved that this type of emissions cannot be neglected per se in the impact assessment. But there was a dispute if the existing LCIA methods can be used without alterations and further methodological development for a valuation. During the discussion several arguments have been brought forward. The following list of pro and contra arguments is intended as an intermediate outcome of the ongoing discussion, and can be used as a basis for further discussions.

Contra

1. **Concentration in the environment:** Today millions of substances are emitted due to human activities. In LCA one does normally consider only these substances which exceed or exceeded certain thresholds and thus have harmed human beings or the nature. These effects are observed today dependent on the existing concentration levels. For a damage modelling it has to be considered that the inventoried emissions are spread over a very long time and thus resulting concentrations in the environment from a fixed amount could be much lower[4] than for emissions that take place at a certain moment of time. It is not clear if potential harmful effect threshold values of these substances in the biosphere will be exceeded in the long-term range due to the emissions. Thus they should not be valued with the same factors as emissions which take place now and for which effects can be observed and LCIA methods have been developed. Appropriate

[2] These 'long-term emissions' should not be confounded with the long-term *effects* of *present* emissions.

[3] For landfills long-term emissions integrate emissions from 100 years to 60'000 years after present; in uranium tailings the integration period is 100 to 80'000 years after present.

[4] They might also be higher due to chemical mechanisms which would deserve also a specific modelling.

factors should consider the fate of the substances until they reach the biosphere and not only the fate to the first ground water contact.

2. **Potential future manageability:** The manageability for this type of emissions is quite unclear. Taking the fast technological development of the last 5000 years from stone age to e.g. global mobile communication it seems quite feasible to avoid such future emissions with technical measures, which can now not be foreseen or to minimize the harm by political measures. It seems feasible to develop new technologies before the leachate pollutes the groundwater. This may even be possible with current technologies that e.g. were not used because of the financial resources involved but may be applied if the problem becomes more pressing.
3. **Insufficient level of proof:** The level of proof for this type of emissions is quite lower in comparison to other types of inventoried emissions. Many air emissions are measured regularly with standardized methods. The results can be used in the inventory. Long-term emissions have to be forecasted based on relatively short time laboratory experiments or a few years experiences with existing landfills, heeding an expected future behaviour.
4. **Prognosis uncertainty:** Forecasting how the world looks like in 60'000 and 80'000 years and how natural and man-made environment changes in this time is quite hypothetic. Looking back shows that forecasting was mainly just an extrapolation of the today situation while real changes have seldom been foreseen.[5] The modelling for the inventory does for example not take into account dramatic changes in the natural environment (e.g. ice ages) as well as changes to the man-made environment.
5. **Decision making for very long time frames:** Decision making of households, companies or politics does normally take into account only time periods of some decades, i.e. for the next generation. There are only very few practical examples for decision making with a time frame of more than 50'000 years. It is questionable if decision-making for these time frames really makes sense.
6. **Common discounting[6] of the future:** Empirical studies (e.g., Ahearne 2000; Leist 1996; Linestone 1973; Okrent 1999; Schelling 2000) show, that people prefer future damages to current damages, also if several generations are involved. This should be considered in the LCIA with lower factors for future emissions.
7. **Lack of common acceptance:** LCA should focus on the assessment of well known problems which are recognized not only within a small scientific community but also in a broader public field. Decision makers will accept results of an LCA to a lesser extent if the outcome is dominated by environmental problems which are not very well known. Thus quite often only well accepted indicators like global warming potential or energy use are used within the discussion of LCA results.
8. **Obscuring today problems:** The possibility exists that future emissions are so important in the assessment result (especially for toxicological impact categories) that they may obscure the effect of present emissions and related problems. Decision-makers who have in mind present emissions will doubt such a result and will not accept it.
9. **Temporal differentiation:** The ISO norms says that "depending on the environmental mechanism and the goal and scope, spatial and temporal differentiation of the characterisation model relating the LCI results to the category indicator should be considered" (International Organization for Standardization (ISO) 2000:5.3.4). This has not been clarified explicitly so far for many of the LCIA methods implemented. The fact that temporal information (see Pro-argument No. 13) is so far not considered in the LCIA is mentioned in the norm also as a limitation of the present LCIA methods (International Organization for Standardization (ISO) 2000:8).
10. **Normalization in the LCIA method:** According to the ISO standard the selection of the reference system for the normalization should consider the consistency of the spatial and temporal scales of the environmental mechanism and the reference value (International Organization for Standardization (ISO) 2000). So far the normalization step in the existing LCIA methods considers only the emissions of one year, i.e. the emissions that take place in the year 2000. According to this interpretation of ISO the future emissions that are caused today, but emitted in the future, should be included in the normalization value in

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[5] The importance of the Internet and mobile communication might serve as an example for a technology development which has not been predicted some decades ago.

[6] Discounting is defined as weighting future damages and utilities differently than current impacts and utilities. Discounting is usually applied with a positive discount rate, so that utilities or damages in the future are weighted less than current utilities and damages. However, the use of negative discount rates is also possible.

order to achieve a consistent reference system.[7] Thus it would be necessary to take today's emissions, then add the future emissions caused by today's processes and then subtract the part of the current emissions caused by past processes to obtain a normalization value. As a consequence, the more a substance would be emitted in the future and the higher the impact would be, the smaller would be the normalized impact factor (this would be the case for e.g. Eco-indicator 99). On the other hand the factors would be higher for methods which use a reference flow, e.g. the ecological scarcity 97. Thus these methods cannot be used without alterations for a much broader range of emissions (i.e. due to the inclusion of long-term emissions). Thus all factors have to be revised if the list of valuated flows is expanded.

11. **Setting of weighting factors in LCIA:** The definition of the normalization value is especially important for methods with a following weighting step, e.g. the Eco-indicator 99. For the weighting it has to be clarified if it is intended for the emissions which *take place* in one year or which are *caused* in one year (including future emissions due today waste disposals). If the users think of the latter it would be necessary to clarify this e.g. for a panel and to include these future emissions also in a normalization step.
12. **Conceptual overlaps in LCI and LCIA:** Modelling of LCIA methods and inventory modelling for long-term emissions might overlap or differ in the taken assumptions. In some LCIA methods the damage modelling starts immediately after the emission has taken place, e.g. after a substance has been released to the soil. The fate modelling then considers e.g. what share will be washed out to groundwater. The inventory modelling for the long-term landfill emissions already includes a part of this fate modelling. Based on the relative timescales of landfill modelling and pollutant dispersion in soil, the long-term landfill emissions are not inventoried as an emission to soil, but as an emission to ground water. In ecoinvent this inconsistency arise i.e. for the modelling of wastes which go to landfarming (immediate emission to soil without modelling of the further fate in the LCI) or to landfills (modelling of the fate over 60'000 years with partial wash out to ground water). The ISO (2000:5.3.4) states, that "The fate and transport of substances should be part of the characterisation model". So far the used fate models in LCIA and LCI have not been fully harmonized. Thus care has to be taken while using factors which have been derived under different prerequisites.

Pro

13. **Default temporal integration in LCA:** In general, LCA makes no explicit differentiation between emissions (and, ultimately, impacts and damages) at different points in time. In LCI, emissions from the past (e.g. infrastructure), the present (e.g. combustion of fuels) and the future (e.g. waste management) are summed up without a clear differentiation of the point of time when they occur.
14. **Default flux integration in LCA:** In LCA concentrations of emissions are not heeded at all, but only fluxes per functional unit. In contrast to other instruments such as risk assessment, emissions below legal thresholds are considered in LCA ('less is better' approach) (Potting & Hauschild 1997a; b; Potting et al. 1999). Toxic emissions above legal thresholds are considered with the same impact factors as below-threshold emissions. In practice, toxic above-threshold emissions are the exception during normal production mode and they therefore only show up in few LCA studies. The assumption that long-term landfill emissions are of low concentration is therefore no argument for discounting such emissions. This argument clashes with the above concept and is also based on a factual error: long-term landfill emissions will not necessarily be of low concentration, but can even surpass threshold limit values for acute toxic impacts.
15. **Default temporal integration in LCIA:** Also, todays LCIA methods look into the future. For instance, the global warming potential describes future impacts in a time frame of 20, 100 or 500 years and ozone depletion with an infinite time frame.
16. **Holistic concept:** Per definition, LCA should consider all emissions and impacts 'from cradle to grave'. This holistic approach is not consistent with harsh temporal cut-offs (Finnveden 1997).
17. **Completeness:** Landfills emit substances for a very long time, as has been shown, e.g. with reference to metal deposits of the ancient Roman Empire (Maskall et al. 1995; Maskall et al. 1996). It is impossible to accurately predict the future over long time horizons, but there is absolutely no evidence for assuming that these emissions may stop without human intervention. Discounting these emissions would mean that important potential impacts of today waste management options would be disregarded (landfills emit the

[7] The same argument can be used as well for methods that use a reference flow, e.g. the ecological scarcity 97 method.

major part of pollutants after 100 years). Thus, the devised impact 'potential' would then only include a very small fraction of the total impact (Hellweg et al. 2003).

18. **Speculations and ethics of manageability:** Technological improvement of dump mining and remediation techniques could be an argument for neglecting long-term emissions. However, first, if such technology development were already considered in LCA, LCA results would not provide incentives to develop such technologies. Second, even if such a technology could be developed, this does not ethically justify the imposition of risks on the future. *Just because A is better able to deal with B's problems than B is, does not mean that B has the right to impose his problems on A* (Shrader-Frechette 2000). Third, contamination of groundwater can cover wide areas and cleanup actions are laborious and time-consuming, limited by the slow groundwater flow and soil retention. Current cleanup programs are very expensive and even considering huge future technological development (e.g. autonomous nanorobots) will remain huge undertakings. Future manageability could even be lower than today, because of transfer of knowledge (landfill locations) and responsibility. Fourth, the inventoried landfill pollutants are *undegradable chemical elements* like lead, cadmium, mercury etc. and even after cleanup procedures they will probably have to be disposed of *again*, as they cannot be transformed into non-toxic compounds. The only known means of destruction of chemical elements (nuclear fission, fusion or transmutation) seems very speculative to justify a negligence of these pollutants in face of the established and observed effect of continuous landfill leaching. Fifth, the assumption of technological improvement is an *optimistic* scenario. A priori equally plausible is a *pessimistic* scenario, e.g. partial collapse of the economic system, poverty, decline of technological sophistication, spread of agrarian cultures which leads to increased pollutant uptake from agricultural soil and groundwater.

19. **Future background level:** With respect to heavy metals, it is likely that concentrations in the environment increase substantially in the (near) future due to heavy accumulation in some environmental compartments (Hellweg et al.; van der Voet et al. 2000). Assuming non-linear dose-response curves, the magnitude of effect of one emission unit is bound to increase with rising concentrations in the environment. The effects of long-term emissions of heavy metals might therefore impose a higher impact on the environment than current emissions. Therefore, they need to be considered and even valuated higher than present emissions, but certainly not neglected.

20. **Anticipation of future generations:** Uncertainty about the presence of a future society and about the preferences of future people has been put forward as an argument for putting less weight on future emissions than on current emissions. However, if there is a probability for humankind to exist in the future, and this probability is large, then current generations automatically have the responsibility not to harm future generations, from an ethical point of view (Leist 1996). And even if the state of the future society differs from today's, it is likely that fatalities, illnesses, and injuries will still be perceived as damages (Leist 1996; Price 2000).

21. **Intergenerational equity:** There seems to be wide agreement among ethicists that the welfare of future generations should be a concern to us and that all members of all generations deserve equal treatment including those not yet born. Only an equal treatment of all people without their temporal and geographical position is accepted as morally correct (e.g., Azar & Sterner 1996; Birnbacher 1989; Leist 1996; Livingstone & Tribe 1995; MacLean 1990; Shrader-Frechette 2000). If LCA wants to comply with fundamental ethical values (and sustainability), the *same* impact should not be valued differently just because of its occurrence in time.

22. **Modelling practice:** Any model is based on assumptions and simplifications and therefore is debatable and uncertain. Nevertheless many models are used in LCA, because an LCA wants to inventory a *comprehensive life cycle* with virtually thousands of processes. Prediction of long-term emissions *must* be based on models, as these emissions *cannot be measured today*. Neglecting emissions in the future because their effects *could be* different in a changed future environment, is inappropriate when occurrence of these emissions under the given circumstances (i.e. "business as usual") is much more plausible than alteration or prevention of these emissions by some unforeseen process. In modelling terms: if you know the present model state and want to predict some future state, it is certainly better to use the *present situation* as a first order approximation of any future state (i.e. assuming everything continues as today) than to use the zero order approximation of simply *neglecting* any future state, which would be like assuming that the future is "not there". Of course, the future will not be *exactly like* the present. But the probability that the future will be *something similar* to the present is much higher than the probability that the future will be "not there". The present state is then a more reliable approximation of the future state than neglecting any future state (cf. Fig. 2.1). In case of the landfill models, some relevant and foreseeable future effects are included, like preferential flow and the development of acid neutralising capacity and pH (Doka 2007).

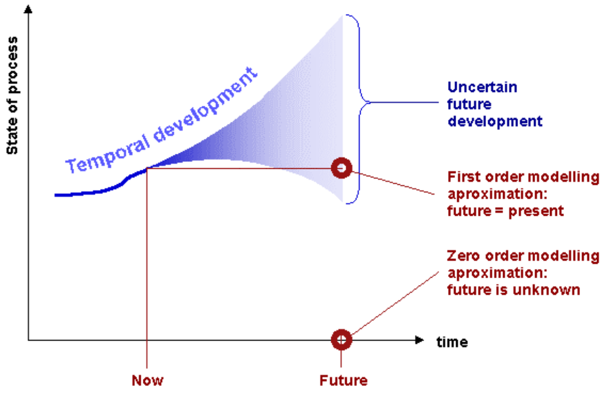

Fig. 2.1 Modelling an uncertain future

23. **Avoiding potential inefficiency of LCA:** LCA is a tool for the synopsis of all environmental damages of processes. The goal of LCA is to prevent environmental damages by pointing out less burdening options. Within that process it is important to heed all damage potentials and effects. Negligence of certain effects or processes (on whatever grounds) bears the risk of merely shifting damage potentials from the heeded to the neglected effects with the chosen options. That one contribution is less known to a broader public or not fully researched scientifically like long-term landfill leaching - is a matter of uncertainty and a logical consequence of an open and unrestricted understanding of scientific knowledge.
24. **Decision making in LCA:** It is true that in everyday *economical* and laymen decision making the *consciously considered reasons* have short time frames, usually not exceeding past the next generation. This however shall not be a *normative prerequisite* for decision making in *ecological* matters. Indeed there are clear notions that the *lack of a long-term time perspective* is the major difference in economy and ecology[8]. It is inappropriate to adapt short time frames in ecological decision making for the mere reason that such time frames are common[9] elsewhere.
25. **Familiarity and acceptance:** The LCA community has known relevant long-term emissions for a long time and accepted the corresponding results without controversy. The widely used ETH inventories contain long-term emissions since 1996. In his 1998 dissertation, Rolf Frischknecht devised a method to valuate radionuclides within the Eco-indicator'95 LCIA method (Frischknecht 1998:129), later also used in Eco-indicator'99. This led to a *significant burden* in the nuclear energy chain. The principal source of this additional burden were long-term air emissions of radon-222 from uranium tailings integrated over 80'000 years. The level of proof for the inventoried processes and involved time spans are quite similar than for long-term landfill leaching.
26. **Normalization and weighting in LCIA:** Contrasting to the understanding of normalization brought forward in contra argument No. 10, normalization may be understood as an *interpretation aid* as described in ISO (International Organization for Standardization (ISO) 2000, chapter 6.2): Normalization serves to better understand the *relative magnitude* of an impact. Since the *current* impact situation (and the resulting current state of the environment) can be grasped best as a reference situation only current emissions should be included in the normalization value. Therefore, the use of *currently observed* annual pollutant fluxes for normalization[10], as applied by all present LCIA methods, is correct and consistent with ISO. Including *future* impacts in normalization values (as suggested in contra argument No. 10) would lower the ability of normalization of being an interpretation aid, because future impacts (and the resulting future state of the environment) are rather abstract to the user. According to this understanding of normalization no changes are required for the weighting and normalization procedure. Thus there is no problem to use the existing LCIA methods and applying the normalization values and weighting factors that have been derived for the

[8] "Ecology is but long-term economy", see Pierre Fornallaz (1986).

[9] There are examples of decision making, where long time frames are considered, such as: planning of final nuclear repositories, rotation cycles in forestry, conservation purpose of scientific libraries, or purpose of Swiss soil fertility protection legislation.

[10] Also in the ecological scarcity 97 method clearly the *currently observed* annual pollutant fluxes of the reference year (1997) are used as the reference flow (and not the currently *caused* fluxes including future emissions).

current emissions, also for long-term emissions. Within this understanding of normalization, the 'consistency of temporal scales' mentioned in ISO 14'042[11] suggests that a normalization value that relates to the assessed system shall be preferred. I.e. temporal consistency means that the reference year should be meaningful in the context of the study (e.g., a reference year 1950 would be inadequate for a present LCA as opposed to the year 2000).

27. **Conceptual overlaps in LCI and LCIA:** The cautious remark made in contra argument No. 12, regarding potential double consideration of fate in LCI and LCIA, is a general remark, which also applies to short-term emissions. Therefore, this argument cannot be taken to justify discounting of long-term effects. Local fate is considered in many LCI's, *because* systems such as landfills may be defined as belonging to the technosphere. For instance, the agricultural field is often understood as belonging to the technosphere (Hellweg & Geisler 2003). Therefore, many approaches (e.g. Geisler 2003; Weidema & Meeusen 2000) model the partition of pesticides on the field (the fraction intercepted by the plant, the fraction leached to the groundwater, drifted away by wind or transported to the surface water) in the LCI. Moreover, LCIA methods lack certain pathways needed to describe local pollutant fates[12]. There is currently *no overlap* or double consideration of pollutant fates. Only if modelling approaches in LCIA methods change in the future a harmonisation of local fate models in LCI and fate models in LCIA will be needed. Fate models in LCI and LCIA must be *mutually compatible*, but this will not be solved by *different damage factors* for long-term emissions.

Conclusion

There was no consensus in the discussion if the same factors should be used for long-term emissions and if they should be included for the implementation of the present LCIA methods. Finally the majority of the persons present decided to use the same factor for long-term emissions as for today emissions if the LCIA method provides no other specific recommendations for this problem.

The discussion showed that there are also quite different views about the role of LCA in general. Everyone agreed that further research and discussion on this question is necessary. This should cover modelling aspects as well as the social discourse. Furthermore there might be some more methodological problems to be clarified (e.g. a clarification for the concepts of normalization and weighting while determining factors for the LCIA).

2.1.4 Factor available for a specific subcategory but not for “unspecified”

In some cases the LCIA method might give only a factor for the subcategories, e.g. “river” and “ocean”, but not for the subcategory “unspecified”. For emissions to water the subcategory “rivers” is taken as a default, because most of the emissions will take place there. For soil emission “unspecified” is approximated with industrial soil. For air emissions this question is not relevant.

2.1.5 Factor only available for one specific category

In some cases a factor might be available only for the same emission in another category. For the Eco-indicator 99, i.e., a factor for eutrophication is given for phosphorus to air but not for phosphorus to water. But it is quite clear that water emissions of phosphorous are quite relevant for the problem of

[11] ISO 140402 states: "The selection of the reference system (for normalisation) should consider the consistency of the spatial and temporal scales of the environmental mechanism and the reference value." (International Organization for Standardization (ISO) 1997-2000:)

[12] E.g. in agricultural processes the local fate of nitrogen in spread manure is considered (partial short-term emission as ammonia to air) because this pathway is not considered in LCIA methods, but this emission is relevant in agriculture. In landfill processes the transport of leachate pollutants from the landfill to the groundwater is included, as the emission media 'deep subsoil' *does not exist* (yet) either in LCI or LCIA, and inventorying of those emissions to the *available category* 'surface soil' would not be appropriate (Doka 2003).

eutrophication. Nevertheless, no factor is assigned in this case if it is not explicitly recommended by the LCIA method developers.

2.1.6 Factor for a sum parameter but not for a single substance

Some methods give factors for sum parameters like NMVOC, COD, etc. For air emissions the factor for NMVOC is also used for individual hydrocarbons since individual NMVOC substances are reported in ecoinvent on the highest level of detail only. Factors for AOX, PAH, Fungicide, Herbicide, Insecticide, etc. are used also for individual elementary flows if specific factors are not available. If factors for sum parameters are available for different levels of hierarchy (according to de Beaufort-Langeveld et al. 2003) the most detailed level is applied. If a substance belongs to different groups of the same hierarchy level the highest factor is applied.

In contrast, the factors for the water emissions TOC, DOC, COD and BOD are not applied for the single substances if a factor is missing. In ecoinvent all individual substances are recorded as TOC, DOC, BOD, COD as well (different approach as compared to NMVOC to air). Further on it has to be checked if the environmental impact is the same for more than one of these sum parameters. If yes, then only one sum parameter has to be valued because otherwise the same emissions might be counted twice.[13]

2.1.7 Use of a factor for “similar” flows, substances or species

We do not apply a factor for one flow (e.g. the pesticide “lindane”) to another “similar” flow (e.g. “DDT”). The most important type of possible errors due to the assignment of factors to similar flows concerns the differentiation of the oxidation form for chemical elements. The toxicology of chemical elements is quite depended on the oxidation level of different species. Some examples can illustrate this. Chlorine (oxidation 0) is a toxic gas. Chloride (oxidation = -1) is essential for the nutrition of human beings, but it might be toxic in high doses for animals and plants in rivers and lakes. Chromate (oxidation = 6) is carcinogenic for humans when inhaled. Other forms of chromium (Oxidation = 0, 2 or 3) are not. Thus special care has to be taken not to assign damage factors for a specific oxidation form of an element to another.

2.2 Emissions to air

2.2.1 Biogenic carbon emissions

Biogenic CO_2 and CO emissions and biogenic CO_2 resource extraction are excluded from the impact assessment. The same weighting factor is applied on methane emissions from fossil and from biogenic sources. If impact assessment results are to be used with regard to carbon sequestration or clean development mechanisms, biogenic CO_2 and CO emissions and biogenic CO_2 resource extraction need to be added to the assessment.

CO_2 emissions due to deforestation of primary forests and land transformation are represented by the elementary flow “Carbon dioxide, land transformation”. The weighting factor of fossil CO_2 emissions is assigned to the elementary flow "Carbon dioxide, land transformation" (see Jungbluth et al. 2007 for further explanation).

[13] If factors are available for individual substances they are not used for the sum parameters, because counting both would mean a double counting.

2.2.2 Carbon monoxide (CO)

Emitted CO is transformed in the atmosphere to CO_2 after some time. Not all LCIA methods do consider the global warming potential of CO. Most methods are based on factors published by the IPCC (IPCC 2001). It is assumed that CO_2 emissions are calculated with the carbon content of the burned fuels and thus all carbon in the fuel is considered. In ecoinvent CO emissions are subtracted from the theoretical CO_2 emissions. Thus a GWP factor is calculated for CO (1.57 kg CO_2-eq per kg CO). Otherwise processes with higher CO emissions would benefit from this gap. This is especially important for biomass combustion. Neglecting the formation of CO_2 from CO would lead in this case to a negative sum of the global warming potential score.

2.2.3 NMVOC

For NMVOC it has to be considered that the emission of single inventoried substances is subtracted in the inventory from the sum indicator NMVOC. Thus a damage factor for NMVOC has to be applied for all such single substance emissions that do not have an individual LCIA factor. See also chapter 2.1.6 'Factor for a sum parameter but not for a single substance' on page 11.

2.2.4 Noise

Noise has not been considered as an elementary flow in ecoinvent. Thus it is not possible to use LCIA methods that deal with this problem. Some methods made an assessment for a technical flow in the inventory, e.g. the ton-kilometres driven (Müller-Wenk 1999). It is not possible to apply this type of LCIA method as in ecoinvent only elementary flows can be valuated.

2.3 Emissions to water

2.3.1 Sum parameter BOD, COD, DOC, TOC

Emissions of single substances with a carbon content are modelled in the database as the single substance as well as a contribution to the four sum parameters BOD, COD, DOC and TOC. This is considered for the impact assessment. A factor can only be applied for the individual substance or for one out of the four sum parameters. See also chapter 2.1.6 'Factor for a sum parameter but not for a single substance' on page 11.

2.4 Resource uses

2.4.1 Land transformation and occupation

The approach for the description of land occupation and transformation in ecoinvent is new. Current LCIA methods do not valuate these particular elementary flows. Missing classes[14] of land occupation and transformation are estimated with similar or higher level class. Until now factors for land use at the bottom of the ocean have not been considered in LCIA methods. Thus all uses of water surfaces and sea-bottoms are not included for the assignment of factors.

But for transformation from or to water surfaces and sea-bottoms an average factor is applied. This is necessary to avoid a bias in case of transformation from land surface (where LCIA factors are available) to water surface (where specific LCIA factors are lacking). If there is a factor for "transformation, to …" the same value with a changed sign is used for "transformation, from …".

[14] CORINE land use classes are used in the ecoinvent database.

2.4.2 Energy and material resources

Factors for energy resources are recalculated with the lower or upper heating values (depending on the definition of the LCIA method) of the resources that are used in ecoinvent. No assignment of factors is made for flows not covered in the LCIA method.

Abiotic resources such as Dolomite, Feldspar etc. contain quite different concentrations of individual chemical elements. Some impact assessment methods such as CML 2001 weight on the basis of individual chemical elements and not on the level of minerals. However, some resources are not extracted in order to exploit the elements, but to use the mineral as such (e.g., Feldspar is extracted to use the mineral as such and not to produce Aluminium). The assignment of factors to such "combined" resources has to be based on the assumptions in the original methodology. Relevant information is normally given in the reserve and yearly extraction figures underlying the impact assessment (e.g., Aluminium reserves in Bauxite feasible for Aluminium production or total Aluminium in the earth crust).

If in the original method the factor for a resource is derived based on the assumption that the resource is used for the production of a certain metal, factors are only assigned to an ecoinvent resources if it can be used for this purpose. If the use of the resource is not specified by the original method, factors are assigned to all ecoinvent resources which contain the element.

2.5 Technosphere to technosphere flows

2.5.1 Waste

Waste is not considered as an elementary flow in ecoinvent. The “ecological scarcity” LCIA method (Brand et al. 1998) gives a factor to waste sent to landfill and to final repositories. These factors are used with an adaptation for the land occupation inventoried for the waste disposal processes. The “ecological scarcity” LCIA method (Brand et al. 1998) gives also a factor to “energy from waste” which is not implemented because waste to energetic recycling is modelled with a cut-off approach. Thus the energy content of the waste is modelled with the first product use, e.g. the crude oil input to produce plastics, but disregarded for the second use, e.g. electricity production from waste burning.

2.6 Known errors and shortcomings of the methods

We do not correct any errors in the LCIA method unless they have been officially corrected by the developers. Known mistakes are described in the chapter for the specific method as well as known shortcomings.

2.7 Summary of general assumptions

Tab. 2-2 shows the general rules for the assignment of factors to elementary flows in ecoinvent. Factors in this context means all types of factors used in impact assessment methods, e.g.:

- characterisation factor
- normalized or weighted factors
- damage factor

Tab. 2-2 General rules for the assignment of factors to elementary flows in ecoinvent

	Case	Air	Water	Soil	Further remarks
0	Factor for the elementary flow and subcategory available:	No problem	No problem	No problem	☺
1	Factor “unspecified” without methodological restrictions available:	In general use of the factor for all subcategories.	In general use of the factor for all subcategories.	In general use of the factor for all subcategories.	Discussion with the method developers or the ecoinvent administrators in case of questionable results.
2	Factor only available for another subcategory. E.G. factor for emission to river but no factor for emission to the ocean:	Might be relevant for emissions to stratosphere. Emissions which cause local effects should not be considered in this case. For persistent emissions factor for other subcategory can be applied.	High relevance. Care has to be taken (e.g. Cl- emissions to rivers do definitely not have the same impact as those to the ocean). Factors for rivers are only applied for groundwater emissions of persistent substances and chemical elements (Cu, Zn, Ni etc.).	Most LCIA methods distinguish agricultural and industrial soil. Agricultural soil applies only for food production, but not for forest, energy plants etc.	The assignment is often difficult. Relevant errors are possible. The modelling in the impact assessment method is valid only for the subcategory considered. Factors shall only be used with a positive feedback the from method developers.
3	No factor available for the subcategory long-term emissions:	Assignment of factors for today situation.	Assignment of factors for today situation. Factor for LT-groundwater emissions is the same as for today groundwater emissions.	No long-term emissions in the inventory. No assignment of factors.	Available guidelines of method developers for value choices have to be considered.
4	Factor available for a subcategory but not for “unspecified”:	Low relevance. No assignment of stratosphere factors (e.g. for water) to ground level emissions.	Factor for “river” as default because most emissions are released to rivers.	Factor for "industrial soil" is used as a default for "unspecified soil" because for food products the subcategory “agricultural” has been considered in the inventory.	
5	Factor only available for another category (e.g. factor for phosphorus to air but not for P to water in Eco-indicator 99).	No factor assigned.	No factor assigned.	No factor assigned.	Use of factors allowed if proposed explicitly by method developers.
6	Factor for sum parameter but not	Factor of sum parameter is used for all individual elementary	Factors are applied only once for TOC, DOC, COD, BOD or for the individual	No example known.	

	Case	Air	Water	Soil	Further remarks
	for single substance, e.g. NMVOC, COD	flows.	emissions, because applying to both would mean a double counting; Factors for AOX, PAH, Fungicide, Herbicide, Insecticide, etc. are used also for single elementary flows.		
7	Use of factor for “similar” flows, e.g. Cr for heavy metals or DDT for pesticides.	No factor assigned.	No factor assigned.	No factor assigned.	Detailed investigation of cases is too complicated. Even in the first view “similar” flows might show big differences in the impact assessment. Special care has to be taken not to mix species with different oxidation levels, e.g. Cr III and Cr VI.
8	Land occupation and transformation	Missing classes are estimated with similar or higher level classes. Bottom of ocean not included. Negative factors are used for “transformation, from …”.			
9	Energy- and material resources	No assignment of factors for missing flows. Adaptation for lower and upper heating values. Consideration of original methodology for abiotic resources.			
10	Errors of the impact assessment method.	Correction only after official statement from developers. No own assumptions. Description of mistakes and shortcomings in the report.			

Abbreviations

(0,0)	Calculation not including age weighting
(0,1)	Calculation including age weighting
(E,E)	Egalitarian, Egalitarian weighting
(H,A)	Hierachist, Average weighting
(I,I)	Individualist, Individualist weighting
CAS	Chemical abstract service
CED	Cumulative energy demand
CML	Centre of Environmental Science
DALY	Disability-Adjusted Life Years
E	Egalitarian
EDIP	Environmental Design of Industrial Products
EI'99	Eco-indicator 99
EPS	environmental priority strategies in product development
H	Hierarchist
HEU	Highly Enriched Uranium
I	Individualist
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LWR	light water reactors
MOX	mixed oxide (nuclear fuel) with a mixture of Pu and U dioxides
PDF	Potentially Disappeared Fraction
points	Unit used for the weighted EI'99 damage factor

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Part II:
Description of the different methods

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1 CML 2001

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Summary

In 2001 CML (Center of Environmental Science of Leiden University) published a new "operational guide to the ISO standards". This guide describes the procedure to be applied for conducting a LCA project according to the ISO standards. For the impact assessment step of LCA a set of impact categories and the characterisation methods and factors for an extensive list of substances (resources from nature / emissions to nature) are recommended. In order to implement these methods in the ecoinvent LCI (life cycle inventory) database it is necessary to assign the characterisation factors to the elementary flows of resources and pollutants reported in this database. The work aims to link the impact assessment factors proposed for the problem oriented approach in CML 01 to the ecoinvent data in order to facilitate the usage and to avoid discrepancies due to misunderstandings or different interpretations of the original reports. Factors given in CML 01 for the damage approach Eco-indicator 99 are not considered because this method is implemented separately (c.f. chapter 2).

1.1 Introduction

In 2001 a group of scientists under the lead of CML (Center of Environmental Science of Leiden University) published a new "operational guide to the ISO standards" (Guinèe et al. (2001b); Guinèe et al. (2001c)). In this guide the authors propose a set of impact categories and characterisation methods for the impact assessment step. A "problem oriented approach" and a "damage approach" are differentiated. Since the damage approaches chosen are the Eco-indicator 99 (c.f. chapter 3) and the EPS (c.f. chapter 6) method, the impact assessment method implemented in ecoinvent as CML 01 methodology is the set of impact categories defined for the problem oriented approach.

In order to use this method, it is necessary to link the elementary flows of ecoinvent data to the substance names given in the publication of the characterisation factors (Guinèe et al. (2001a)). This background paper describes the implementation of the problem oriented approach according to CML 01 with its difficulties in the assignment and some assumptions that had to be made.

The work consists of this background paper and an EXCEL table. The work aims to support users of the databases mentioned while using the CML 01 impact assessment method. This should lead to comparable results of LCA that use the same database and the same valuation method.

For all users it is strongly recommended to refer to the original publications to understand the details of the CML 01 method (Guinèe et al. (2001a); Guinèe et al. (2001b); Guinèe et al. (2001c)).

Tab. 1-1 shows an overview of the CML 01 impact categories implemented for the ecoinvent data.

Tab. 1-1 Problem oriented impact categories according to CML 01 implemented in the database ecoinvent

Category	SubCategory	Name	Unit	Location
Baseline impact categories				
CML 2001	acidification potential	average European	kg SO_2-Eq	RER
CML 2001	acidification potential	generic	kg SO_2-Eq	GLO
CML 2001	climate change	GWP 100a	kg CO_2-Eq	GLO
CML 2001	climate change	GWP 20a	kg CO_2-Eq	GLO
CML 2001	climate change	GWP 500a	kg CO_2-Eq	GLO
CML 2001	climate change	lower limit of net GWP	kg CO_2-Eq	GLO
CML 2001	climate change	upper limit of net GWP	kg CO_2-Eq	GLO
CML 2001	eutrophication potential	average European	kg NO_x-Eq	RER
CML 2001	eutrophication potential	generic	kg PO_4-Eq	GLO
CML 2001	freshwater aquatic ecotoxicity	FAETP 100a	kg 1,4-DCB-Eq	GLO
CML 2001	freshwater aquatic ecotoxicity	FAETP 20a	kg 1,4-DCB-Eq	GLO
CML 2001	freshwater aquatic ecotoxicity	FAETP 500a	kg 1,4-DCB-Eq	GLO
CML 2001	freshwater aquatic ecotoxicity	FAETP infinite	kg 1,4-DCB-Eq	GLO
CML 2001	human toxicity	HTP 100a	kg 1,4-DCB-Eq	GLO
CML 2001	human toxicity	HTP 20a	kg 1,4-DCB-Eq	GLO
CML 2001	human toxicity	HTP 500a	kg 1,4-DCB-Eq	GLO
CML 2001	human toxicity	HTP infinite	kg 1,4-DCB-Eq	GLO
CML 2001	land use	competition	m2a	GLO
CML 2001	marine aquatic ecotoxicity	MAETP 100a	kg 1,4-DCB-Eq	GLO
CML 2001	marine aquatic ecotoxicity	MAETP 20a	kg 1,4-DCB-Eq	GLO
CML 2001	marine aquatic ecotoxicity	MAETP 500a	kg 1,4-DCB-Eq	GLO
CML 2001	marine aquatic ecotoxicity	MAETP infinite	kg 1,4-DCB-Eq	GLO
CML 2001	photochemical oxidation (summer smog)	EBIR	kg formed ozone	RER
CML 2001	photochemical oxidation (summer smog)	MIR	kg formed ozone	RER
CML 2001	photochemical oxidation (summer smog)	MOIR	kg formed ozone	RER
CML 2001	photochemical oxidation (summer smog)	high NOx POCP	kg ethylene-Eq	RER
CML 2001	photochemical oxidation (summer smog)	low NOx POCP	kg ethylene-Eq	RER
CML 2001	resources	depletion of abiotic resources	kg antimony-Eq	GLO
CML 2001	stratospheric ozone depletion	ODP 10a	kg CFC-11-Eq	GLO
CML 2001	stratospheric ozone depletion	ODP 15a	kg CFC-11-Eq	GLO
CML 2001	stratospheric ozone depletion	ODP 20a	kg CFC-11-Eq	GLO
CML 2001	stratospheric ozone depletion	ODP 25a	kg CFC-11-Eq	GLO
CML 2001	stratospheric ozone depletion	ODP 30a	kg CFC-11-Eq	GLO
CML 2001	stratospheric ozone depletion	ODP 40a	kg CFC-11-Eq	GLO
CML 2001	stratospheric ozone depletion	ODP 5a	kg CFC-11-Eq	GLO
CML 2001	stratospheric ozone depletion	ODP steady state	kg CFC-11-Eq	GLO
CML 2001	terrestrial ecotoxicity	TAETP 100a	kg 1,4-DCB-Eq	GLO
CML 2001	terrestrial ecotoxicity	TAETP 20a	kg 1,4-DCB-Eq	GLO
CML 2001	terrestrial ecotoxicity	TAETP 500a	kg 1,4-DCB-Eq	GLO
CML 2001	terrestrial ecotoxicity	TAETP infinite	kg 1,4-DCB-Eq	GLO

Tab. 1-1 Problem oriented impact categories according to CML 01 implemented in the database ecoinvent

Category	SubCategory	Name	Unit	Loca-tion
Study specific impact categories				
CML 2001	freshwater sediment ecotoxicity	FSETP 100a	kg 1,4-DCB-Eq	GLO
CML 2001	freshwater sediment ecotoxicity	FSETP 20a	kg 1,4-DCB-Eq	GLO
CML 2001	freshwater sediment ecotoxicity	FSETP 500a	kg 1,4-DCB-Eq	GLO
CML 2001	freshwater sediment ecotoxicity	FSETP infinite	kg 1,4-DCB-Eq	GLO
CML 2001	malodours air	malodours air	m3 air	GLO
CML 2001	marine sediment ecotoxicity	MSETP 100a	kg 1,4-DCB-Eq	GLO
CML 2001	marine sediment ecotoxicity	MSETP 20a	kg 1,4-DCB-Eq	GLO
CML 2001	marine sediment ecotoxicity	MSETP 500a	kg 1,4-DCB-Eq	GLO
CML 2001	marine sediment ecotoxicity	MSETP infinite	kg 1,4-DCB-Eq	GLO
CML 2001	ionising radiation	ionising radiation	DALYs	GLO

1.2 Use of the method

The problem oriented characterisation and normalisation factors are implemented in an EXCEL worksheet that can be found on the ecoinvent CD. More information about this worksheet is given in the “intro”-table of the worksheet itself.

1.2.1 Normalisation

The normalisation factors for the different impact categories from the original publication (Guinèe et al. (2001a)) are shown in Tab. 1-2. They are not implemented in the ecoinvent database.

The normalization factor for a given impact category and region is obtained by multiplying the characterisation factors by their respective emissions. The sum of these products in every impact category gives the normalization factor.

To go from the characterized results to the normalized results, one has to divide the characterisation factors by the normalization factor calculated as explained before and reported in Tab. 1-2 of this document.

Tab. 1-2 Normalisation factors (Guinèe et al. (2001a))

Impact category	Name	Normalisation factor				
		the Netherlands, 1997	West Europe, 1995	World, 1995	World, 1990	Unit
acidification potential	average European	6.69E+8	2.74E+10	3.22E+11	3.24E+11	kg SO2-Eq/a
acidification potential	generic	7.93E+8	2.94E+10	3.35E+11	3.29E+11	kg SO2-Eq/a
climate change	GWP 100a	2.53E+11	4.82E+12	4.15E+13	4.41E+13	kg CO2-Eq/a
climate change	GWP 20a	2.96E+11	5.83E+12	5.40E+13	5.69E+13	kg CO2-Eq/a
climate change	GWP 500a	2.21E+11	4.04E+12	3.31E+13	3.36E+13	kg CO2-Eq/a
climate change	lower limit of net GWP	2.51E+11	4.49E+12	4.04E+13	4.02E+13	kg CO2-Eq/a
climate change	upper limit of net GWP	2.56E+11	4.93E+12	4.41E+13	4.61E+13	kg CO2-Eq/a
eutrophication potential	average European	1.35E+9	3.22E+10	3.90E+11	3.56E+11	kg NOx-Eq/a
eutrophication potential	generic	5.02E+8	1.25E+10	1.32E+11	1.33E+11	kg PO4-Eq/a
freshwater aquatic ecotoxicity	FAETP 100a	6.44E+9	4.72E+11	1.81E+12	1.81E+12	kg 1,4-DCB-Eq/a
freshwater aquatic ecotoxicity	FAETP 20a	6.33E+9	4.69E+11	1.79E+12	1.78E+12	kg 1,4-DCB-Eq/a
freshwater aquatic ecotoxicity	FAETP 500a	6.76E+9	4.82E+11	1.88E+12	1.89E+12	kg 1,4-DCB-Eq/a
freshwater aquatic ecotoxicity	FAETP infinite	7.54E+9	5.05E+11	2.04E+12	2.07E+12	kg 1,4-DCB-Eq/a
freshwater sediment ecotoxicity	FSETP 100a	7.45E+9	4.38E+11	1.89E+12	1.89E+12	kg 1,4-DCB-Eq/a
freshwater sediment ecotoxicity	FSETP 20a	7.18E+9	4.31E+11	1.84E+12	1.83E+12	kg 1,4-DCB-Eq/a
freshwater sediment ecotoxicity	FSETP 500a	8.27E+9	4.62E+11	2.07E+12	2.09E+12	kg 1,4-DCB-Eq/a
freshwater sediment ecotoxicity	FSETP infinite	1.02E+10	5.18E+11	2.46E+12	2.53E+12	kg 1,4-DCB-Eq/a
human toxicity	HTP 100a	1.87E+11	7.49E+12	5.67E+13	5.94E+13	kg 1,4-DCB-Eq/a
human toxicity	HTP 20a	1.86E+11	7.48E+12	5.67E+13	5.94E+13	kg 1,4-DCB-Eq/a
human toxicity	HTP 500a	1.87E+11	7.50E+12	5.68E+13	5.94E+13	kg 1,4-DCB-Eq/a
human toxicity	HTP infinite	1.88E+11	7.57E+12	5.71E+13	6.00E+13	kg 1,4-DCB-Eq/a
ionising radiation	ionising radiation	1.43E+2	4.86E+4	1.34E+5	1.12E+5	DALYs/a
land use	competition	3.04E+10	3.27E+12	1.24E+14	1.24E+14	m2a/a
malodours air	malodours air					m3 air/a
marine aquatic ecotoxicity	MAETP 100a	1.16E+10	4.64E+11	1.90E+12	2.94E+12	kg 1,4-DCB-Eq/a
marine aquatic ecotoxicity	MAETP 20a	2.74E+9	1.16E+11	4.83E+11	6.59E+11	kg 1,4-DCB-Eq/a
marine aquatic ecotoxicity	MAETP 500a	6.01E+10	2.33E+12	9.83E+12	1.55E+13	kg 1,4-DCB-Eq/a
marine aquatic ecotoxicity	MAETP infinite	3.18E+12	1.14E+14	5.12E+14	7.55E+14	kg 1,4-DCB-Eq/a
marine sediment ecotoxicity	MSETP 100a	1.37E+10	5.90E+11	2.40E+12	3.56E+12	kg 1,4-DCB-Eq/a
marine sediment ecotoxicity	MSETP 20a	4.54E+9	2.17E+11	8.91E+11	1.14E+12	kg 1,4-DCB-Eq/a
marine sediment ecotoxicity	MSETP 500a	6.01E+10	2.38E+12	1.00E+13	1.57E+13	kg 1,4-DCB-Eq/a
marine sediment ecotoxicity	MSETP infinite	2.99E+12	1.04E+14	4.69E+14	6.79E+14	kg 1,4-DCB-Eq/a
photochemical oxidation (summer smog)	EBIR					kg formed ozone/a
photochemical oxidation (summer smog)	high NOx POCP	1.82E+8	8.24E+9	9.59E+10	1.04E+11	kg ethylene-Eq/a
photochemical oxidation (summer smog)	low NOx POCP	1.57E+8	6.31E+9	8.69E+10	9.19E+10	kg ethylene-Eq/a
photochemical oxidation (summer smog)	MIR					kg formed ozone/a
photochemical oxidation (summer smog)	MOIR					kg formed ozone/a
resources	depletion of abiotic resources	1.71E+9	1.48E+10	1.57E+11	1.58E+11	kg antimony-Eq/a
stratospheric ozone depletion	ODP 10a	1.17E+6	1.87E+8	8.99E+8	1.64E+9	kg CFC-11-Eq/a
stratospheric ozone depletion	ODP 15a	1.08E+6	1.46E+8	6.93E+8	1.32E+9	kg CFC-11-Eq/a
stratospheric ozone depletion	ODP 20a	1.02E+6	1.26E+8	6.01E+8	1.17E+9	kg CFC-11-Eq/a
stratospheric ozone depletion	ODP 25a	9.87E+5	1.14E+8	5.43E+8	1.07E+9	kg CFC-11-Eq/a
stratospheric ozone depletion	ODP 30a	9.57E+5	1.05E+8	5.01E+8	1.00E+9	kg CFC-11-Eq/a
stratospheric ozone depletion	ODP 40a	9.21E+5	9.54E+7	4.50E+8	9.23E+8	kg CFC-11-Eq/a
stratospheric ozone depletion	ODP 5a	1.38E+6	3.11E+8	1.61E+9	2.59E+9	kg CFC-11-Eq/a
stratospheric ozone depletion	ODP steady state	9.77E+5	8.30E+7	5.15E+8	1.14E+9	kg CFC-11-Eq/a
terrestrial ecotoxicity	TAETP 100a	1.72E+8	2.03E+10	1.40E+11	1.48E+11	kg 1,4-DCB-Eq/a
terrestrial ecotoxicity	TAETP 20a	1.50E+8	1.92E+10	1.35E+11	1.41E+11	kg 1,4-DCB-Eq/a
terrestrial ecotoxicity	TAETP 500a	2.61E+8	2.44E+10	1.61E+11	1.78E+11	kg 1,4-DCB-Eq/a
terrestrial ecotoxicity	TAETP infinite	9.20E+8	4.73E+10	2.69E+11	2.64E+11	kg 1,4-DCB-Eq/a

1.3 Implementation

1.3.1 General assignments

As far as possible we used the figures given in the excel spreadsheet that can be downloaded with the reports (Guinèe et al. (2001a)). For some substances (mixtures) we re-calculated a characterization factor using a correction factor that accounts for the mass fraction of the pure chemical in the mixture (e.g. the characterisation factor for “chromium(VI)-ion” is assigned to the ecoinvent emission “Sodium dichromate” ($Na_2Cr_2O_7$) with a correction factor of 0.397 because 39.7% (w/w) of $Na_2Cr_2O_7$ is Cr).

If no value for a specific flow in the CML spreadsheet (Guinèe et al. (2001a)) in a certain impact category is given, the characterisation factor for this flow in this impact category is taken as zero. This is also done in case a value for the sum parameter to which the specific flow belongs is given.

For details check the excel sheet with this report.

Long-term emissions

In a sometimes controversial discussion among the ecoinvent administrators it was decided, that long-term emissions are principally valuated the same as today emissions as long as the impact assessment method doesn't states clearly that the factor is not representative for long term emissions and thus has only to be used for today emissions.

1.3.2 Emissions to air

Greenhouse gases and ozone depleting substances

The same characterisation factors are used for biogenic and fossil emissions except for CO and CO_2. Consequently, no characterisation factor is used for the CO_2 that is taken up as resource by plants. If impact assessment results are to be used in the context of carbon sequestration in biomass, biogenic CO and CO_2 emissions as well as the CO_2-resource uptake from air need to be assigned the corresponding characterisation factors.

For CO we calculated a characterisation factor for global warming potential equals 1.53 kg CO_2-eq per kg, considering it is oxidized to CO_2. This is necessary because in the ecoinvent data the amount of carbon emitted as CO has been subtracted from the total stoichiometric CO_2-emission calculated based on the carbon content of a fuel. A calculation of the CO_2-emissions would also be possible for other hydrocarbons emitted into air. But normally their contribution (for the greenhouse effect) is relatively small.

Particulates

The CML spreadsheet (Guinèe et al. (2001a)) includes specific flows for PM2.5 and TSP. However, no characterisation factor is given for these flows while a characterisation factor is given for PM10. This characterisation factor for PM10 is used for the ecoinvent inventory flows "particulates, < 2.5 µm" and "particulates > 2.5 µm, and < 10 µm" and the factor for TSP (which is zero) is used for the ecoinvent inventory flow "particulates, > 10 µm". Since the characterisation factor for TSP is zero, the fact that PM2.5 and PM10 are included in TSP while they are excluded in the ecoinvent flow "particulates > 10 µm" is not relevant in this assignment.

PAH

The characterisation factor for carcinogenic polycyclic aromatic hydrocarbons is assigned to the unspecific PAH in ecoinvent. This represents a worst case scenario.

1.3.3 Emissions to water

General assignments

Characterisation factors for emissions to rivers are applied for emissions to ground-, ground- long-term, lake, river long-term and unspecified, but not for emissions to ocean and fossil water.

Sum parameters

Since the ecoinvent database contains data for all the sum parameters BOD, COD, DOC and TOC, only the characterisation factor for COD is applied to avoid double counting.

1.3.4 Emissions to soil

Pesticides

Characterisation factors are available only for few of the substances considered in the agricultural inventories (Nemecek et al. 2007). Thus not all pesticide emissions in the database have a characterisation factor.

1.3.5 Resource uses

Material resources

Guinèe et al. (2001a) gives characterisation factors for metals and for some of the ores of these metals. Since the resources in ecoinvent refer to the metal content in the ore, the factors for the metals are chosen.

For mineral resources extracted a characterisation factor is calculated using the weight ratio and the characterisation factors for the classified elements. Thus the characterisation factor (CF) for NaCl is calculated as 0.393*CF(Na)+0.607*CF(Cl). If no stoichiometric composition of a mineral could be found, no characterisation factor is calculated. The calculated characterisation factors are found in the excel sheet with this report.

Land use

The problem oriented approach in CML 01 does not valuate the different land uses differently and the damage oriented approach is basically the eco-indicator 99 method. The land occupation and transformation may be assigned in the same way as for the eco-indicator 99 (c.f. chapter 3.3.5).

An important implication for the problem oriented approach is that the occupation of water surface and sea ground are not valuated because no characterisation factors are given in Guinèe et al. (2001a).

1.4 Uncertainties and shortcomings

Since only the characterisation methods described in the original publications (Guinèe et al. (2001a); Guinèe et al. (2001b); Guinèe et al. (2001c)) are included, the implementation of CML 2001 in ecoinvent does not include (yet) all characterisation methods and associated characterisation factors, which are recommended as baseline or alternative in the new Guide (Guinèe et al. (2001c)).

1.4.1 Human toxicity and marine ecotoxicity (infinite classes): hydrogen fluoride and other inorganic chemicals

The characterisation factors for hydrogen fluoride (HF) and other inorganic chemicals, such as Beryllium, in the classes human toxicity (HTP infinite), marine aquatic ecotoxicity (MAETP infinite) and marine sediment ecotoxicity (MSETP infinite) are very uncertain. The uncertain average oceanic residence time in fate modelling of inorganic pollutants is the main source of this uncertainty. An alternative is to base the fate calculations on semi-empirical oceanic residence times. For the elements F and Be this would lead to substantially lower HTPs and METPs for infinite time horizons (cf. Tab. 1-3). However, the authors of the CML 2001 reports refuse to only modify the characterisation factor for HF without modifying all other characterisation factors for the other inorganic chemicals. They argue that an isolated correction may lead to an inconsistent treatment of emissions of inorganic chemicals. The residence times for all inorganic pollutants are now based on the same literature source and thus it is possible that the residence times of several pollutants might be inaccurate.[15]

The lack of characterisation data for CFC emissions in the toxicity classes may also lead to uncertainty in the impact assessment results. Since CFC's are cracked in the stratosphere and fluorine is returned to the surface by rain, these fluorine emissions should be considered in the impact assessment.

Since we decided to implement the original versions of the impact assessment methods only with corrections communicated officially by the authors, we did not implement alternative characterisation factors in ecoinvent. The use of the corrected factors would imply a recalculation of the normalisation factors.

Tab. 1-3 Characterisation factors for HF emissions in the original publication and corrected factors. The factors of the original publication are implemented in ecoinvent.

	HTP inf. [kg 1,4-DCB-Eq]		MAETP inf. [kg 1,4-DCB-Eq]		MSETP inf. [kg 1,4-DCB-Eq]	
1 kg HF emission to:	Original (Guinèe et al. (2001c))	Corrected (Huijbregts (2000))	Original (Guinèe et al. (2001c))	Corrected (Huijbregts (2000))	Original (Guinèe et al. (2001c))	Corrected (Huijbregts (2000))
air	2.85E+03	1.30E+02	4.07E+07	5.20E+05	1.34E+07	1.70E+05
marine water	3.64E+03	4.70E+01	5.38E+07	6.80E+05	1.77E+07	2.20E+05
fresh water	3.64E+03	4.90E+01	5.38E+07	6.80E+05	1.77E+07	2.20E+05
agric. soil	1.85E+03	5.10E+01	2.69E+07	3.40E+05	8.86E+06	1.10E+05
indus. soil	1.82E+03	2.40E+01	2.69E+07	3.40E+05	8.86E+06	1.10E+05

1.5 Quality considerations

48% of the elementary flows in the ecoinvent database have a corresponding elementary flow in CML 2001. But for many of these flows no characterisation factors are given in the problem oriented approach. Thus only for 20% of the elementary flows in the ecoinvent database a characterisation factor other then zero is implemented.

Abbreviations

	English
(E,H)	Egalitarian, Hierachist weighting
CAS	Chemical abstract service
DALY	Disability-Adjusted Life Years
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory

Appendices

EXCEL Sheet

Details about the information included in each of the different tables in the EXCEL-worksheet can be found in the table "intro" of the sheet itself.

[15] Personal email communication between Gabor Doka, Jeroen Guinee and Mark Huijbregts in October 2002

EcoSpold Meta Information

The full meta information can be assessed via the homepage http://www.ecoinvent.org. The following table shows an example.

Type	ID	Field name	2	3	4
ReferenceFunction	495	Category	CML 2001	CML 2001	CML 2001
	496	SubCategory	acidification potential	acidification potential	climate change
	401	Name	average European	generic	GWP 100a
Geography	662	Location	RER	GLO	GLO
ReferenceFunction	403	Unit	kg SO2-Eq	kg SO2-Eq	kg CO2-Eq
DataSetInformation	201	Type	4	4	4
	202	Version	1.1	1.1	1.1
	203	energyValues	0	0	0
	205	LanguageCode	en	en	en
	206	LocalLanguageCode	de	de	de
DataEntryBy	302	Person	8	8	8
	304	QualityNetwork	1	1	1
ReferenceFunction	400	DataSetRelatesToProduct	0	0	0
	404	Amount	1	1	1
	490	LocalName	Europäischer Durchschnitt	Generisch	GWP 100a
	491	Synonyms	CML'01	CML'01	CML'01
	492	GeneralComment	Implementation of the impact assessment method with the characterisation factors. Normalisation factors: The Netherlands 1997: 6.69E+8, W-Europe 1995: 2.74E+10, World 1995: 3.22E+11, World 1990: 3.24E+11 [kg SO2 eq. / yr]	Implementation of the impact assessment method with the characterisation factors. Normalisation factors: The Netherlands 1997: 7.93E+8, W-Europe 1995: 2.94E+10, World 1995: 3.35E+11, World 1990: 3.29E+11 [kg SO2 eq. / yr]	Implementation of the impact assessment method with the characterisation factors. Normalisation factors: The Netherlands 1997: 2.53E+11, W-Europe 1995: 4.82E+12, World 1995: 4.15E+13, World 1990: 4.41E+13 [kg CO2 eq. / yr]
	497	LocalCategory	CML 2001	CML 2001	CML 2001
	498	LocalSubCategory	Versauerungspotential	Versauerungspotential	Klimawandel
TimePeriod	601	StartDate	2001	2001	2001
	602	EndDate	2001	2001	2001
	603	DataValidForEntirePeriod	1	1	1
	611	OtherPeriodText	Time of publication.	Time of publication.	Time of publication.
Geography	663	Text	Modelling for the European situation.	Modelling for a Global situation.	Modelling for a Global situation.
DataGenerator AndPublication	751	Person	8	8	8
	756	DataPublishedIn	2	2	2
	757	ReferenceToPublishedSource	3	3	3
	758	Copyright	1	1	1
	759	AccessRestrictedTo	0	0	0
	760	CompanyCode			
	761	CountryCode			
	762	PageNumbers			

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2 Cumulative energy demand

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Last changes: 2007

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2.1 Introduction

Cumulative Energy Requirements Analysis (CERA) aims to investigate the energy use throughout the life cycle of a good or a service. This includes the direct uses as well as the indirect or grey consumption of energy due to the use of, e.g. construction materials or raw materials. This method has been developed in the early seventies after the first oil price crisis and has a long tradition (Boustead & Hancock 1979; Pimentel 1973).

According to VDI (1997) "*the data on the cumulative energy demand ... form an important base in order to point out the priorities of energy saving potentials in their complex relationship between design, production, use and disposal*". However, the cumulative energy demand (CED) is also widely used as a screening indicator for environmental impacts. Furthermore, CED-values can be used to compare the results of a detailed LCA study to others where only primary energy demand is reported. Finally CED-results can be used for plausibility checks because it is quite easy to judge on the basis of the CED whether or not major errors have been made.

Cumulative energy analysis can be a good 'entry point' into life cycle thinking. But it does not replace an assessment with the help of comprehensive impact assessment methods such as Eco-indicator 99 or ecological scarcity. If more detailed information on the actual environmental burdens and especially on process-specific emissions are available - and the ecoinvent database provides such information - more reliable results are available with such methods. Thus Kasser & Pöll (1999:9) e.g. write that the CED “makes only sense in combination with other methods".

Different concepts for determining the primary energy requirement exist. For CED calculations one may chose the lower or the upper heating value of primary energy carriers where the latter includes the evaporation energy of the water present in the flue gas. Furthermore one may distinguish between energy requirements of renewable and non-renewable resources. Finally, different ways exist how to handle nuclear and hydro electricity. But so far there is no standardized way for this type of assessment method. Tab. 2-1 shows an overview for some methods. A discussion on the pros and cons for this indicator can be found in (Frischknecht et al. 1998).

Tab. 2-1 Impact methods proposed for the cumulative energy demand by different authors

Name	Includes	Source
Cumulative Energy Demand, CED (or KEA)	Different types of renewable and non-renewable energy resources	(VDI 1997)
Kumulierter Energie Verbrauch (KEV, Cumulative Energy Use)	Energetic use of resources not including use of resources for materials, e.g. plastics.	
Graue Energie (grey energy)	Non-renewable energy resources and hydro energy	(Kasser & Pöll 1999)
Endenergie (end energy)	Direct energy use not considering the supply chain. For the Minergie-calculations for houses all types of electricity consumption are multiplied with two.	(BFE 2001; Binz et al. 2000)
Consumption of non renewable energetic resources	non-renewable and unsustainably used renewable energy resources	(Frischknecht et al. 1998)

Due to the existence of diverging concepts and the unclear basis for the characterization of the different primary energy carriers, the CED-indicator is split up into eight categories for the ecoinvent database and no aggregated value is presented (see Tab. 1-2). Common to all categories is the thesis that all energy carriers have an intrinsic value. This intrinsic value is determined by the amount of energy withdrawn from nature. However, the intrinsic value of energy resources expressed in MJ-equivalents need not be comparable across the subcategories listed in Tab. 1-2. The user may adjust and combine these categories as intended for own calculations. Wastes, which are used for energy purposes are dealt with a cut-off approach. Thus they are not accounted for in the CED values. Their energy content and thus the demand is allocated to the primary use.

Tab. 2-2 Impact assessment method cumulative energy demand (CED) implemented in ecoinvent

	subcategory	includes
non-renewable resources	fossil	hard coal, lignite, crude oil, natural gas, coal mining off-gas, peat
	nuclear	uranium
	primary forest	wood and biomass from primary forests
renewable resources	biomass	wood, food products, biomass from agriculture, e.g. straw
	wind,	wind energy
	solar	solar energy (used for heat & electricity),
	geothermal	geothermal energy (shallow: 100-300m)
	water	run-of-river hydro power, reservoir hydro power

2.2 Implementation

2.2.1 Resource uses

Fossil

The upper heating value of the fossil fuel resources is used as the characterization factor for this method. The upper heating values are taken from the respective final reports (Faist Emmenegger et al. 2007; Jungbluth 2007; Röder et al. 2007).

Peat is considered as a fossil resource even if it originates from biomass, because it is not renewable within a manageable time horizon.

Sulphur and other material resources with a heating value (e.g. sulphidic ores) are not considered as an energy resource, because they are normally not extracted in order to use their energy content.

The Cumulative Energy Demand (CED) values of the ecoinvent v2.0 datasets "lignite, burned in power plant; [MJ]; AT, FR, BA, CZ, SK", Dataset-ID 1026, 1030, 1032, 1033, 1038, respectively, are below 1 MJ-eq (CED)/MJ (lignite input).

The reason lies in the structure of the lignite chain. The heating value of lignite burned in mine-mouth power plants of different countries is country-specific, whereas there is only one average lignite resource with one average heating value defined for the calculation of fossil CED. This average heating value is lower than the country-specific values of the above-mentioned countries.

If CED for lignite power plants is essential for a LCA case study, the corresponding value should be manually corrected.

Nuclear

The characterisation of the CED for nuclear energy and the resource natural uranium[16] is quite disputed and different approaches have been used in the literature. Many approaches use the production of electricity with current nuclear technology as a starting point. BP Amoco (1999) applies the substitution method, which assumes the use of fossil fuels in a conventional thermal power plant with 33% efficiency instead of nuclear fuel (resulting in a primary energy requirement of 10.9 MJ/kWh_e). Similarly, the average thermal efficiency of a nuclear power plant (31%, nowadays between 32%-33%, corresponding to 10.9 to 11.6 MJ/kWh_e) has been applied. Other approaches quantify the "energy content" of the fissile isotope in the natural uranium extracted from the mines. The latter approach is used in ecoinvent (with modifications) because the same idea is applied for fossil fuels, where the extracted resources are weighted with their (upper) heating values.

The definition of the adequate energy value for 1 kg of natural uranium is not straightforward and requires some subjective decisions because the energy conversion of uranium strongly depends on the technology and fuel management of the used system. The energy value used in the CED assessment for ecoinvent is based on the following consideration:

The energy value is calculated based on the nuclear fuel chain as modelled in ecoinvent, including cumulative uranium requirements. Hereby the fuel supply and the characteristics of the average German pressurized water reactors are used. This cycle has the highest share in MOX (mixed oxide) fuel (15% of total fuel), which corresponds to the best utilisation of the energy extractable from natural uranium among the performances of the nuclear fuel cycles analysed in ecoinvent. This definition excludes the breeding option, for which the performance of uranium fuel could be several tens of times higher than for cycles associated with light water reactors (LWR) because fast breeder reactors transform fertile isotopes (U238) into fissile isotopes (Pu239) in greater quantities than actually burned. The calculation based on the German fuel cycle results in an energy value of 560 GJth/kgUnat. The value is dependent on the burn-up rate and the corresponding enrichment. The value may therefore vary by plus/minus 5 to 10 % for current systems associated with LWR in Europe.

The following is not included in this energy value:

- the energy content in the depleted uranium from enrichment;
- the energy content of the U235 remaining in the spent no-MOX fuel at its final discharge from the reactor (between 0.4% and 0.6% U235 of total uranium in spent fuel for current fuel management in LWR);
- the energy content in the Pu239 remaining after MOX fuels are finally discharged from the reactor (the nuclear fuel cycle considers only one MOX utilization in a reactor, as commercially viable; this means that the spent MOX fuel is not further reprocessed, because the plutonium left at discharge has a high share of non-fissile Pu isotopes).

However, part of the fuel is nowadays obtained by mixing weapon-grade uranium (Highly Enriched Uranium HEU, with about 90% U235, from the dismantling of nuclear weapons from the Russian stock) with the uranium reprocessed from spent fuel, to obtain fuel for commercial LWR with a low

[16] Natural uranium is composed by 0.72% of the fissile isotope U235, 99.27% of the fertile isotope U239 and traces of U234.

enrichment of 4.7%-5% U235. Within ecoinvent, the weapon-grade uranium mixed with the reprocessed uranium is treated as if the blend were fresh, i.e., low enrichment (and its environmental burdens) is included for this part of the fuel although the uranium was actually enriched for other purposes.

One might discuss whether it is justified to define the energy value as made above by not including the natural uranium required to compensate for the losses of fissile uranium occurring during enrichment (fissile U235 in depleted uranium, on average 0.25%) and in final disposal (fissile uranium in spent fuel). Some of the arguments in favour of including the natural uranium required to compensate for the losses:

- No loss adjustments are made for the other fuels such as crude oil or natural gas. Fossil fuels partly end up as feedstock for plastics. If these plastics are landfilled, their energy content is preserved and is (theoretically) still available in the future.
- Not all of the depleted uranium can be recovered for energy purposes. A share of between 10 and 30% of the depleted uranium could further be depleted to produce "natural" uranium-235 (0.71% uranium-235), which then would be fed into the conventional enrichment process again. However, this further depletion is economically not (yet) feasible and the energy requirement is substantially higher per kg enriched uranium-235 (wise 1998).
- Uranium disposed of in final geological repositories for high-level radioactive waste may not be recovered ever.

The inclusion of the natural uranium required to compensate for one or several of the losses mentioned above would lead to a significantly higher energy value per kg natural uranium. However, recalling the concept that CED values should ideally represent the intrinsic value of energy resources, there is no straightforwardly defensible energy value for natural uranium used as nuclear fuel. The determination of the energy value using the mass flows of the nuclear fuel cycle (including or excluding losses) remains a patch-up solution to determine an intrinsic value. That is why the eight CED indicators (fossil, nuclear, biomass, water, as well as solar, wind and geothermal) are reported separately. This should facilitate the use of a different energy value for natural uranium if considered more appropriate to one's own value scheme. Anyway, the definition used in ecoinvent allows a comparison with past CED studies based on a "substitution method" or a "thermal efficiency method" as described in this section.

Biomass from primary forests, clear-cut

The same principles to determine the cumulative energy demand apply as for biomass classified renewable (see below). The CED value is classified non-renewable and recorded separately. Beware that biomass in sustainably managed primary forests is not to be inventoried as "Energy, gross calorific value, in biomass, from primary forests".

Biomass

The calculation for biomass (wood, food products, agricultural by-products, etc.) is based on the upper heating value of the biomass product at the point of harvest (not considering residues, like roots, which remain in the forest or field). In the inventory the upper heating value of the specific wood types and the agricultural products is inventoried as “Energy, gross calorific value, in biomass”. Further on wood resources as such are also considered as an inventory item. An CED factor shall not be used for the wood resources, because this would be a double counting. The amount of biomass energy in wood is inventoried as shown in Tab. 2-3.

Tab. 2-3 Calculation of upper heating value for the wood resources

Type of wood	Upper heating value	specific weight (atro)	Upper heating value
	MJ/kg (atro)	kg/m^3	MJ/m^3
Wood, hard, standing	19.61	650	12740
Wood, soft, standing	20.4	450	9180

atro = absolutely dry, u=0%

Water

For hydro energy the rotation energy transmitted to the turbine for hydro power generation is used as a characterisation factor. The rotation energy equals the converted potential energy of the water in the hydropower reservoir. Hydro energy from pumping storage hydro power is excluded in the inventory, if the pumping energy comes from a non-hydro source.

Other renewable resources

The energy input of other renewable energy resources (wind, solar, geothermal etc.) equals the amount of energy harvested (or converted).

Solar

The solar energy converted (harvested) by photovoltaic power plants equals the electric energy produced by photovoltaics and transmitted to the inverter. The solar energy converted (harvested) by a solar collector equals the thermal energy delivered to the hot water storage. The efficiency of the panel and collector to convert solar energy to electricity and heat, respectively is not taken into account.

Wind

The kinetic energy converted (harvested) by a wind power plant equals the rotation energy of the turbine blades delivered to the gearbox. The efficiency of the blades to convert kinetic wind energy to rotation energy is not taken into account (Burger & Bauer 2007).

Geothermal

The geothermal energy converted (harvested) by brine-water heat exchangers equals the amount of energy delivered to the heat pump.

It has to be noted that *deep* geothermal plants (e.g. <1000 m) are usually designed to over-exploit the available heat reservoir and actually cool down the affected area for an extended period. Exploitation can be expanded by drilling sideways into other areas, until a site is “depleted”. After about 30 years a site will not be able to run at nominal power and another site will be chosen. It is thus debatable if such use of this energy source is actually “renewable”. However, life cycle inventories of geothermal power plants are not yet available in ecoinvent data v2.0.

Ambient air

The energy of ambient air converted (harvested) by air-water heat exchangers is not included in the life cycle inventories of air-water heat pumps. In case this information is required, the amount of energy delivered to the heat pump can be added manually.

2.2.2 List of impact assessment factors in ecoinvent

Tab. 2-4 shows the impact factors for the cumulative energy demand implemented for the ecoinvent database.

Tab. 2-4 Impact factors for the cumulative energy demand implemented in ecoinvent data v2.0

Name	Category	SubCategory	Unit	cumulative energy demand	cumulative energy demand	cumulative energy demand	cumulative energy demand	cumulative energy demand	cumulative energy demand	cumulative energy demand	cumulative energy demand
SubCategory				fossil	nuclear	primary forest	biomass	wind	solar	geothermal	water
Name				non-renewable energy resources, fossil	non-renewable energy resources, nuclear	non-renewable energy resources, primary forest	renewable energy resources, biomass	renewable energy resources, kinetic (in wind), converted	renewable energy resources, solar, converted	renewable energy resources, geothermal, converted	renewable energy resources, potential (in barrage water), converted
Location				GLO	GLO	GLO	GLO	GLO	GLO	GLO	GLO
Unit				MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq
Coal, brown, in ground	resource	in ground	kg	9.90							
Coal, hard, unspecified, in ground	resource	in ground	kg	19.10							
Energy, gross calorific value, in biomass	resource	biotic	MJ				1.00				
Gas, mine, off-gas, process, coal mining	resource	in ground	Nm3	39.80							
Gas, natural, in ground	resource	in ground	Nm3	38.29							
Uranium, in ground	resource	in ground	kg		560'000						
Oil, crude, in ground	resource	in ground	kg	45.80							
Peat, in ground	resource	biotic	kg	9.90							
Energy, geothermal, converted	resource	in ground	MJ							1.00	
Energy, kinetic (in wind), converted	resource	in air	MJ					1.00			
Energy, potential (in hydropower reservoir), converted	resource	in water	MJ								1.00
Energy, solar, converted	resource	in air	MJ						1.00		
Energy, gross calorific value, in biomass, primary forest	resource	biotic	MJ			1.00					

2.3 Quality considerations

The technical uncertainty is low, because all figures are used in line with the assumptions taken in the modelling of the ecoinvent data.

Major uncertainties arise from value choices for the characterization of different energy resources. For uranium it is, as said before, quite disputable, which value to chose. Hence a bias exists especially between the CED-values reported for "non renewable energy resources/nuclear", and "non renewable energy resources/fossil".

It has to be noted that there is also a bias between the CED-values reported for "renewable energy resources/wind, solar, geothermal" and "renewable energy resources/biomass". There is a considerable difference in accounting the use of solar energy in technical systems like photovoltaic and solar collectors on one hand and the use of sun for biomass production on the other. While the former takes into account the efficiency of the technical system (the solar energy needed to produce solar electricity and heat is quantified in terms of CED), the latter does not take into account the efficiency of the natural system (the amount of biomass extracted from the wood is quantified in terms of CED). Considering the actual solar energy input for biomass production would lead to much higher energy values per kg biomass. A similar approach would be required to quantify the solar energy required to produce the fossil fuels. Further on it has to be noted that solar energy input to buildings, streets and other artificial surfaces is not considered at all. In the cases mentioned before solar energy input might also have a positive effect, e.g. the heating of a house via the radiation to windows, roof and walls or a negative effect (additional need for cooling during hot weather). Due to this technical system the solar energy is not available for natural systems.

That is why we refrain from giving an aggregated total of the eight CED-indicators. But within each of the eight CED-indicators, model choice uncertainties are rather low.

The reduction of energy consumption is one important prerequisite for sustainable development. As several environmental problems, e.g. climate change or nuclear waste disposal, are linked to the energy use, this indicator can serve as a yardstick for improvements. It is also easily understandable for decision-makers such as consumers, politicians or managers of private enterprises.

Thus, the method of cumulative energy requirements analysis is useful to get a general view of the energy related environmental impacts in a life cycle and for a first comparison of individual products. The total energy use in a country, of specific sectors of the economy, or of individual products is a good yardstick to measure and control the success of policy measures that aim to reduce the energy use.

But energy use does not give a full picture for all environmental impacts in the life cycle of goods and services. Eutrophication caused by intensive animal production for instance is one problem that is not recorded by the energy use. Furthermore the environmental impacts vary among different energy resources. The impacts of coal use in relation to the energy content are normally more severe than these due to using natural gas. Thus, cumulative energy demand analysis cannot be the one and only method for evaluating the environmental impacts of a good or service.

EcoSpold Meta Information

Category	cumulative energy demand	cumulative energy demand	cumulative energy demand	cumulative energy demand	cumulative energy demand	cumulative energy demand	cumulative energy demand	cumulative energy demand
SubCategory	fossil	nuclear	primary forest	biomass	wind	solar	geothermal	water
Name	non-renewable energy resources, fossil	non-renewable energy resources, nuclear	non-renewable energy resources, primary forest	renewable energy resources, biomass	renewable energy resources, kinetic (in wind),	renewable energy resources, solar, converted	renewable energy resources, geothermal,	renewable energy resources, potential (in
Location	GLO	GLO	GLO	GLO	GLO	GLO	GLO	GLO
Unit	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq
LocalName	Nicht-erneuerbare Energieressourcen, Fossil	Nicht-erneuerbare Energieressourcen, Nuklear	Nicht-erneuerbare Energieressourcen, Primärwald	Erneuerbare Energieressourcen, Biomasse	Erneuerbare Energieressourcen, kinetisch (im Wind), umgewandelt	Erneuerbare Energieressourcen, Sonne, umgewandelt	Erneuerbare Energieressourcen, Geothermie, umgewandelt	Erneuerbare Energieressourcen, potentiell (im Staubecken), umgewandelt
Synonyms	Graue	Graue	Graue	Graue	Graue	Graue	Graue	Graue
GeneralComment	Characterisation with the upper heating value of the fossil energy resources extracted.	Characterisation of fissile Uranium resource with the amount of energy that can be generated in a modern light water nuclear power plant. Uranium resource demand due to losses along the fuel chain (depleted Uranium, fissile Uranium remains in burnt-up fuel) is characterised with 0 MJ/kg	Characterisation with the upper heating value of the biomass harvested. It is classified "non-renewable", because the biomass is wood from clear cutting of primary forests.	Characterisation with the upper heating value of the biomass harvested.	Characterisation with the amount of kinetic energy converted to mechanical energy on the rotor of the wind power plant.	Characterisation with the amount of solar energy converted by the photovoltaic cell to electricity, and by the solar collector to heat.	Characterisation with the amount of geothermal energy delivered to the geothermal power plant or to the heat pump.	For hydro energy the electricity production by the turbine is taken into account. Losses in the system are included. Hydro energy from pumping storage hydro power is excluded in the inventory, if the pumping energy comes from a non-hydro source.
LocalCategory	Kumulierter Energieaufwand	Kumulierter Energieaufwand	Kumulierter Energieaufwand	Kumulierter Energieaufwand	Kumulierter Energieaufwand	Kumulierter Energieaufwand	Kumulierter Energieaufwand	Kumulierter Energieaufwand
LocalSubCategory	Fossil	Nuklear	Primärwald	Biomasse	Wind	Sonne	Geothermie	Wasser
StartDate	2000	2000	2007	2000	2007	2007	2007	2007
EndDate	2000	2000	2007	2000	2007	2007	2007	2007
OtherPeriodText	Time of	Time of	Time of	Time of	Time of	Time of	Time of	Time of
Text	No country specific	No country specific	No country specific	No country specific	No country specific	No country specific	No country specific	No country specific

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3 Cumulative exergy demand

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Summary

In 2007 a paper on the implementation of the method "Cumulative Exergy Demand" into the ecoinvent Database v1.2 has been published (Boesch et al. 2007), based on previous publications of Finnveden & Östlund (1997), Szargut et al. (1988) and Szargut (2005). It contains the development of an exergy-based LCIA method and demonstrates its application for the ecoinvent Database. This paper is the basis for the implementation of the Cumulative Exergy Demand method in the ecoinvent database v 2.0. In the current report, only changes in implementation deviating from Boesch et al. (2007) are reported.

3.1 Introduction

The paper on the development of the exergy based LCIA method "Cumulative Exergy Demand (CExD)" and its implementation into the ecoinvent Database v1.2 (Boesch et al. 2007) is the basis for the implementation of the CExD method in the updated ecoinvent Database v2.0. In the following, the amendments for the actual implementation into the database v2.0 are described. For a detailed understanding of the CExD method it is strongly recommended to refer to the original publication (Boesch et al. 2007).

Tab. 1 shows the eight impact categories of the CExD method.

Table 1: Impact categories in cumulative exergy demand (CExD) as implemented in ecoinvent data v2.0

category	subcategory	name
cumulative exergy demand	fossil	non-renewable energy resources, fossil
	nuclear	non-renewable energy resources, nuclear
	wind	renewable energy resources, kinetic (in wind), converted
	solar	renewable energy resources, solar, converted
	water	renewable energy resources, potential (in barrage water), converted
	primary forest	non-renewable energy resources, primary forest
	biomass	renewable energy resources, biomass
	water resources	renewable material resources, water
	metals	non-renewable material resources, metals
	minerals	non-renewable material resources, minerals

3.2 Implementation

The characterisation factors for the elementary flows of resources were implemented according to the publication (Boesch et al. 2007). Required amendments to confirm with the updated database as well as essential information for the implementation are presented in the following.

The names of the impact categories have been adapted to the new ecoinvent version v2.0 (Tab. 2). There is no impact category for geothermal energy, because no characterisation factor is assigned to 'Energy, geothermal'. This is due to the fact that this elementary flow is mainly input to heat pump systems. It was assumed that the average environmental temperature of the heat sources for heat pumps is below the temperature in the reference environment (298.15 K), which is applied for the calculation of the characterisation factors.

Table 2 Impact categories in ecoinvent and in the original publication (Boesch et al. 2007)

Impact categories in ...	
ecoinvent data v2.0	**Boesch et al. (2007)**
fossil	Fossil energy
nuclear	Nuclear energy
wind	Wind, solar, geothermal energy
solar	Wind, solar, geothermal energy
water	Hydroenergy
primary forest	-
biomass	Biomass
water resources	Water
metals	Metal ores
minerals	Minerals

No characterisation factors are assigned to the elementary flows 'Wood, hard, standing', 'Wood, soft, standing', 'Wood unspecified standing', and 'Wood, primary forest, standing', in order to avoid double counting of biomass. Biomass is accounted for by the elementary flows 'Energy, gross calorific value, in biomass' and 'Energy, gross calorific value, in biomass, primary forest'.

No characterisation factor is assigned to the elementary flow 'Water, turbine use, unspecified natural origin'. Although the water enters the technosphere by passing the turbine, it is released almost unchanged into the environment and therefore not taken into account.

For all ores with multiple target metals, revenue allocation has been applied, based on the average stock market prices of the years 1996, 2001, and 2005 (USGS, 2007). This allocation is in line with the allocation applied to new metal resource flows in ecoinvent v2.0 and thus consistent for all metals. Hence, the implemented characterisation factors presented in table 3 may differ from those in the original publication (Boesch et al. 2007).

Table 3 Characterisation factors for metals from ores with multiple target metals

Name	Unit	MJ-Eq
Cadmium, 0.30% in sulfide, Cd 0.18%, Pb, Zn, Ag, In, in ground	kg	8.58E+0
Copper, 0.52% in sulfide, Cu 0.27% and Mo 8.2E-3% in crude ore, in ground	kg	1.96E+2
Copper, 0.59% in sulfide, Cu 0.22% and Mo 8.2E-3% in crude ore, in ground	kg	2.32E+2
Copper, 0.97% in sulfide, Cu 0.36% and Mo 4.1E-2% in crude ore, in ground	kg	1.01E+2
Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	kg	1.53E+2
Copper, 1.13% in sulfide, Cu 0.76% and Ni 0.76% in crude ore, in ground	kg	2.68E+1
Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	kg	1.43E+2
Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	kg	7.32E+1
Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	kg	3.35E+1
Copper, Cu 0.38%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Pb 0.014%, in ore, in ground	kg	7.04E+0
Cu, Cu 3.2E+0%, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0% in ore, in ground	kg	5.77E+0
Cu, Cu 5.2E-2%, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2% in ore, in ground	kg	2.17E+1
Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore, in ground	kg	3.46E+5
Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore, in ground	kg	4.82E+5

Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore, in ground	kg	2.95E+5
Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	kg	5.81E+4
Indium, 0.005% in sulfide, In 0.003%, Pb, Zn, Ag, Cd, in ground	kg	2.77E+3
Lead, 5.0% in sulfide, Pb 3.0%, Zn, Ag, Cd, In, in ground	kg	4.29E+0
Lead, Pb 0.014%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, in ore, in ground	kg	1.67E+1
Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore, in ground	kg	2.09E+2
Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore, in ground	kg	4.56E+2
Molybdenum, 0.016% in sulfide, Mo 8.2E-3% and Cu 0.27% in crude ore, in ground	kg	1.22E+3
Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.22% in crude ore, in ground	kg	1.45E+3
Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	kg	9.55E+2
Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground	kg	8.90E+2
Molybdenum, 0.11% in sulfide, Mo 4.1E-2% and Cu 0.36% in crude ore, in ground	kg	6.39E+2
Ni, Ni 2.3E+0%, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Cu 3.2E+0% in ore, in ground	kg	1.20E+1
Ni, Ni 3.7E-2%, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Cu 5.2E-2% in ore, in ground	kg	4.54E+1
Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground	kg	5.61E+1
Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	kg	4.89E+4
Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	kg	1.30E+4
Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	kg	2.51E+4
Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	kg	9.48E+4
Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	kg	5.44E+4
Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	kg	2.05E+5
Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In, in ground	kg	9.61E+2
Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore, in ground	kg	1.03E+4
Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore, in ground	kg	5.06E+3
Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore, in ground	kg	5.94E+3
Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore, in ground	kg	8.26E+3
Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	kg	9.96E+2
Tellurium, 0.5ppm in sulfide, Te 0.2ppm, Cu and Ag, in crude ore, in ground	kg	2.78E+2
Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground	kg	6.79E+0
Zinc, Zn 0.63%, Au 9.7E-4%, Ag 9.7E-4%, Cu 0.38%, Pb 0.014%, in ore, in ground	kg	4.44E+0

Characterisation factors have been assigned for elementary flows of resources that were integrated into the ecoinvent Database after the publication of Bösch et al. (2007). Tab. 4 lists the new resources and the respective characterisation factors. These were calculated according to the method described in Bösch et al. (2007).

Table 4 New elementary flows of resources in ecoinvent v2.0

Name	Unit	MJ-Eq
Cadmium, 0.30% in sulfide, Cd 0.18%, Pb, Zn, Ag, In, in ground	kg	8.58E+0
Carbon, in organic matter, in soil	kg	+
Cerium, 24% in bastnasite, 2.4% in crude ore, in ground	kg	2.63E+1
Copper, Cu 0.38%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Pb 0.014%, in ore, in ground	kg	7.04E+0
Energy, gross calorific value, in biomass, primary forest	MJ	1.05E+0
Europium, 0.06% in bastnasite, 0.006% in crude ore, in ground	kg	1.05E+4
Gadolinium, 0.15% in bastnasite, 0.015% in crude ore, in ground	kg	4.20E+3
Gallium, 0.014% in bauxite, in ground	kg	4.50E+3
Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore, in ground	kg	3.46E+5
Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore, in ground	kg	4.82E+5
Gold, Au 1.4E-4%, in ore, in ground	kg	4.50E+5
Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore, in ground	kg	2.95E+5
Gold, Au 4.3E-4%, in ore, in ground	kg	1.47E+5
Gold, Au 4.9E-5%, in ore, in ground	kg	1.29E+6
Gold, Au 6.7E-4%, in ore, in ground	kg	9.40E+4
Gold, Au 7.1E-4%, in ore, in ground	kg	8.87E+4

Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	kg	5.81E+4
Helium, 0.08% in natural gas, in ground	kg	++
Indium, 0.005% in sulfide, In 0.003%, Pb, Zn, Ag, Cd, in ground	kg	2.77E+3
Lanthanum, 7.2% in bastnasite, 0.72% in crude ore, in ground	kg	8.75E+1
Lead, 5.0% in sulfide, Pb 3.0%, Zn, Ag, Cd, In, in ground	kg	4.29E+0
Lead, Pb 0.014%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, in ore, in ground	kg	1.67E+1
Neodymium, 4% in bastnasite, 0.4% in crude ore, in ground	kg	1.58E+2
Praseodymium, 0.42% in bastnasite, 0.042% in crude ore, in ground	kg	1.50E+3
Samarium, 0.3% in bastnasite, 0.03% in crude ore, in ground	kg	2.10E+3
Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In, in ground	kg	9.61E+2
Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore, in ground	kg	1.03E+4
Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore, in ground	kg	5.06E+3
Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore, in ground	kg	5.94E+3
Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore, in ground	kg	8.26E+3
Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	kg	9.96E+2
Tantalum, 39.5% in tantalite, 7.7E-5% in crude ore, in ground	kg	8.18E+5
Tellurium, 0.5ppm in sulfide, Te 0.2ppm, Cu and Ag, in crude ore, in ground	kg	2.78E+2
TiO2, 54% in ilmenite, 2.6% in crude ore, in ground	kg	2.42E+1
TiO2, 95% in rutile, 0.40% in crude ore, in ground	kg	1.58E+2
Wood, primary forest, standing	m3	+++
Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground	kg	6.79E+0
Zinc, Zn 0.63%, Au 9.7E-4%, Ag 9.7E-4%, Cu 0.38%, Pb 0.014%, in ore, in ground	kg	4.44E+0
Zirconium, 50% in zircon, 0.39% in crude ore, in ground	kg	1.62E+2

+No characterisation factor assigned to avoid double counting with biomass ++No characterisation factor assigned to avoid double counting with natural gas +++No characterisation factor assigned to avoid double counting with biomass, primary forest.

3.3 Known mistakes and shortcomings

To obtain a comprehensive set of characterisation factors, some minerals had to be approximated by related minerals, because no accurate data was available. These resource and the approximations are listed in the original publication (Boesch et al. 2007). Even so, for the five resources borax, colemanite, stibnite, ulexite and zirconia no characterisation factors were defined (Boesch et al. 2007).

The change in the accounting for renewable energies in the update of the ecoinvent Database v1.2 to v2.0 entailed new system boundaries for the resource flows 'Energy, kinetic (in wind), converted', 'Energy, potential (in hydropower reservoir), converted', 'Energy, solar, converted'. The characterisation factors in Bösch et al. (2007) were referred to the old system boundaries. The structure of the ecoinvent database does not allow a straight adaptation of the characterisation factors to take into consideration the total exergy input, as defined in Bösch et al. (2007). Hence, in analogue to the new version of the CED, for renewable energies, the efficiency of the respective technologies was taken into account in the present database version, thus lowering the CExD score of renewable exergy sources considerably.

EcoSpold Meta Information

The full meta information can be assessed via the homepage www.ecoinvent.org.

Category	cumulative exergy demand	cumulative exergy demand	cumulative exergy demand	cumulative exergy demand	cumulative exergy demand	cumulative exergy demand	cumulative exergy demand	cumulative exergy demand	cumulative exergy demand	cumulative exergy demand
SubCategory	fossil	nuclear	wind	solar	water	primary forest	biomass	water resources	metals	minerals
Name	non-renewable energy resources, fossil	non-renewable energy resources, nuclear	renewable energy resources, kinetic (in wind), converted	renewable energy resources, solar, converted	renewable energy resources, potential (in barrage water), converted	non-renewable energy resources, primary forest	renewable energy resources, biomass	renewable material resources, water	non-renewable material resources, metals	non-renewable material resources, minerals
Location	GLO	GLO	GLO	GLO	GLO	GLO	GLO	GLO	GLO	GLO
Unit	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq	MJ-Eq
Type	4	4	4	4	4	4	4	4	4	4
Version	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
energyValues	0	0	0	0	0	0	0	0	0	0
LanguageCode	en	en	en	en	en	en	en	en	en	en
LocalLanguageCode	de	de	de	de	de	de	de	de	de	de
Person	86	86	86	86	86	86	86	86	86	86
QualityNetwork	1	1	1	1	1	1	1	1	1	1
DataSetRelatesToProduc	No	No	No	No	No	No	No	No	No	No
Amount	1	1	1	1	1	1	1	1	1	1
LocalName	Nicht-erneuerbare Energieressourcen, Fossil	Nicht-erneuerbare Energieressourcen, Nuklear	Erneuerbare Energieressourcen, kinetisch (im Wind), umgewandelt	Erneuerbare Energieressourcen, Sonne, umgewandelt	Erneuerbare Energieressourcen, potentiell (im Staubecken), umgewandelt	Nicht-erneuerbare Energieressourcen, Primärwald	Erneuerbare Energieressourcen, Biomasse	Erneuerbare Materialressourcen, Wasser	Nicht-erneuerbare Materialressourcen, Metalle	Nicht-erneuerbare Materialressourcen, Mineralien
Synonyms	CExD	CExD	CExD	CExD	CExD	CExD	CExD	CExD	CExD	CExD
GeneralComment	Cumulative exergy demand is defined as the total exergy removal from nature to provide a product, summing up the exergy of all resources required	Cumulative exergy demand is defined as the total exergy removal from nature to provide a product, summing up the exergy of all resources required	Cumulative exergy demand is defined as the total exergy removal from nature to provide a product, summing up the exergy of all resources required	Cumulative exergy demand is defined as the total exergy removal from nature to provide a product, summing up the exergy of all resources required	Cumulative exergy demand is defined as the total exergy removal from nature to provide a product, summing up the exergy of all resources required	Cumulative exergy demand is defined as the total exergy removal from nature to provide a product, summing up the exergy of all resources required	Cumulative exergy demand is defined as the total exergy removal from nature to provide a product, summing up the exergy of all resources required	Cumulative exergy demand is defined as the total exergy removal from nature to provide a product, summing up the exergy of all resources required	Cumulative exergy demand is defined as the total exergy removal from nature to provide a product, summing up the exergy of all resources required	Cumulative exergy demand is defined as the total exergy removal from nature to provide a product, summing up the exergy of all resources required
LocalCategory	Kumulierter Exergieaufwand	Kumulierter Exergieaufwand	Kumulierter Exergieaufwand	Kumulierter Exergieaufwand	Kumulierter Exergieaufwand	Kumulierter Exergieaufwand	Kumulierter Exergieaufwand	Kumulierter Exergieaufwand	Kumulierter Exergieaufwand	Kumulierter Exergieaufwand
LocalSubCategory	Fossil	Nuklear	Wind	Sonne	Wasser	Primärwald	Biomasse	Wasserressourcen	Metalle	Mineralien
StartDate	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007
EndDate	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007
DataValidForEntirePeriod	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
OtherPeriodText	Time of publication.	Time of publication.	Time of publication.	Time of publication.	Time of publication.	Time of publication.	Time of publication.	Time of publication.	Time of publication.	Time of publication.
Text	Characterisation factors refer to the reference environment as specified in the original publication	Characterisation factors refer to the reference environment as specified in the original publication	Characterisation factors refer to the reference environment as specified in the original publication	Characterisation factors refer to the reference environment as specified in the original publication	Characterisation factors refer to the reference environment as specified in the	Characterisation factors refer to the reference environment as specified in the original publication	Characterisation factors refer to the reference environment as specified in the original publication	Characterisation factors refer to the reference environment as specified in the original publication	Characterisation factors refer to the reference environment as specified in the original publication	Characterisation factors refer to the reference environment as specified in the original publication
Person	86	86	86	86	86	86	86	86	86	86
DataPublishedIn	2	2	2	2	2	2	2	2	2	2
ReferenceToPublishedSo	3	3	3	3	3	3	3	3	3	3
Copyright	1	1	1	1	1	1	1	1	1	1
AccessRestrictedTo										
CompanyCode										
CountryCode										
PageNumbers	Cumulative exergy demand	Cumulative exergy demand	Cumulative exergy demand	Cumulative exergy demand	Cumulative exergy demand	Cumulative exergy demand	Cumulative exergy demand	Cumulative exergy demand	Cumulative exergy demand	Cumulative exergy demand

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4 Eco-indicator 99

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Last changes: 2007

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Summary

In 1999 the new method "Eco-indicator 99" for life cycle impact assessment has been published. The method has got much attention in the mean time. In order to implement this method in the ecoinvent LCI (life cycle inventory) database it is necessary to assign the damage factors to the elementary flows of resources and pollutants reported in this database. The work aims to link the impact assessment method Eco-indicator 99 to the ecoinvent data in order to facilitate the usage and to avoid discrepancies due to misunderstandings or different interpretations of the original reports. New Eco-indicator 99 damage factors have been extrapolated for some substances contributing to greenhouse effect and ozone depletion. Some mistakes of the original method have been corrected.

4.1 Introduction

In 1997 a group of scientists introduced a new method for life cycle impact assessment – The **Eco-indicator 99** (Goedkoop et al. 1998). The final report was published in 1999 (Goedkoop & Spriensma 1999a; b) and a first revised issue has been made available via the Internet in 2000 (Goedkoop & Spriensma 2000a; b).

In order to use this method, the damage factors[17] have to be linked to existing life cycle inventories. Primarily this implementation has been made for the old "Ökoinventare von Energiesystemen" by Jungbluth & Frischknecht (2000). This work is the basis for the implementation of the method in the updated ecoinvent data.

In order to use the impact assessment method Eco-indicator 99, it is necessary to link the elementary flows of ecoinvent data to the substance names given in the Eco-indicator 99 report. This background paper describes the implementation of Eco-indicator 99 with its difficulties in the assignment and some assumptions that had to be made.

The work consists of this background paper and an EXCEL table. The work aims to support users of the databases mentioned while using the Eco-indicator 99 impact assessment method. This should lead to comparable results of LCA that use the same database and the same valuation method.

For all users it is strongly recommended to refer to the original publications to understand the details of the Eco-indicator 99 method (Goedkoop et al. 1998; Goedkoop & Spriensma 2000a; b).

Tab. 4-1 shows an overview about the impact assessment methods implemented for the ecoinvent data.

[17] Two non ISO terms are used in the Eco-indicator 99 methodology: A *damage category* is comparable to an endpoint. A *damage factor* describes the damage due to the emission of a pollutant or the use of a resource.

Tab. 4-1 Impact Assessment Methods implemented in the database ecoinvent

Name	LocalName	Locati	Unit	LocalCategory	LocalSubCategory	Category	SubCategory
acidification & eutrophication	Versauerung & Eutrophierung	RER	points	Eco-indicator 99, (E,E)	Ökosystemqualität	eco-indicator 99, (E,E)	ecosystem quality
ecotoxicity	Ökotoxizität	RER	points	Eco-indicator 99, (E,E)	Ökosystemqualität	eco-indicator 99, (E,E)	ecosystem quality
land occupation	Landnutzung	RER	points	Eco-indicator 99, (E,E)	Ökosystemqualität	eco-indicator 99, (E,E)	ecosystem quality
total	Total	RER	points	Eco-indicator 99, (E,E)	Ökosystemqualität	eco-indicator 99, (E,E)	ecosystem quality
carcinogenics	Krebserregende Stoffe	RER	points	Eco-indicator 99, (E,E)	Menschliche Gesundheit	eco-indicator 99, (E,E)	human health
climate change	Klimawandel	RER	points	Eco-indicator 99, (E,E)	Menschliche Gesundheit	eco-indicator 99, (E,E)	human health
ionising radiation	Radioaktive Strahlung	RER	points	Eco-indicator 99, (E,E)	Menschliche Gesundheit	eco-indicator 99, (E,E)	human health
ozone layer depletion	Ozonabbau	RER	points	Eco-indicator 99, (E,E)	Menschliche Gesundheit	eco-indicator 99, (E,E)	human health
respiratory effects	Atemwegserkrankungen	RER	points	Eco-indicator 99, (E,E)	Menschliche Gesundheit	eco-indicator 99, (E,E)	human health
total	Total	RER	points	Eco-indicator 99, (E,E)	Menschliche Gesundheit	eco-indicator 99, (E,E)	human health
fossil fuels	Fossile Brennstoffe	RER	points	Eco-indicator 99, (E,E)	Ressourcen	eco-indicator 99, (E,E)	resources
mineral extraction	Mineralien	RER	points	Eco-indicator 99, (E,E)	Ressourcen	eco-indicator 99, (E,E)	resources
total	Total	RER	points	Eco-indicator 99, (E,E)	Ressourcen	eco-indicator 99, (E,E)	resources
total	Total	RER	points	Eco-indicator 99, (E,E)	Total	eco-indicator 99, (E,E)	total
acidification & eutrophication	Versauerung & Eutrophierung	RER	points	Eco-indicator 99, (H,A)	Ökosystemqualität	eco-indicator 99, (H,A)	ecosystem quality
ecotoxicity	Ökotoxizität	RER	points	Eco-indicator 99, (H,A)	Ökosystemqualität	eco-indicator 99, (H,A)	ecosystem quality
land occupation	Landnutzung	RER	points	Eco-indicator 99, (H,A)	Ökosystemqualität	eco-indicator 99, (H,A)	ecosystem quality
total	Total	RER	points	Eco-indicator 99, (H,A)	Ökosystemqualität	eco-indicator 99, (H,A)	ecosystem quality
carcinogenics	Krebserregende Stoffe	RER	points	Eco-indicator 99, (H,A)	Menschliche Gesundheit	eco-indicator 99, (H,A)	human health
climate change	Klimawandel	RER	points	Eco-indicator 99, (H,A)	Menschliche Gesundheit	eco-indicator 99, (H,A)	human health
ionising radiation	Radioaktive Strahlung	RER	points	Eco-indicator 99, (H,A)	Menschliche Gesundheit	eco-indicator 99, (H,A)	human health
ozone layer depletion	Ozonabbau	RER	points	Eco-indicator 99, (H,A)	Menschliche Gesundheit	eco-indicator 99, (H,A)	human health
respiratory effects	Atemwegserkrankungen	RER	points	Eco-indicator 99, (H,A)	Menschliche Gesundheit	eco-indicator 99, (H,A)	human health
total	Total	RER	points	Eco-indicator 99, (H,A)	Menschliche Gesundheit	eco-indicator 99, (H,A)	human health
fossil fuels	Fossile Brennstoffe	RER	points	Eco-indicator 99, (H,A)	Ressourcen	eco-indicator 99, (H,A)	resources
mineral extraction	Mineralien	RER	points	Eco-indicator 99, (H,A)	Ressourcen	eco-indicator 99, (H,A)	resources
total	Total	RER	points	Eco-indicator 99, (H,A)	Ressourcen	eco-indicator 99, (H,A)	resources
total	Total	RER	points	Eco-indicator 99, (H,A)	Total	eco-indicator 99, (H,A)	total
acidification & eutrophication	Versauerung & Eutrophierung	RER	points	Eco-indicator 99, (I,I)	Ökosystemqualität	eco-indicator 99, (I,I)	ecosystem quality
ecotoxicity	Ökotoxizität	RER	points	Eco-indicator 99, (I,I)	Ökosystemqualität	eco-indicator 99, (I,I)	ecosystem quality
land occupation	Landnutzung	RER	points	Eco-indicator 99, (I,I)	Ökosystemqualität	eco-indicator 99, (I,I)	ecosystem quality
total	Total	RER	points	Eco-indicator 99, (I,I)	Ökosystemqualität	eco-indicator 99, (I,I)	ecosystem quality
carcinogenics	Krebserregende Stoffe	RER	points	Eco-indicator 99, (I,I)	Menschliche Gesundheit	eco-indicator 99, (I,I)	human health
climate change	Klimawandel	RER	points	Eco-indicator 99, (I,I)	Menschliche Gesundheit	eco-indicator 99, (I,I)	human health
ionising radiation	Radioaktive Strahlung	RER	points	Eco-indicator 99, (I,I)	Menschliche Gesundheit	eco-indicator 99, (I,I)	human health
ozone layer depletion	Ozonabbau	RER	points	Eco-indicator 99, (I,I)	Menschliche Gesundheit	eco-indicator 99, (I,I)	human health
respiratory effects	Atemwegserkrankungen	RER	points	Eco-indicator 99, (I,I)	Menschliche Gesundheit	eco-indicator 99, (I,I)	human health
total	Total	RER	points	Eco-indicator 99, (I,I)	Menschliche Gesundheit	eco-indicator 99, (I,I)	human health
fossil fuels	Fossile Brennstoffe	RER	points	Eco-indicator 99, (I,I)	Ressourcen	eco-indicator 99, (I,I)	resources
mineral extraction	Mineralien	RER	points	Eco-indicator 99, (I,I)	Ressourcen	eco-indicator 99, (I,I)	resources
total	Total	RER	points	Eco-indicator 99, (I,I)	Ressourcen	eco-indicator 99, (I,I)	resources
total	Total	RER	points	Eco-indicator 99, (I,I)	Total	eco-indicator 99, (I,I)	total

4.2 Use of the method

Eco-indicator 99 valuation factors are calculated in three steps:

- Damage factors for the pollutants or resource uses are calculated for different impact categories.[18]
- Normalisation[19] of the damage factors on the level of damage categories[20].
- Weighting for the three damage categories and calculation of weighted Eco-indicator 99 damage factors.

The Eco-indicator 99 damage, normalisation and weighting factors have been implemented in an EXCEL worksheet (/ecoinventTools/3_EI'99.xls). All inputs are linked together in the table according to the Eco-indicator 99 method. Thus a change of the normalisation factor leads for example to an automatic recalculation of all results for Eco-indicator 99 factors. The calculation for the work sheet consists of the following tables:

- intro
- EI'99 damage factors
- Normalization & Weights

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[18] Impact category refers to the Name (LocalName) shown in Tab. 1.2.

[19] Following strictly the ISO standard (International Organization for Standardization (ISO) 1997-2000), impact category indicator results are usually normalized instead of normalizing on the level of damage factors.

[20] Damage category refers to the SubCategory shown in . 1.2.

- X-ImpactFactor (with the weighted damage factors implemented in the database)

Repeated formulas have been removed from two worksheets of the EXCEL-table in order to minimize the file size for downloading. After opening the EXCEL-worksheet it is necessary to change the worksheets "X-ImpactFactor". Please start the EXCEL-Macro "expand" with CTRL-e, or copy row 8 to row 9 until 3250 in "X-ImpactFactor" before working with these tables.

4.2.1 Normalisation & Weighting

Tab. 4-2 shows the normalisation and weighting factors that have been used to calculate the weighted Eco-indicator 99 from the damage factors in ecoinvent. These factors are directly taken from the original revised report. The average weighting factors are used for the hierarchist perspective (EI'99 H/A). The weights given in the table are shown as percentages. They are multiplied with 1000 while calculating the "weighted damage factor" in order to be consistent with the original methodology report.

The unit "points" is assigned to the results of the multiplication of the weighted damage factors with the inventory flows. In other publications or software the results are also shown with the unit "Pt" for short. Also mPt (millipoints) is used sometimes, which would be mathematically correct because of the multiplication by 1000.

Due to the inclusion of damage factors for some more substances and the consideration of long-term emissions it would be necessary to recalculate updated normalization factors including the total emissions of these substances caused in one year. But, the subsequent changes to all weighted Eco-indicator 99 damage factors might give rise to confusion and has not been followed in the ecoinvent implementation.

The weighting factors in the EXCEL worksheet "Normalization & Weights" can be changed in order to use own weighting assumptions (or the specific weighting set for the hierarchist). If all weights are set to 1 (i.e. 100%), one can use the characterised and normalised results for further own calculations with different weighting sets (e.g. the mixing triangle described by Hofstetter *et al.* (2000)).[21] We use the proposed standard weights.

Tab. 4-2 Normalisation and weighting factors for the three perspectives.

	Hierachist (EI'99 H/A)		Egalitarian (EI'99 E/E)		Individualist (EI'99 I/I)	
	Normalisation	Weights	Normalisation	Weights	Normalisation	Weights
Human Health	0.0154 DALYs(0,0)	40%	0.0155 DALYs(0,0)	30%	0.00825 DALYs(0,1)	55%
Ecosystem Quality	5130 PDF*m2*a	40%	5130 PDF*m2*a	50%	4510 PDF*m2*a	25%
Resources	8410 MJ	20%	5940 MJ	20%	150 MJ	20%

[21] The standard weighting set for each cultural or archetypical perspective (Hierarchist, Individualist, Egalitarian) is based on a panel survey. These necessarily subjective choices represent only one possible choice of weights. A result of a comparative product LCA is more reliable, if it can be shown, that the result is stable for a wide range of reasonable weighting sets or even for all possible weighting sets. It is possible to depict the outcome of all possible weighting sets in a mixing triangle. Within this triangle it can be displayed which product option is environmentally least burdening for which weighting set. Hence, it is easy to see when a small change in the weighting set would alter the ranking of the product options. The use of the weighting triangle concept is explained in detail in Hofstetter *et al.* (2000). Software tools to draw mixing triangles from damage data are TRIANGLE by PRé consultants (DOS-PC application for 2 product options, free download from http://www.pre.nl/eco-indicator99/download_triangle.htm) and MIXTRI v.2.0 by Gabor Doka (MS Excel sheet for an unlimited number of products, free download from http://www.doka.ch/EI99/mixtri.htm).

4.3 Implementation

4.3.1 General assignments

As far as possible we used the figures given in the Annexe 1 of the updated Eco-indicator 99 methodology report (Goedkoop & Spriensma 2000a). Further on, these data are referred to as main-report data. For substances without damage factors given in the main-report, we checked also the updated annexe-report (Goedkoop & Spriensma 2000b). These data are referred to as annexe-report data.

Long-term emissions

After a sometimes controversial email discussion with the developers[22] and among the ecoinvent administrators (see chapter 2.1.3 "Assessment for long-term emissions") and the publication of (Frischknecht et al. 2000) it was decided, that long-term emissions are valuated the same as today emissions in the egalitarian and hierarchist perspective, because these perspectives do not use an inverse discounting. The Individualist has a short time perspective, so all long term emissions are ignored.

4.3.2 Emissions to air

Greenhouse gases and ozone depleting substances

UNEP (1999) published new characterization factors for some gases in the inventory that are known to contribute to global warming. We used these factors to extrapolate additional damage factors strictly according to the Eco-indicator 99 procedure.[23] We use the same differentiation between CO_2, CH_4 and N_2O according to the lifetime of the substance as described by Goedkoop & Spriensma (2000a:40) for the extrapolation of damage factors for greenhouse gases. The new damage factors are shown in Tab. 4-3. The damage factors for the last four substance mixes have been calculated as a weighted mean of the ingredients and their damage factors (Jungbluth & Frischknecht 2000).

For CO we calculated the damage factor (1.57 kg CO_2-eq per kg CO) for its global warming potential because it is oxidized to CO_2. This is necessary because in the ecoinvent data the amount of carbon emitted as CO has been subtracted from the total stoichiometric CO_2-emission calculated based on the carbon content of a fuel. A calculation of the CO_2-emissions would also be possible for other hydrocarbons emitted into air. But normally their contribution (for the greenhouse effect) is relatively small.

UNEP (1999) has published new characterization factors for some gases included in the database that are known to contribute to ozone depletion. For ozone depleting substances a damage factor has been extrapolated from the Eco-indicator damage factor for CFC-11 and the ozone depleting potentials. The new damage factors are shown in Tab. 4-3 (Jungbluth & Frischknecht 2000).

[22] Emails of Mark Goedkoop and Patrick Hofstetter, June 2003.

[23] Further proposals for the inclusion of additional substances with new calculated damage factors might be circulated via the Eco-indicator 99 email discussion list (www.pre.nl).

Tab. 4-3 New damage factors extrapolated from the ozone depleting potential and the global warming potential (UNEP 1999:Appendix L) and damage factors for mixtures of halogenated hydrocarbons.

Module name in "Ökoinventare von Energiesystemen"		Ozone depleting Potential	GWPs from 1998 Ozone assessment	Lifetime	EI'99 Greenhouse Effect, Egalitarian	EI'99 Greenhouse Effect, Hierarchist	EI'99 Greenhouse Effect, Individualist	EI'99 Ozone Depletion, Egalitarian	EI'99 Ozone Depletion, Hierarchist	EI'99 Ozone Depletion, Individualist
	Unit	kg CFC-11 eq	kg CO2-eq, 100 years, direct	years	DALYs(0,0)	DALYs(0,0)	DALYs(0,1)	DALYs(0,0)	DALYs(0,0)	DALYs(0,1)
Butan s	kg	-	3	0.02	6.29E-7	6.29E-7	6.29E-7			
Butan p	kg	-	3	0.02	6.29E-7	6.29E-7	6.29E-7			
Dichlormonofluormethan p	kg	0.04	210	2	4.40E-5	4.40E-5	4.40E-5	4.20E-5	4.20E-5	3.40E-5
H 1211 Halon p	kg	-	1300	11	2.72E-4	2.72E-4	2.72E-4			
Propan p	kg	-	3	0.04	6.29E-7	6.29E-7	6.29E-7			
Propan s	kg	-	3	0.04	6.29E-7	6.29E-7	6.29E-7			
R114 FCKW p	kg	-	9800	300	2.18E-3	2.18E-3	2.12E-3			
R115 FCKW p	kg	-	10300	1700	2.29E-3	2.29E-3	2.23E-3			
R13 FCKW p	kg	640	14000	640	3.12E-3	3.12E-3	3.03E-3	1.05E-3	1.05E-3	8.50E-4
Weighted average of damage factors of different ingredients										
R404A FKW p	kg				6.67E-4	6.72E-4	6.62E-4	0	0	0
R407C FKW p	kg				3.64E-4	3.68E-4	3.62E-4	0	0	0
R410A FKW p	kg				-4.15E-4	-4.10E-4	-3.65E-4	0	0	0
R502 FCKW p	kg				1.31E-3	1.31E-3	1.28E-3	2.36E-4	2.36E-4	1.91E-4

Particulates

The carcinogenics factor “particles diesel soot” is used for the Particulates, < 2.5 um because they make the highest share in particle emissions from diesel vehicles (Spielmann et al. 2004). No factor for carcinogenics is used for the two other particulate fractions.

For respiratory effects, no factor is used for Particulates, > 10 um as it is assumed that this fraction is harmless.[24]

Individual hydrocarbons

For several individual hydrocarbons a damage factor has been introduced. Therefore appropriate factors from the following more general substance classes have been used:

- aldehydes
- alkanes
- CxHy aromatic
- CxHy chloro
- CxHy halogenated
- NMVOC
- PAHs

Details of this implementation are documented in the column “Remarks and substance names in the EI'99 report” of the EXCEL File 03_EI’99.xls.

[24] Email of Mark Goedkoop, June 2004.

4.3.3 Emissions to water

General assignments

Damage factors for direct emissions of carcinogenic substances into ocean water have not been modelled in the Eco-indicator 99. Damage factors for emissions to rivers are applied for emissions to ground-, ground- long-term, lake, and unspecified, but not for emissions to ocean water.

Radioactive substances

The implementation in ecoinvent includes also damage factors for radioactive emissions into oceans. These are only shown in the annexe report. The factor for radionuclides without a given EI'99 damage factor was set to zero. Damage factors for emission to the ocean are not applied for other categories.

Sum parameters

There are no damage factors for sum parameters (CSB, BOD, TOC, etc.) in Eco-indicator 99. Thus double counting is no problem.

4.3.4 Emissions to soil

Heavy metals

Direct emissions of heavy metals into agricultural soil are valuated with the factors provided in Tab. 5.1 of the annexe-report (Goedkoop & Spriensma 2000b). Unspecific emissions of heavy metals into soil are valued with the damage factor for industrial soil.

The general damage factor for "metals" was not applied for other non-valuated metals as it is meant to be used only for inventories in which all metals are summarized to one value.

Chromium

The main report provides a damage factor for "chromium (ind.)" emissions to soil in the category carcinogenics. This factor has been applied only for "Chromium VI" but not for "Chromium III" as the later is not carcinogenic. This information can be found in the annexe-report and has been confirmed in personal communication with M. Goedkoop. A mistake for this damage factors has been corrected (see chapter 4.3.6).

Pesticides

Damage factors were available only for few of the substances considered in the agricultural inventories (Nemecek et al. 2004). Thus not all pesticide emissions in the database have a damage factor.

4.3.5 Resource uses

Resources Surplus Energy

The resource uses "Extraction of minerals" and "Extraction of fossil fuels" are taken from the original report. The energy figure for the energy resources have been adapted to the assumptions used in ecoinvent for the heating values. Abiotic resource, that contain metals, are only valuated if the resource is extracted for the purpose of metal production.

It has to be noted that in the Individualist perspective, the extraction of fossil resources is not considered as a problem and thus there is no method implemented for this.

Land occupation

The description of land occupation categories used in ecoinvent is more detailed than in Eco-indicator 99. Thus the damage factors had to be assessed with less detailed data (Tab. 4-4). Damage factors for land occupation of water bodies were not available. Thus all uses of water surface and sea ground are not valuated. In Switzerland, most of agricultural areas are used for integrated production (IP). Thus the damage factors for this category and not for conventional agriculture have been applied. It might be necessary to adapt this if the data are used for other countries.

The damage factor for the ecoinvent category unknown has been estimated with “Disscont. urban land” as a rough estimation. This category has a factor that is near the average of the different classes. Intensive forestry is estimated to have the same impacts as “Convent arable land”. For “industrial area, built up” a worst-case assumption with the highest damage factor is applied.[25]

Tab. 4-4 Assignment of land occupation categories in Eco-indicator (right side) to categories used in ecoinvent (left side) and damage factors for the calculation

Name	Category	SubCategory	Unit	Remarks and substance names in the EI'99 report	EI99 Land Use, Egalitarian	EI99 Land Use, Hierarchist	EI99 Land Use, Individualist
3702	3506	3507	###		PDF*m2*a	PDF*m2*a	PDF*m2*a
Occupation, arable	resource	land	m2a	Occup. as Integrated arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, arable, non-irrigated	resource	land	m2a	Occup. as Integrated arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, arable, non-irrigated, diverse-intensive	resource	land	m2a	Occup. as Integrated arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, arable, non-irrigated, fallow	resource	land	m2a	Occup. as Integrated arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, arable, non-irrigated, monotone-intens	resource	land	m2a	Occup. as Convent. arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, construction site	resource	land	m2a	Occup. as Industrial area	8.40E-1	8.40E-1	8.40E-1
Occupation, dump site	resource	land	m2a	Occup. as Industrial area	8.40E-1	8.40E-1	8.40E-1
Occupation, dump site, benthos	resource	land	m2a	no characterisation factor	0	0	0
Occupation, forest	resource	land	m2a	Occup. as Forest land	1.10E-1	1.10E-1	1.10E-1
Occupation, forest, extensive	resource	land	m2a	Occup. as Forest land	1.10E-1	1.10E-1	1.10E-1
Occupation, forest, intensive	resource	land	m2a	Occup. as Forest land	1.10E-1	1.10E-1	1.10E-1
Occupation, forest, intensive, clear-cutting	resource	land	m2a	Occup. as Convent. arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, forest, intensive, normal	resource	land	m2a	Occup. as Forest land	1.10E-1	1.10E-1	1.10E-1
Occupation, forest, intensive, short-cycle	resource	land	m2a	Occup. as Convent. arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, heterogeneous, agricultural	resource	land	m2a	Occup. as Integrated arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, industrial area	resource	land	m2a	Occup. as Industrial area	8.40E-1	8.40E-1	8.40E-1
Occupation, industrial area, benthos	resource	land	m2a	no characterisation factor	0	0	0
Occupation, industrial area, built up	resource	land	m2a	no factor, estimation as worst case	1.15E+0	1.15E+0	1.15E+0
Occupation, industrial area, vegetation	resource	land	m2a	Occup. as green urban land	8.40E-1	8.40E-1	8.40E-1
Occupation, mineral extraction site	resource	land	m2a	Occup. as Industrial area	8.40E-1	8.40E-1	8.40E-1
Occupation, pasture and meadow	resource	land	m2a	Occup. as less intens. meadow land	1.02E+0	1.02E+0	1.02E+0
Occupation, pasture and meadow, extensive	resource	land	m2a	Occup. as less intens. meadow land	1.02E+0	1.02E+0	1.02E+0
Occupation, pasture and meadow, intensive	resource	land	m2a	Occup. as intens. meadow land	1.13E+0	1.13E+0	1.13E+0
Occupation, permanent crop	resource	land	m2a	Occup. as Integrated arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, permanent crop, fruit	resource	land	m2a	Occup. as Integrated arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, permanent crop, fruit, extensive	resource	land	m2a	Occup. as Integrated arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, permanent crop, fruit, intensive	resource	land	m2a	Occup. as Integrated arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, permanent crop, vine	resource	land	m2a	Occup. as Integrated arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, permanent crop, vine, extensive	resource	land	m2a	Occup. as Integrated arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, permanent crop, vine, intensive	resource	land	m2a	Occup. as Integrated arable land	1.15E+0	1.15E+0	1.15E+0
Occupation, sea and ocean	resource	land	m2a	no characterisation factor	0	0	0
Occupation, shrub land, sclerophyllous	resource	land	m2a	Occup. as Forest land	1.10E-1	1.10E-1	1.10E-1
Occupation, traffic area, rail embankment	resource	land	m2a	Occup. as green urban land	8.40E-1	8.40E-1	8.40E-1
Occupation, traffic area, rail network	resource	land	m2a	Occup. as rail/ road area	8.40E-1	8.40E-1	8.40E-1
Occupation, traffic area, road embankment	resource	land	m2a	Occup. as green urban land	8.40E-1	8.40E-1	8.40E-1
Occupation, traffic area, road network	resource	land	m2a	Occup. as rail/ road area	8.40E-1	8.40E-1	8.40E-1
Occupation, unknown	resource	land	m2a	Occup. as Discont. urban land as rough estimat	9.60E-1	9.60E-1	9.60E-1
Occupation, urban, continuously built	resource	land	m2a	Occup. as Contin. urban land	1.15E+0	1.15E+0	1.15E+0
Occupation, urban, discontinuously built	resource	land	m2a	Occup. as Discont. urban land	9.60E-1	9.60E-1	9.60E-1
Occupation, water bodies, artificial	resource	land	m2a	no characterisation factor	0	0	0
Occupation, water courses, artificial	resource	land	m2a	no characterisation factor	0	0	0

Land transformation

In Eco-indicator land transformation is described with a factor for the transformation to a certain state. These factors are used as shown in Tab. 4-5 for “Transformation, to …”. For “Transformation, from …” the same assignment is used with negative damage factors. The assignment follows the same ideas described before for land occupation. A damage factor for conversion to forest was not available. It

[25] Personal communication with Thomas Köllner, June 2003.

has been estimated by using the ratio between factors for conversion and occupation found for other categories, which is about 30. This has been multiplied with the damage factor for forest occupation.

A special problem is the transformation "from" or "to" different types of water surfaces. A factor can not be assessed, because the method has only been developed for land surfaces. If the factor is left zero for water surfaces this would lead to a clear negative value for hydro power because the calculation would account only for the "transformation, from unknown" (land surface). Thus all water surfaces are estimated with the factor for unknown. A transformation of water bodies or from unknown land surface to water bodies (hydro power) is equalled out in this way and not valuated in the sum.

Tab. 4-5 Assignment of land conversion categories in Eco-indicator (right side) to transformation categories used in ecoinvent (left side) and damage factors for the calculation

Name	Unit	Remarks and substance names in the EI'99 report	EI99 Land Use, Egalitarian	EI99 Land Use, Hierarchist	EI99 Land Use, Individualist
3702	###		PDF*m2*a	PDF*m2*a	PDF*m2*a
Transformation, to arable	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to arable, non-irrigated	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to arable, non-irrigated, diverse-intensive	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to arable, non-irrigated, fallow	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to arable, non-irrigated, monotone-intensive	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to dump site	m2	Conv. to Industrial area	2.52E+1	2.52E+1	2.52E+1
Transformation, to dump site, benthos	m2	no damage factor, estimation as transf., to unknown	2.87E+1	2.87E+1	2.87E+1
Transformation, to dump site, inert material landfill	m2	Conv. to Industrial area	2.52E+1	2.52E+1	2.52E+1
Transformation, to dump site, residual material landfill	m2	Conv. to Industrial area	2.52E+1	2.52E+1	2.52E+1
Transformation, to dump site, sanitary landfill	m2	Conv. to Industrial area	2.52E+1	2.52E+1	2.52E+1
Transformation, to dump site, slag compartment	m2	Conv. to Industrial area	2.52E+1	2.52E+1	2.52E+1
Transformation, to forest	m2	No damage factor, own estimation	3.30E+0	3.30E+0	3.30E+0
Transformation, to forest, extensive	m2	No damage factor, own estimation	3.30E+0	3.30E+0	3.30E+0
Transformation, to forest, intensive	m2	No damage factor, own estimation	3.30E+0	3.30E+0	3.30E+0
Transformation, to forest, intensive, clear-cutting	m2	No damage factor, own estimation	3.44E+1	3.44E+1	3.44E+1
Transformation, to forest, intensive, normal	m2	No damage factor, own estimation	3.30E+0	3.30E+0	3.30E+0
Transformation, to forest, intensive, short-cycle	m2	No damage factor, own estimation	3.44E+1	3.44E+1	3.44E+1
Transformation, to heterogeneous, agricultural	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to industrial area	m2	Conv. to Industrial area	2.52E+1	2.52E+1	2.52E+1
Transformation, to industrial area, benthos	m2	no damage factor, estimation as transf., to unknown	2.87E+1	2.87E+1	2.87E+1
Transformation, to industrial area, built up	m2	no factor, estimation as worst case	3.44E+1	3.44E+1	3.44E+1
Transformation, to industrial area, vegetation	m2	Conv. to Green urban	2.52E+1	2.52E+1	2.52E+1
Transformation, to mineral extraction site	m2	Conv. to Industrial area	2.52E+1	2.52E+1	2.52E+1
Transformation, to pasture and meadow	m2	Conv. to Less intensive meadow	3.06E+1	3.06E+1	3.06E+1
Transformation, to pasture and meadow, extensive	m2	Conv. to Less intensive meadow	3.06E+1	3.06E+1	3.06E+1
Transformation, to pasture and meadow, intensive	m2	Conv. to Intensive meadow	3.40E+1	3.40E+1	3.40E+1
Transformation, to permanent crop	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to permanent crop, fruit	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to permanent crop, fruit, extensive	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to permanent crop, fruit, intensive	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to permanent crop, vine	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to permanent crop, vine, extensive	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to permanent crop, vine, intensive	m2	Conv. to Integr. arable land	3.44E+1	3.44E+1	3.44E+1
Transformation, to sea and ocean	m2	no damage factor, estimation as transf., to unknown	2.87E+1	2.87E+1	2.87E+1
Transformation, to shrub land, sclerophyllous	m2	No damage factor, own estimation	3.30E+0	3.30E+0	3.30E+0
Transformation, to traffic area, rail embankment	m2	Conv. to Green urban	2.52E+1	2.52E+1	2.52E+1
Transformation, to traffic area, rail network	m2	Conv. to rail/ road area	2.52E+1	2.52E+1	2.52E+1
Transformation, to traffic area, road embankment	m2	Conv. to Green urban	2.52E+1	2.52E+1	2.52E+1
Transformation, to traffic area, road network	m2	Conv. to rail/ road area	2.52E+1	2.52E+1	2.52E+1
Transformation, to unknown	m2	Conv. to Discontinuous urban as rough estimation	2.87E+1	2.87E+1	2.87E+1
Transformation, to urban, continuously built	m2	Conv. to Continuous urban land	3.45E+1	3.45E+1	3.45E+1
Transformation, to urban, discontinuously built	m2	Conv. to Discontinuous urban	2.87E+1	2.87E+1	2.87E+1
Transformation, to water bodies, artificial	m2	no damage factor, estimation as transf., to unknown	2.87E+1	2.87E+1	2.87E+1
Transformation, to water courses, artificial	m2	no damage factor, estimation as transf., to unknown	2.87E+1	2.87E+1	2.87E+1
Transformation, to tropical rain forest	m2	own estimation with minimum figure	3.30E+0	3.30E+0	3.30E+0

4.3.6 Known mistakes and shortcomings

Acidification & Eutrophication

The Eco-indicator 99 report gives no damage factors for emissions of nutrients and acids into water nor soil. But it is stated, that for water and soil emissions the "damage factors for air can be used as temporary, but crude solution". We did not use this possibility after a discussion with the EI'99 developers.[26] The table "Acidification+" (Tab. 4-6) gives the additional factors that might be used for a sensitivity analysis. Furthermore, the report does neither provide damage factors for a range of acids like hydrogen chloride or hydrogen sulphide nor for the important nutrient phosphate. Thus for an LCA of, e.g. agricultural products it seems to be necessary to discuss the important impact categories acidification and eutrophication separately, e.g. with the impact assessment method published by (Guinée et al. 2001), which is also implemented in ecoinvent.

Tab. 4-6 Crude assumption of damage factors for water and soil emissions related to acidification and eutrophication. Not considered for ecoinvent data

Name	Category	SubCategory	Unit	EI'99 Acidification & Eutrophication, Egalitarian	EI'99 Acidification & Eutrophication, Hierarchist	EI'99 Acidification & Eutrophication, Individualist
				PDF*m2*a	PDF*m2*a	PDF*m2*a
Nitrogen	soil	agricultural	kg	1.88E+1	1.88E+1	1.88E+1
Ammonium, ion	water	river	kg	1.89E+1	1.89E+1	1.89E+1
Hydrogen sulfide	water	river	kg	1.96E+0	1.96E+0	1.96E+0
Nitrate	water	river	kg	4.24E+0	4.24E+0	4.24E+0
Nitrite	water	river	kg	5.71E+0	5.71E+0	5.71E+0
Nitrogen	water	river	kg	1.88E+1	1.88E+1	1.88E+1
Nitrogen, organic bound	water	river	kg	1.88E+1	1.88E+1	1.88E+1
Sulfate	water	river	kg	6.94E-1	6.94E-1	6.94E-1
Sulfide	water	river	kg	2.08E+0	2.08E+0	2.08E+0
Sulfite	water	river	kg	8.32E-1	8.32E-1	8.32E-1
Sulfur	water	river	kg	2.08E+0	2.08E+0	2.08E+0

Carcinogenic substances, emissions to oceans

The Eco-indicator 99 report is, according to our reading, not fully precise on this issue, whether emissions to ocean water shall be treated in the same way as emissions to fresh water. There are two possible interpretations:

1) Extrapolation of "fresh water" damage factors to "ocean" damage factors, because the report does provide factors for water emissions without explicitly limiting this to a certain sub-category.
2) No such extrapolation, because the effect for many substances seems to be dominated by uptake via drinking water and this pathway cannot be assumed for emissions to ocean water.

We decided not to apply the factors provided for water emissions on emissions to ocean water. An update of the Eco-indicator methodology should clarify this point.

Carcinogenic substances, nickel and chromium VI

Emissions of chromium VI and nickel to water and soil are considered to be carcinogenic in the original Eco-indicator 99 publication. A detailed analysis of research results showed that only the uptake path via air is causing cancer, but for the direct uptake via water or food there is no proof for carcinogenic. Mark Goedkoop[27] recalculated the damage factors for these substances. Tab. 4-7 shows the new factors that have been used for the ecoinvent database and that replace the factors shown in

[26] Mark Goedkoop (email communication, 20.7.2000).

[27] Personal communication with Mark Goedkoop, 8.2003.

(Goedkoop & Spriensma 2000a). Factors for dichromate have been calculated with the share of Cr for the total weight of the substance.

Tab. 4-7 Recalculated damage factors for chromium Vi and nickel

Hierarchist DALY per kg emission				
Emission compartment:	Air	Waterborne	Industrial soil	Agricultural soil
Chromium VI	5.84E-03	8.26E-10	3.68E-07	3.68E-07
Nickel	4.29E-05	6.91E-11	4.21E-09	4.21E-09
Nickel-refinery-dust	2.35E-05	3.79E-11	2.31E-09	2.31E-09
Nickel-subsulfide	4.71E-05	7.57E-11	4.62E-09	4.62E-09
Egalitarian DALY per kg emission				
Emission compartment:	Air	Waterborne	Industrial soil	Agricultural soil
Chromium VI	5.84E-03	8.26E-10	3.68E-07	3.68E-07
Nickel	4.29E-05	6.91E-11	4.21E-09	4.21E-09
Nickel-refinery-dust	2.35E-05	3.79E-11	2.31E-09	2.31E-09
Nickel-subsulfide	4.71E-05	7.57E-11	4.62E-09	4.62E-09
Individualist DALY per kg emission				
Emission compartment:	Air	Waterborne	Industrial soil	Agricultural soil
Chromium VI	3.77E-03	4.27E-10	6.81E-09	1.72E-09
Nickel	2.77E-05	3.63E-11	4.32E-10	1.26E-10
Nickel-refinery-dust	1.96E-05	2.56E-11	3.05E-10	8.86E-11
Nickel-subsulfide	3.92E-05	5.12E-11	6.11E-10	1.77E-10

Land occupation

The damage factors used in the Eco-indicator 99 method are based on intermediate results of the Ph.D. thesis from (Köllner 1999; 2001). But, the outcome of a valuation with the damage factors derived for the Eco-indicator 99 by (Goedkoop & Spriensma 2000a) and the factors later on published by (Köllner 2001) differ considerably. Especially the comparison of agricultural products from organic and conventional farming shows opposite results (much better for organic products using (Köllner 1999), but about equal with the Eco-indicator 99 land use category). The calculations for the Eco-indicator 99 did include only a rough estimation for the field borders which might be more relevant than the cropland itself. It is intended to rework this shortcoming of the method for a further updated version.[28]

So far these shortcomings have not been corrected in the implementation of ecoinvent. Thus it cannot be recommended to use the damage factors for land occupation for a detailed discussion of this impact category.

Long-term emissions

The question if and how long-term emissions should be included in the assessment has been intensively discussed within the ecoinvent group and with the method developers. So far this point has not been accommodated in the methodology. Finally we agreed on the procedure described in this report. But, this issue has not been finally solved with the solution implemented.[29]

A further problem tackled so far not consistently is the fate modelling. For long-term emission from landfills the fate of the substances is modelled over 60000 years. But, also the Eco-indicator 99 makes

[28] Email communication with Mark Goedkoop 3.4.2003.

[29] Email communication with Mark Goedkoop July 2003.

a fate modelling e.g. for substances which are emitted to the soil. So far these two approaches have not been harmonized.

4.3.7 List of impact assessment factors in ecoinvent

The list of damage factors can be found in an EXCEL table supplied with the CD-ROM (\ecoinventTools\03_EI'99.xls).

4.4 Quality considerations

As described before, many implementation problems could be solved in close cooperation with the developers of the method. Sometimes these solutions are preliminary and further research work would be necessary. For a lot of substances included in the database, the Eco-indicator 99 reports do not provide damage factors. Thus for only 34% of the substances of the ecoinvent data damage factors are available.

Abbreviations

(0,0)	Calculation not including age weighting
(0,1)	Calculation including age weighting
(E,E)	Egalitarian, Egalitarian weighting
(H,A)	Hierachist, Average weighting
(I,I)	Individualist, Individualist weighting
CAS	Chemical abstract service
DALY	Disability-Adjusted Life Years
E	Egalitarian
EI'99	Eco-indicator 99
H	Hierarchist
I	Individualist
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
PDF	Potentially Disappeared Fraction
points	Unit used for the weighted EI'99 damage factor

Appendices

EXCEL Sheet

The next chapter gives details about the information included in each of the different tables in the EXCEL-worksheet with the name "03_EI'99.xls". This file can be found on the CD-ROM in the directory /ecoinventTools/.

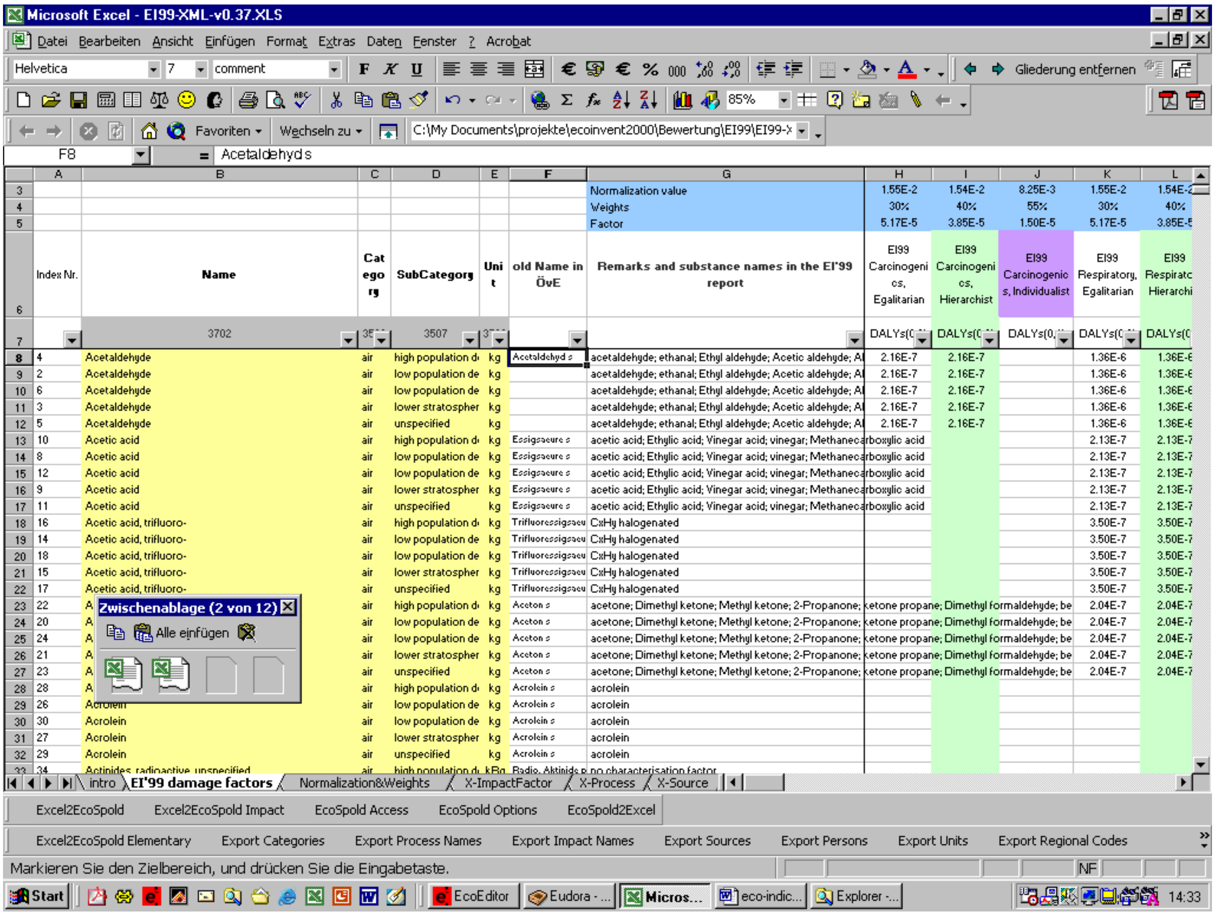
intro

This worksheet gives a short introduction and general information about the implementation of the Eco-indicator 99 impact assessment method.

EI'99 damage factors

The "EI'99 damage factors" table includes the main information for the assignment of Eco-indicator 99 damage factors from the original report to the ecoinvent data. Tab. 4-8 shows an example for the "EI'99 damage factors" table.

Tab. 4-8 Example from the "EI'99 damage factors" table of the Eco-indicator 99 implementation worksheet.



The first columns give the description of elementary flows in the ecoinvent data. Column E gives the unit for the elementary flow in the inventory. The text in column G explains the main assumptions for the assignment of damage factors for each elementary flow. It shows the English substance names from the Eco-indicator 99 publication that had been assigned to the pollutant or resource as well as other synonyms. Difficulties in the assignment, additional information and comments are also given in this column.

In column H to AN, the damage factor table starts with the first Eco-indicator 99 impact category. Damage factors for each perspective of all Eco-indicator 99 impact categories (10 * 3 = 30 columns) and summed damage factors for each perspective of the three damage categories "Human Health", "Ecosystem Quality" and "Resources Surplus Energy" (3 * 3 = 9 columns) are given in this worksheet.

Normalisation & Weighting

This sheet contains normalisation and weighting factors that were used to calculate the weighted Eco-indicator 99 from the damage factors

X-ImpactFactor

This table presents the impact factors calculated for the ecoinvent data. The weighted damage factors are calculated with the given damage and normalization factors and the weights for the different perspectives for all impact categories, safeguard subjects and for the aggregated total.

X-Process, X-Source, X-Person

These sheet contains meta information for the impact assessment methods.

Acidification+

This table shows damage factors for the emission of nitrogen and sulphur compounds to water and soil that contribute to acidification and eutrophication. The table may be used for sensitivity analyses. The damage factors correspond to the damage factors of air emissions of the same substances, which is a crude first assumption. The cells with additional figures have a green background in Tab. 4-6.

NamesImpact

Overview for names of the implemented methods.

Original weighting factors

The original damage factors can be found in (Goedkoop & Spriensma 2000a; b).

WWW addresses

EPA homepage for ozone depleting potential:
www.epa.gov/docs/ozone/ods.html

Eco-indicator 99 main page:
www.pre.nl

EcoSpold Meta information

The full meta information can be assessed via the homepage www.ecoinvent.org. The following table shows an example.

ReferenceFunctio	Category	eco-indicator 99, (E,E)	eco-indicator 99, (H,A)	eco-indicator 99, (I,I)
	SubCategory	human health	human health	human health
	Name	carcinogenics	carcinogenics	carcinogenics
Geography	Location	RER	RER	RER
ReferenceFunctio	Unit	points	points	points
DataSetInformatic	Type	4	4	4
	Version	1.0	1.0	1.0
	energyValues	0	0	0
	LanguageCode	en	en	en
	LocalLanguageCode	de	de	de
DataEntryBy	Person	41	41	41
	QualityNetwork	1	1	1
ReferenceFunctio	DataSetRelatesToProduc	0	0	0
	Amount	1	1	1
	LocalName	Krebserregende Stoffe	Krebserregende Stoffe	Krebserregende Stoffe
	Synonyms	EI'99	EI'99	EI'99
	GeneralComment	Implementation of the impact assessment method with the normalized and weighted damage factor. Weights (30% human health, 50% ecosystem quality, 20% resources) and normalization for Egalitarian perspective. Correction of factors for nickel and chromium emissions and nickel and zinc resource. Own assessment for new land use categories.	Implementation of the impact assessment method with the normalized and weighted damage factor. Average weights (40% human health, 40% ecosystem quality, 20% resources) and normalization for Hierachist perspective. Correction of factors for nickel and chromium emissions and nickel and zinc resource. Own assessment for new land use categories.	Implementation of the impact assessment method with the normalized and weighted damage factor. Weights (55% human health, 25% ecosystem quality, 20% resources) and normalization for Individualist perspective. Long-term emissions are not taken into account. Correction of factors for nickel and chromium emissions and nickel and zinc resource. Own assessment for new land use categories.
	LocalCategory	Eco-indicator 99,	Eco-indicator 99,	Eco-indicator 99, (I,I)
	LocalSubCategory	Menschliche Gesundheit	Menschliche Gesundheit	Menschliche Gesundheit
TimePeriod	StartDate	2000	2000	2000
	EndDate	2000	2000	2000
	DataValidForEntirePeriod	1	1	1
	OtherPeriodText	Time of publication.	Time of publication.	Time of publication.
Geography	Text	Normalization and damage modelling for the European situation. Weighting based on panel of scientists in Europe.	Normalization and damage modelling for the European situation. Weighting based on panel of scientists in Europe.	Normalization and damage modelling for the European situation. Weighting based on panel of scientists in Europe.
DataGeneratorAn	Person	41	41	41
	DataPublishedIn	2	2	2
	ReferenceToPublishedSo	3	3	3
	Copyright	1	1	1
	AccessRestrictedTo	0	0	0
	CompanyCode			
	CountryCode			
	PageNumbers	Eco-indicator 99	Eco-indicator 99	Eco-indicator 99

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Spielmann et al. 2004	Spielmann M., Kägi T., Stadler P. and Tietje O. (2004) Life Cycle Inventories of Transport Services. Final report ecoinvent 2000 No. 14. UNS, ETH-Zurich, Swiss Centre for Life Cycle Inventories, Dübendorf, CH, retrieved from: www.ecoinvent.org.
UNEP 1999	UNEP (1999) The Implications to the montreal protocol of the inclusion of hfcs and pfcs in the kyoto protocol. HFC and PFC Task Force of the Technology and Economic Assessment Panel, retrieved from: www.unep.org/ozone/HFC-PFC-Rep.1999/.

5 Ecosystem damage potential - EDP

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Last changes: 2007

5.1 Introduction

The following description of this life cycle impact assessment methodology for the characterisation of land occupation and transformation is taken from the underlying publications (Koellner & Scholz 2007a; b).

Goal, Scope and Background. Land use is an economic activity that generates large benefits for human society. One side effect, however, is that it has caused many environmental problems throughout history and still does today. Biodiversity, in particular, has been negatively influenced by intensive agriculture, forestry and the increase in urban areas and infrastructure. Integrated assessment such as Life Cycle Assessment (LCA) thus incorporate impacts on biodiversity. The main objective of this paper is to develop generic characterization factors for land use types using empirical information on species diversity from Central Europe, which can be used in the assessment method developed in the first part of this series of paper.

Methods. Based on an extensive meta-analysis with information about species diversity on 5581 sample plots we calculated characterization factors for 53 land use types and six intensity classes. The typology is based on the CORINE Plus classification. We took information on the standardized α-diversity of plants into account. In addition threatened plants were considered. Linear were used for the calculation of damage potentials (EDP^S). In our approach we use the current mean species number in the region as a reference, because this allows whether specific land use types hold more or less species diversity per area. The damage potential calculated is endpoint oriented. The corresponding characterization factors EDP^S can be used in the Life Cycle Impact Assessment as weighting factors for different types of land occupation and land use change as described in the part 1 of this paper series.

Results. The result from ranking the intensity classes based on the mean plant species number is as expected. High intensive forestry and agriculture exhibit the lowest species richness (5.7-5.8 plant species/m^2), artificial surfaces, low intensity forestry and non-use have medium species richness (9.4-11.1 plant species/m^2) and low-intensity agriculture has the highest species richness (16.6 plant species/m^2). The mean and median are very close, indicating that the skewness of the distribution is low. Standard error is low and is similar for all intensity classes. Linear transformations of the relative species numbers are linearly transformed into ecosystem damage potentials (EDP^S_{linear}). The integration of threatened plant species diversity into a more differentiated damage function $EDP^{S_{total}}_{linear}$ makes it possible to differentiate between land use types that have similar total species numbers, but intensities of land use that are clearly different (e.g., artificial meadow and broad-leafed forest). Negative impact values indicate that land use types hold more species per m^2 than the reference does. In terms of species diversity, these land use types are superior (e.g. near-to-nature meadow, hedgerows, agricultural fallow).

Discussion. Land use has severe impacts on the environment. The ecosystem damage potential EDP^S is based on assessment of impacts of land use on species diversity. We clearly base EDP^S factors on α-diversity, which correlates with the local aspect of species diversity of land use types. Based on an extensive meta-analysis of biologists' field research, we were able to include data on the diversity of plant species, threatened plant species in the EDP^S. The integration of other animal species groups (e.g. insects, birds, mammals, amphibians) with their specific habitat preferences could change the characterization factors values specific for each land use type. Those mobile species groups support ecosystem functions, because they provide functional links between habitats in the landscape.

Conclusion. The use of generic characterization factors in life cycle impact assessment of land use, which we have developed, can improve the basis for decision-making in industry and other organizations. It can best be applied for marginal land use decisions. However, if the goal and scope of an LCA requires it, this generic assessment can be complemented with a site-dependent assessment.

5.2 Implementation

The implementation of the methodology is based on the factors published (Koellner & Scholz 2007b: Table 5). Only the factors based on a linear model are implemented. The factors, which are based on the ecoinvent typology have been assigned as far as possible to the ecoinvent classification for land cover types.

For sea and ocean water surface no factor is available. Artificial water bodies are assessed with the factor of “water courses”.

Factors for the transformation of tropical rain forest (primary forest) were not available, because only land use types in Middle Europe are investigated. The factor for semi-natural coniferous forests above 800m and a restoration time of 1000 years is assumed.

In order to calculate the characterisation factors for transformation it is necessary to know the restoration time of different types of land uses. These are shown in Tab. 5-1.

In order to calculate the characterisation factors for the transformation it is also necessary to define a reference state. The impact factor for the unknown reference land use type (ref) before or after the land transformation is chosen as EDP(ref)= 0.80. This represents the maximum EDP, i.e. the land use type with the most negative impact. It is necessary to use the highest EDP for this calculation in ecoinvent, because of the calculation formula that uses an absolute value of the subtraction of the actual occupation. Not using the highest EDP would result in non-linear results.

Thus, the factors for “transformation, from land use type *i*” and “transformation, to land use type *i*” are calculated according to the following equations.

For transformation from *i*: (1)

$$EDP_{trans\_from} = 0.5*(EDP(ref) – EDP(occupation, from land use type i))*restoration time$$

For transformation to *i*: (2)

$$EDP_{trans\_to} = 0.5*(EDP(occupation, from land use type i) – EDP(ref))*restoration time$$

The damage from specific transformation is finally calculated as:

$$EDP_{trans} = EDP_{trans\_from} + EDP_{trans\_to} \text{ (Frischknecht et al. 2007:5.7.3)} \quad (3)$$

The factor for “occupation, land use type *i*” can be found in Tab. 5-3. The restoration time is shown in Tab. 5-1. The results for “transformation, from land use type *i*” are shown in Tab. 5-4. The factor for “transformation, to land use type *i*” is shown in Tab. 5-5.

Tab. 5-1 Restoration time of ecosystem types, range provided by (Koellner & Scholz 2007a: Table 1) and assumptions in this study

Ecosystems (biotope types)	Restoration time (years)	This study	Categories in ecoinvent
Vegetation of arable land, pioneer vegetation	< 5	1	Arable land
Species poor meadows and tall-herb communities, mature pioneer vegetation	5 – 25	1	Meadows
Species poor immature hedgerows and shrubs, oligotroph vegetation of areas silting up, relatively species rich marshland with sedges, meadows, dry meadows and heathland	25 – 50	10	Permanent crops
Forests quite rich in species, shrubs and hedgerows	50 – 200	50	Forest
Low and medium (immature) peatbogs, old dry meadows and heathland	200 – 1'000		
High (mature) peatbogs, old growth forests	1'000 – 10'000	1000	Rainforest
Others		0.5	All artificial types of land

Tab. 5-2 shows the classification of land-cover types used by the European Environmental Agency (Bossard et al. 2000) compared with the ecoinvent classification. As far as possible the factors have been assigned to the ecoinvent flows by matching CORINE levels.

Tab. 5-2 Classification of land-cover types used by the European Environmental Agency (Bossard et al. 2000) compared with the Ecoinvent classification. Italic entries in the CORINE classification indicate types added by (Koellner 2003), in order to derive a land use typology better suited for LCIA.

CORINE				**ecoinvent elementary flow**
Level 1	**Level 2**	**Level 3**	***Level 4***	
1 Artificial Surfaces	11 Urban fabric	111 Continuous urban fabric		Occupation, urban, continuously built
		112 Discontinuous urban fabric		Occupation, urban, discontinuously built
		113 Urban fallow		–
		114 Rural settlement		–
	12 Industrial, commercial and transport	121 Industrial or commercial units	*121a Industrial area built up part*	Occupation, industrial area Occupation, industrial area, built up Occupation, industrial area, benthos
			121b Industrial area part with vegetation	Occupation, industrial area, vegetation
		122 Road and rail networks and associated land	*122a Road networks*	Occupation, traffic area, road network
			122b Road embankments and associated land	Occupation, traffic area, road embankment
			122c Rail networks	Occupation, traffic area, rail network
			122d Rail embankments and associated land	Occupation, traffic area, rail embankment
			122e Rail fallow	–
		123 Port areas		–
		124 Airports		–

CORINE				**ecoinvent elementary flow**
Level 1	**Level 2**	**Level 3**	***Level 4***	
		125 Industrial fallow		–
	13 Mine, dump and construction sites	131 Mineral extraction sites		Occupation, mineral extraction site
		132 Dump sites		Occupation, dump site
		133 Construction sites		Occupation, construction site
		134 Mining fallow		
	14 Artificial, non-agricultural areas with vegetation	141 Green urban areas		Occupation, urban, green areas
		142 Sport and leisure facilities		–
2 Agricultural Areas	21 Arable land	211 Non-irrigated arable land		Occupation, arable, non-irrigated
			211a Intensive	Occupation, arable, non-irrigated, monotone-intensive
			211b Integrated	Occupation, arable, non-irrigated, diverse-intensive
			211c Organic	Occupation, arable, non-irrigated, organic
			211d Fiber/energy crops	
			211e Agricultural fallow	Occupation, arable, non-irrigated, fallow
			211f Artificial meadow	–
		212 Permanently irrigated land		–
		213 Rice fields		–
	22 Permanent crops	221 Vineyards	*221a Intensive*	Occupation, permanent crop, vine, intensive
			221b Organic	Occupation, permanent crop, vine, extensive
		222 Fruit trees and berry plantations	*222a Intensive orchards*	Occupation, permanent crop, fruit, intensive
			222b Organic orchards	Occupation, permanent crop, fruit, extensive
		223 Olive groves		–
	23 Pastures *and meadows*	231 Pastures *and meadows*		Occupation, pasture and meadow
			231a Intensive pasture and meadows	Occupation, pasture and meadow, intensive
			231b Less intensive pasture and meadows	Occupation, pasture and meadow, extensive
			231c Organic pasture and meadows	Occupation, pasture and meadow, organic
	24 Heterogeneous	241 Annual crops		Occupation, heterogeneous, agricultural

CORINE				**ecoinvent elementary flow**
Level 1	**Level 2**	**Level 3**	***Level 4***	
	agricultural areas	associated with permanent crops		
		242 Complex cultivation		Occupation, heterogeneous, agricultural
		243 Land principally occupied by agriculture		Occupation, heterogeneous, agricultural
		244 Agro-forestry areas		Occupation, heterogeneous, agricultural
		245 Agricultural fallow with hedgerows		–
3 Forests and semi-natural areas	31 Forests			Occupation, forest
		311 Broad-leafed forest	*311a Broad leafed plantations*	Occupation, forest, intensive
			311b Semi-natural broad-leafed forests	Occupation, forest, extensive
		312 Coniferous forest	*312a Coniferous plantations*	Occupation, forest, intensive
			312b Semi-natural coniferous forests	Occupation, forest, extensive
		313 Mixed forest	*313a Mixed broad-leafed forest*	Occupation, forest, extensive
			313b Mixed coniferous forest	Occupation, forest, extensive
			313c Mixed plantation	Occupation, forest, intensive
		314 Forest Edge		–
	32 Shrub and/or herbaceous vegetation associations	321 *Semi*-Natural grassland		Occupation, shrub land, sclerophyllous
		322 Moors and heath land		Occupation, shrub land, sclerophyllous
		323 Sclerophyllous vegetation		Occupation, shrub land, sclerophyllous
		324 Transitional woodland/shrub		Occupation, shrub land, sclerophyllous
		325 Hedgerows		–
	33 Open spaces with little or no vegetation	331 Beaches, dunes, and sand plains		–
		332 Bare rock		–
		333 Sparsely vegetated areas		–
		334 Burnt areas		–
		335 Glaciers and perpetual snow		–
4 Wetlands	41 Inland wetlands	411 Inland marshes		–
		412 Peat bogs		–
	42 Coastal wetlands	421 Salt marshes		–
		422 Salines		–

CORINE				**ecoinvent elementary flow**
Level 1	**Level 2**	**Level 3**	***Level 4***	
		423 Intertidal flats		–
5 Waters	51 Inland waters	511 Water courses		Occupation, water courses, artificial
		512 Water bodies	*512a Artificial lakes*	Occupation, water bodies, artificial
			512b Natural lakes	–
	52 Marine waters	521 Coastal lagoons		–
		522 Estuaries		–
		523 Sea and ocean		Occupation, sea and ocean

The factors presented in this paper are used for implementation in ecoinvent data. Tab. 5-3, Tab. 5-4 and Tab. 5-5 shows the factors for the main categories.

Tab. 5-3 Impact factors of the ecosystem damage potential (EDP) implemented in ecoinvent for the main categories, occupation. The EDP factors given are valid for Central Europe (besides the factor for tropical rainforest).

Name SubCategory Name Location Unit	Category	SubCategory	Unit	ecosystem damage potential total linear, land occupation RER points	ecosystem damage potential total linear, land transformation RER points	ecosystem damage potential total linear, land use, total RER points
Occupation, arable	resource	land	m2a	0.61	0	0.61
Occupation, arable, non-irrigated	resource	land	m2a	0.61	0	0.61
Occupation, arable, non-irrigated, diverse-intensive	resource	land	m2a	0.61	0	0.61
Occupation, arable, non-irrigated, fallow	resource	land	m2a	-0.11	0	--0.11
Occupation, arable, non-irrigated, monotone-intensive	resource	land	m2a	0.74	0	0.74
Occupation, construction site	resource	land	m2a	0.70	0	0.70
Occupation, dump site	resource	land	m2a	0.70	0	0.70
Occupation, dump site, benthos	resource	land	m2a	0.70	0	0.70
Occupation, forest	resource	land	m2a	0.49	0	0.49
Occupation, forest, extensive	resource	land	m2a	0.29	0	0.29
Occupation, forest, intensive	resource	land	m2a	0.63	0	0.63
Occupation, forest, intensive, clear-cutting	resource	land	m2a	0.73	0	0.73
Occupation, forest, intensive, normal	resource	land	m2a	0.73	0	0.73
Occupation, forest, intensive, short-cycle	resource	land	m2a	0.73	0	0.73
Occupation, heterogeneous, agricultural	resource	land	m2a	0.61	0	0.61
Occupation, industrial area	resource	land	m2a	0.80	0	0.80
Occupation, industrial area, benthos	resource	land	m2a	0.80	0	0.80
Occupation, industrial area, built up	resource	land	m2a	0.80	0	0.80
Occupation, industrial area, vegetation	resource	land	m2a	0.39	0	0.39
Occupation, mineral extraction site	resource	land	m2a	0.70	0	0.70
Occupation, pasture and meadow	resource	land	m2a	0.52	0	0.52
Occupation, pasture and meadow, extensive	resource	land	m2a	0.52	0	0.52
Occupation, pasture and meadow, intensive	resource	land	m2a	0.52	0	0.52
Occupation, permanent crop	resource	land	m2a	0.57	0	0.57
Occupation, permanent crop, fruit	resource	land	m2a	0.57	0	0.57
Occupation, permanent crop, fruit, extensive	resource	land	m2a	0.42	0	0.42
Occupation, permanent crop, fruit, intensive	resource	land	m2a	0.57	0	0.57
Occupation, permanent crop, vine	resource	land	m2a	0.57	0	0.57
Occupation, permanent crop, vine, extensive	resource	land	m2a	0.42	0	0.42
Occupation, permanent crop, vine, intensive	resource	land	m2a	0.57	0	0.57
Occupation, sea and ocean	resource	land	m2a	0.00	0	0
Occupation, shrub land, sclerophyllous	resource	land	m2a	-0.26	0	--0.26
Occupation, traffic area, rail embankment	resource	land	m2a	0.10	0	0.10
Occupation, traffic area, rail network	resource	land	m2a	0.59	0	0.59
Occupation, traffic area, road embankment	resource	land	m2a	0.59	0	0.59
Occupation, traffic area, road network	resource	land	m2a	0.59	0	0.59
Occupation, unknown	resource	land	m2a	0.63	0	0.63
Occupation, urban, continuously built	resource	land	m2a	0.70	0	0.70
Occupation, urban, discontinuously built	resource	land	m2a	0.30	0	0.30
Occupation, water bodies, artificial	resource	land	m2a	0.61	0	0.61
Occupation, water courses, artificial	resource	land	m2a	0.61	0	0.61
Occupation, tropical rain forest	resource	land	m2a	-0.76	0	--0.76

Tab. 5-4 Impact factors of the ecosystem damage potential EDP implemented in ecoinvent for the main categories, "transformation, from …". The EDP factors given are valid for Central Europe (besides the factor for tropical rainforest). Please note the EDP for the final damage is calculated according to formula (3)

Name SubCategory Name Location Unit	Category	SubCategory	Unit	ecosystem damage potential total linear, land occupation RER points	ecosystem damage potential total linear, land transformation RER points	ecosystem damage potential total linear, land use, total RER points
Transformation, from arable	resource	land	m2	0	0.10	0.10
Transformation, from arable, non-irrigated	resource	land	m2	0	0.10	0.10
Transformation, from arable, non-irrigated, diverse-intensive	resource	land	m2	0	0.10	0.10
Transformation, from arable, non-irrigated, fallow	resource	land	m2	0	0.46	0.46
Transformation, from arable, non-irrigated, monotone-intensive	resource	land	m2	0	0.03	0.03
Transformation, from dump site	resource	land	m2	0	0.03	0.03
Transformation, from dump site, benthos	resource	land	m2	0	0.03	0.03
Transformation, from forest	resource	land	m2	0	7.75	7.75
Transformation, from forest, extensive	resource	land	m2	0	12.75	12.75
Transformation, from forest, intensive	resource	land	m2	0	4.25	4.25
Transformation, from forest, intensive, clear-cutting	resource	land	m2	0	1.75	1.75
Transformation, from forest, intensive, normal	resource	land	m2	0	1.75	1.75
Transformation, from forest, intensive, short-cycle	resource	land	m2	0	1.75	1.75
Transformation, from heterogeneous, agricultural	resource	land	m2	0	0.10	0.10
Transformation, from industrial area	resource	land	m2	0	0	0
Transformation, from industrial area, benthos	resource	land	m2	0	0	0
Transformation, from industrial area, built up	resource	land	m2	0	0	0
Transformation, from industrial area, vegetation	resource	land	m2	0	0.10	0.10
Transformation, from mineral extraction site	resource	land	m2	0	0.03	0.03
Transformation, from pasture and meadow	resource	land	m2	0	0.14	0.14
Transformation, from pasture and meadow, extensive	resource	land	m2	0	0.14	0.14
Transformation, from pasture and meadow, intensive	resource	land	m2	0	0.14	0.14
Transformation, from permanent crop	resource	land	m2	0	1.15	1.15
Transformation, from permanent crop, fruit	resource	land	m2	0	1.15	1.15
Transformation, from permanent crop, fruit, extensive	resource	land	m2	0	1.90	1.90
Transformation, from permanent crop, fruit, intensive	resource	land	m2	0	1.15	1.15
Transformation, from permanent crop, vine	resource	land	m2	0	1.15	1.15
Transformation, from permanent crop, vine, extensive	resource	land	m2	0	1.90	1.90
Transformation, from permanent crop, vine, intensive	resource	land	m2	0	1.15	1.15
Transformation, from sea and ocean	resource	land	m2	0	0.20	0.20
Transformation, from shrub land, sclerophyllous	resource	land	m2	0	5.30	5.30
Transformation, from traffic area, rail embankment	resource	land	m2	0	0.18	0.18
Transformation, from traffic area, rail network	resource	land	m2	0	0.05	0.05
Transformation, from traffic area, road embankment	resource	land	m2	0	0.05	0.05
Transformation, from traffic area, road network	resource	land	m2	0	0.05	0.05
Transformation, from unknown	resource	land	m2	0	0.04	0.04
Transformation, from urban, continuously built	resource	land	m2	0	0.03	0.03
Transformation, from urban, discontinuously built	resource	land	m2	0	0.13	0.13
Transformation, from water bodies, artificial	resource	land	m2	0	0.05	0.05
Transformation, from water courses, artificial	resource	land	m2	0	0.05	0.05
Transformation, from dump site, inert material landfill	resource	land	m2	0	0.03	0.03
Transformation, from dump site, residual material landfill	resource	land	m2	0	0.03	0.03
Transformation, from dump site, sanitary landfill	resource	land	m2	0	0.03	0.03
Transformation, from dump site, slag compartment	resource	land	m2	0	0.03	0.03
Transformation, from tropical rain forest	resource	land	m2	0	780.00	780.00

Tab. 5-5 Impact factors of the ecosystem damage potential implemented in ecoinvent for the main categories, "transformation, to …". The EDP factors given are valid for Central Europe (besides the factor for tropical rainforest). Please note the EDP for the final damage is calculated according to formula (3)

Name SubCategory Name Location Unit	Category	SubCategory	Unit	ecosystem damage potential total linear, land occupation RER points	ecosystem damage potential total linear, land transformation RER points	ecosystem damage potential total linear, land use, total RER points
Transformation, to arable	resource	land	m2	0	--0.10	--0.10
Transformation, to arable, non-irrigated	resource	land	m2	0	--0.10	--0.10
Transformation, to arable, non-irrigated, diverse-intensive	resource	land	m2	0	--0.10	--0.10
Transformation, to arable, non-irrigated, fallow	resource	land	m2	0	--0.46	--0.46
Transformation, to arable, non-irrigated, monotone-intensive	resource	land	m2	0	--0.03	--0.03
Transformation, to dump site	resource	land	m2	0	--0.03	--0.03
Transformation, to dump site, benthos	resource	land	m2	0	--0.03	--0.03
Transformation, to forest	resource	land	m2	0	--7.75	--7.75
Transformation, to forest, extensive	resource	land	m2	0	--12.75	--12.75
Transformation, to forest, intensive	resource	land	m2	0	--4.25	--4.25
Transformation, to forest, intensive, clear-cutting	resource	land	m2	0	--1.75	--1.75
Transformation, to forest, intensive, normal	resource	land	m2	0	--1.75	--1.75
Transformation, to forest, intensive, short-cycle	resource	land	m2	0	--1.75	--1.75
Transformation, to heterogeneous, agricultural	resource	land	m2	0	--0.10	--0.10
Transformation, to industrial area	resource	land	m2	0	0	0
Transformation, to industrial area, benthos	resource	land	m2	0	0	0
Transformation, to industrial area, built up	resource	land	m2	0	0	0
Transformation, to industrial area, vegetation	resource	land	m2	0	--0.10	--0.10
Transformation, to mineral extraction site	resource	land	m2	0	--0.03	--0.03
Transformation, to pasture and meadow	resource	land	m2	0	--0.14	--0.14
Transformation, to pasture and meadow, extensive	resource	land	m2	0	--0.14	--0.14
Transformation, to pasture and meadow, intensive	resource	land	m2	0	--0.14	--0.14
Transformation, to permanent crop	resource	land	m2	0	--1.15	--1.15
Transformation, to permanent crop, fruit	resource	land	m2	0	--1.15	--1.15
Transformation, to permanent crop, fruit, extensive	resource	land	m2	0	--1.90	--1.90
Transformation, to permanent crop, fruit, intensive	resource	land	m2	0	--1.15	--1.15
Transformation, to permanent crop, vine	resource	land	m2	0	--1.15	--1.15
Transformation, to permanent crop, vine, extensive	resource	land	m2	0	--1.90	--1.90
Transformation, to permanent crop, vine, intensive	resource	land	m2	0	--1.15	--1.15
Transformation, to sea and ocean	resource	land	m2	0	--0.20	--0.20
Transformation, to shrub land, sclerophyllous	resource	land	m2	0	--5.30	--5.30
Transformation, to traffic area, rail embankment	resource	land	m2	0	--0.18	--0.18
Transformation, to traffic area, rail network	resource	land	m2	0	--0.05	--0.05
Transformation, to traffic area, road embankment	resource	land	m2	0	--0.05	--0.05
Transformation, to traffic area, road network	resource	land	m2	0	--0.05	--0.05
Transformation, to unknown	resource	land	m2	0	--0.04	--0.04
Transformation, to urban, continuously built	resource	land	m2	0	--0.03	--0.03
Transformation, to urban, discontinuously built	resource	land	m2	0	--0.13	--0.13
Transformation, to water bodies, artificial	resource	land	m2	0	--0.05	--0.05
Transformation, to water courses, artificial	resource	land	m2	0	--0.05	--0.05
Transformation, to dump site, inert material landfill	resource	land	m2	0	--0.03	--0.03
Transformation, to dump site, residual material landfill	resource	land	m2	0	--0.03	--0.03
Transformation, to dump site, sanitary landfill	resource	land	m2	0	--0.03	--0.03
Transformation, to dump site, slag compartment	resource	land	m2	0	--0.03	--0.03
Transformation, to tropical rain forest	resource	land	m2	0	--780.00	--780.00

Tab. 5-6 EcoSpold meta information of the ecological footprint implemented in ecoinvent

ReferenceFunction	Category	ecosystem damage potential
	SubCategory	total
	Name	linear, land occupation
Geography	Location	RER
ReferenceFunction	Unit	points
	LocalName	Linear, Landnutzung
	Synonyms	EDP//EDPS
	GeneralComment	The ecosystem damage potential EDPS is based on an assessment of impacts of land use on species diversity. The diversity correlates with the local aspect of species diversity of land use types. Based on an extensive meta-analysis of biologists' field research, data on the diversity of plant species, threatened plant species, moss and molluscs are included in the EDPS. The integration of other animal species groups (e.g. insects, birds, mammals, amphibians) with their specific habitat preferences could change the characterization factors. We recommend utilizing the developed characterization factors for land use in Central Europe. In order to assess the impacts of land use in other regions it would be necessary to sample empirical data on species diversity and to develop region specific characterization factors on a worldwide basis, because species diversity and the impact of land use on it can very much differ from region to region.
	LocalCategory	Ökosystem Schadenspotential
	LocalSubCategory	Total
TimePeriod	StartDate	2006
	EndDate	2007
	OtherPeriodText	Time of publication
Geography	Text	Methodology valid for Central Europe
DataGeneratorAndPu	Person	74
	DataPublishedIn	2
	ReferenceToPublishedSo	3
	Copyright	1
	AccessRestrictedTo	0
	CompanyCode	
	CountryCode	
	PageNumbers	ecosystem damage potential

5.3 Quality considerations

The implementation of this method is rather straightforward. Thus, the uncertainty of the implementation is quite low.

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6 Ecological Footprint

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6.1 Introduction

The ecological footprint is defined as the biologically productive land and water a population requires to produce the resources it consumes and to absorb part of the waste generated by fossil and nuclear fuel consumption (Huijbregts et al. 2006; Wackernagel et al. 1996). In the context of LCA, the ecological footprint of a product is defined as the sum of time integrated direct land occupation and indirect land occupation, related to nuclear energy use and to CO_2 emissions from fossil energy use, clinker production (e.g. CO_2 emitted when burning the limestone for cement production):

$$EF = EF_{direct} + EF_{CO2} + EF_{nuclear} \qquad (1)$$

6.2 Implementation

The implementation of the methodology is described by Huijbregts *et al.* (2006). The factors presented in this paper are used for implementation in ecoinvent data. Tab. 5-3 shows the factors for the main categories. The factor for CO_2 is applied for fossil CO_2 emissions and emissions from land transformation. The factor for uranium is based on an assumed energy content of 560'000 MJ per kg of uranium. Factors for land occupation are applied to all similar categories of land occupation (e.g. factors for "forest" are applied to all categories "forest, ..."). The categories "..., benthos" are approximated with "fisheries" and hence with a factor of 0.36 m^2a. The category "Occupation, unknown" is assigned a factor of 1 m^2a, which represents the average of all the bio productive area on Earth (Huijbregts et al. 2006; Wackernagel et al. 1996).

Tab. 6-1 Impact factors of the ecological footprint implemented in ecoinvent data v2.0 for the main categories

Name SubCategory Name Location Unit	Category	SubCategory	Unit	ecological footprint total CO2 GLO m2a	ecological footprint total nuclear GLO m2a	ecological footprint total land occupation GLO m2a	ecological footprint total total GLO m2a
Carbon dioxide, fossil	air	unspecified	kg	2.67E+0	0	0	2.67
Uranium, in ground	resource	in ground	kg	0	109'738	0	109'738
Occupation, arable	resource	land	m2a	0	0	2.19	2.19
Occupation, construction site	resource	land	m2a	0	0	2.19	2.19
Occupation, dump site	resource	land	m2a	0	0	2.19	2.19
Occupation, forest	resource	land	m2a	0	0	1.38	1.38
Occupation, industrial area	resource	land	m2a	0	0	2.19	2.19
Occupation, industrial area, benthos	resource	land	m2a	0	0	0.36	0.36
Occupation, pasture and meadow	resource	land	m2a	0	0	0.48	0.48
Occupation, permanent crop	resource	land	m2a	0	0	2.19	2.19
Occupation, sea and ocean	resource	land	m2a	0	0	0.36	0.36
Occupation, unknown	resource	land	m2a	0	0	1.00	1.00

Tab. 6-2 EcoSpold meta information of the ecological footprint implemented in ecoinvent data v2.0

Category	ecological footprint	ecological footprint	ecological footprint	ecological footprint
SubCategory	total	total	total	total
Name	CO2	nuclear	land occupation	total
Location	GLO	GLO	GLO	GLO
Unit	m2a	m2a	m2a	m2a
LocalName	CO2	Nuklear	Landnutzung	Total
Synonyms	EF	EF	EF	EF
GeneralComment	The ecological footprint is defined as the biologically productive land and water a population requires to produce the resources it consumes and to absorb part of the waste generated by fossil and nuclear fuel consumption. In the context of LCA, the ecological footprint of a product is defined as the sum of time integrated direct land occupation and indirect land occupation, related to nuclear energy use and to CO2 emissions from fossil energy use and cement burning.	The ecological footprint is defined as the biologically productive land and water a population requires to produce the resources it consumes and to absorb part of the waste generated by fossil and nuclear fuel consumption. In the context of LCA, the ecological footprint of a product is defined as the sum of time integrated direct land occupation and indirect land occupation, related to nuclear energy use and to CO2 emissions from fossil energy use and cement burning.	The ecological footprint is defined as the biologically productive land and water a population requires to produce the resources it consumes and to absorb part of the waste generated by fossil and nuclear fuel consumption. In the context of LCA, the ecological footprint of a product is defined as the sum of time integrated direct land occupation and indirect land occupation, related to nuclear energy use and to CO2 emissions from fossil energy use and cement burning.	The ecological footprint is defined as the biologically productive land and water a population requires to produce the resources it consumes and to absorb part of the waste generated by fossil and nuclear fuel consumption. In the context of LCA, the ecological footprint of a product is defined as the sum of time integrated direct land occupation and indirect land occupation, related to nuclear energy use and to CO2 emissions from fossil energy use and cement burning.
LocalCategory	ökologischer Fussabdruck	ökologischer Fussabdruck	ökologischer Fussabdruck	ökologischer Fussabdruck
LocalSubCategory	Total	Total	Total	Total
StartDate	1996	1996	1996	1996
EndDate	2006	2006	2006	2006
DataValidForEntirePeriod	1	1	1	1
OtherPeriodText	Time of first publication and	Time of publication.	Time of publication.	Time of publication.
Text	Global impact category.	Global impact category.	Global impact category.	Global impact category.

6.3 Quality considerations

The implementation of this method is rather straightforward. Thus, the uncertainty of the implementation is quite low.

References

Huijbregts et al. 2006 — Huijbregts M. A. J., Hellweg S., Frischknecht R., Hungerbühler K. and Hendriks A. J. (2006) Ecological Footprint Accounting in the Life Cycle Assessment of Products. *In: accepted for publication in Ecological Economics*, pp.

Wackernagel et al. 1996 — Wackernagel M., Rees W. and Testemale P. I. (1996) Our Ecological Footprint - Reducing Human Impact on the Earth. New Society Publishers, Philadelphia, PA, and Gabriola Island, BC, Canada.

7 The method of Ecological scarcity (Umweltbelastungspunkte, UBP'97)

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7.1 Introduction

The method of ecological scarcity – also called eco-scarcity or eco-points method (from the German name of the unit used – "Umweltbelastungspunkte") allows according to Brand et al. (1998) "a comparative weighting and aggregation of various environmental interventions by use of so-called eco-factors". Brand et al. (1998) is the second report that actually updates and complements the first publication of this method, published in 1990 (Ahbe et al. (1990)).

The method contains characterisation factors for different emissions to air, water and top-soil/groundwater as well as for the use of energy resources and some types of waste. All these factors are calculated from the present pollution level (current flows) and on the pollution considered as critical (critical flows). The latter ones are thereby deduced from the scientifically supported goals of the Swiss environmental policy.

The method integrated into the database ecoinvent is the mentioned update from 1997. It is described in detail in Brand et al. (1998). In the following chapters only those substances are mentioned that are not explicitly listed in Brand et al. (1998) but nevertheless have a characterisation factor in the actual integration of this method into the database ecoinvent. As a further source the reported impact assessment of packaging data (Stahel et al. (1998)) is used. All weighting factors mentioned in Brand et al. (1998) are summarized in Tab. 7-7 to Tab. 7-11in the appendix at the end of this chapter.

7.2 Project specific aspects of the integration of the method

7.2.1 Emissions to air

Biogenic carbon containing emissions

In Tab. 7-1, only weighting factors for the fossil form of CO_2 and CH_4 are listed. From the author point of view, there are two possibilities for the weighting factor of the biogenic forms:

- No weighting factor for the biogenic part, as it is taken in form of CO_2 from the nature as a resource and therefore doesn't influence the overall balance;
- A similar weighting factor like for the fossil part and a similar, but negative weighting factor for the part that is taken up as resource by plants.

In accordance with the other methods in ecoinvent, the first of these two possibilities – i.e. no weighting factors for the biogenic part – is chosen. For the respective CO_2 emissions from deforestation in tropical areas (i.e. factor CO_2, from land transformation) the factor of fossil CO_2 is applied.

Carbon monoxide emissions

The original method does not contain any factor for carbon monoxide. According to the general methodology for the implementation of impact assessment methods (see Chapter 2.1 of part I of this report) "a GWP factor is calculated for CO (1.57 kg CO_2-eq per kg CO)". Main reason therefore is, that the C balance is taken into account within the database and thus without a CO factor processes with higher CO emissions would benefit from this gap.

The method of ecological scarcity is based on the principle that when a substance has more than one effect, the highest eco factor is used. Carbon monoxide has not only a GWP factor, but has also direct toxic effects for humans. In the extension of the ecological scarcity method to so-called mobility eco-points'97 (MUBP'97) reported in Doka (2003), this second CO factor is calculated as 1012 eco-points per kg CO – a value that is almost three times higher than the GWP factor of CO. This latter value is used in the ecoinvent implementation.

Non-Methane Volatile Organic Compounds (NMVOC)

According to Tab. 7-7 in the appendix, this method has a weighting factor for NMVOC substances. Following the rule for case 6 in Tab. 2-2 of part I of this report, this factor is assigned to all NMVOC-emissions listed in Tab. 7-1. These entries are based on the NMVOC category of the hierarchical elementary flow list in de Beaufort et al. (2003).

Tab. 7-1 Emissions to air of the database ecoinvent that are weighted with the NMVOC weighting factor from Brand et al. (1998)

Emission to air	Emission to air	Emission to air
1,4-Butanediol	Cyclohexane	Isocyanic acid
2-Methyl-1-propanol	Diethylene glycol	Isoprene
2-Methyl-2-butene	Diethyl ether	Methanol
2-Methyl pentane	Dimethylamine	Methyl acrylate
2-Propanol	Dioxins, measured as 2,3,7,8-tetrachloro-dibenzo-p-dioxin	Methyl amine
3-Methyl-1-butanol		Methyl borate
4-Methyl-2-pentanone	Epichlorohydrin	Methyl ethyl ketone
Acenaphthene	Ethane	Methyl formate
Acetaldehyde	Ethane thiol	Monochloroethane
Acetic acid	Ethane, 1,1,2-trichloro-	Monoethanolamine
Acetic acid, trifluoro-	Ethane, 1,2-dichloro-	m-Xylene
Acetone	Ethanol	Nitrobenzene
Acetonitrile	Ethene	N-Bromoacetamide
Acrolein	Ethene, chloro-	o-Xylene
Acrylic acid	Ethene, tetrachloro-	PAH, polycyclic aromatic hydrocarbons
Aldehydes, unspecified	Ethene, trichloro-	Paraffins
Benzal chloride	Ethyl acetate	Pentane
Benzaldehyde	Ethyl cellulose	Phenol
Benzene	Ethylene diamine	Phenol, pentachloro-
Benzene, ethyl-	Ethylene glycol monoethyl ether	Polychlorinated biphenyls
Benzene, hexachloro-	Ethylene oxide	Propanal
Benzene, pentachloro-	Ethyne	Propane
Benzo(a)pyrene	Formaldehyde	Propanol
Butadiene	Formic acid	Propene
Butane	Furan	Propionic acid
Butanol	Heptane	Propylene oxide
Butene	Hexane	Styrene
Butyrolactone	Hydrocarbons, aliphatic, alkanes, cyclic	t-Butyl methyl ether
Carbon disulfide	Hydrocarbons, aliphatic, alkanes, unspecified	Terpenes
Chloroform	Hydrocarbons, aliphatic, unsaturated	Toluene
Cumene	Hydrocarbons, aromatic	Xylene

Halogenated hydrocarbons

Within Brand et al. (1998) weighting factors for a variety of halogenated hydrocarbons are calculated, based on their global warming potential (GWP) or their ozone depletion potential (ODP). The weighting factors are then calculated with the following formulas:

$$\text{Weighting Factor}_{\text{halogenated hydrocarbon}} = \frac{\text{GWP}_{\text{halogenated hydrocarbon}}}{\text{GWP}_{\text{carbon dioxide}}} * \text{Weighting Factor}_{\text{carbon dioxide}} \qquad [3.1]$$

$$\text{Weighting Factor}_{\text{halogenated hydrocarbon}} = \frac{\text{ODP}_{\text{halogenated hydrocarbon}}}{\text{ODP}_{\text{R11}}} * \text{Weighting Factor}_{\text{R11}} \qquad [3.2]$$

In case of substances that have GWP and ODP values, the higher of the calculated weighting factors is used. For most halogenated hydrocarbons these calculations have been already made and thus their respective weighting factors are reported in Tab. 7-7 in the appendix of this chapter. For those substances these reported weighting factors are used in the ecoinvent database.

In case of a few substances, no factors are given in Brand et al. (1998) and thus, these calculations are done within the ecoinvent framework. The respective values for these substances are taken from IPCC (1996) in case of GWP respective from Albritton et al. (1995) in case of ODP. These values together with the resulting weighting factors are summarized in Tab. 7-2.

Tab. 7-2 Calculation base and calculated weighting factors (as UBP/g) for halogenated hydrocarbons

	GWP [kg CO_2-Eq]	Weighting factor	ODP [kg R11-Eq]	Weighting factor	used weighting factor
Methane, monochloro- (R-40)	8	1.6	0.02	40	**40**
Methane, chlorofluoro- (HCFC-31)	-	-	0.01	20	**20**
Methane, dichloro- (HCC-30)	9	1.8	-	-	**1.8**
Methane, dichlorofluoro- (HCFC-21)	-	-	0.01	20	**20**

Unspecified halogenated hydrocarbons

For the unspecific emission "halogenated hydrocarbons, chlorinated" the weighting factor of R11 is used in ecoinvent data v2.0.

Nitrogen and sulphur compounds

According to Tab. 7-7, the eco-scarcity method contains a weighting factor for NO_x. Therefore, this factor is not only used for "NO_x as NO_2", but also in case of emissions of nitrate (NO_3^-) to air in the database ecoinvent.

Concerning sulphur compounds, the method contains only a weighting factor for SO_2. Therefore, this factor is only used for "sulphur dioxide" and for no other sulphur compounds.

Particulates

In Brand et al. (1998) only a weighing factor for PM10 is mentioned. PM10 is therefore synonym for particulates with a diameter of 10 um and less. As this type of emissions is represented in the present database ecoinvent by two emission factors – "particulates, <2.5 um" and "particulates, >2.5 um and, <10 um" – both of them are integrated with the weighting factor reported in Brand et al. (1998).

7.2.2 Emissions to water

Within the emissions to water, the database ecoinvent distinguishes between 8 different compartments (ground, ground long-term, lake, ocean, river, river long-term, fossil & unspecified). For the assignment of the weighting factors in Brand et al. (1998) to the emissions reported in the database ecoinvent, the following rules have been applied:

- The weighting factors "emissions to surface water" of Brand et al. (1998) are applied to the respective emissions to the following compartments: unspecified, lake, river, river long-term (only in case of persistent substances), ground (only in case of persistent substances) and ground long-term (only in case of persistent substances)
- The weighing factor "emissions to groundwater" for nitrate in Brand et al. (1998) is applied to the nitrate emission to the following compartment: ground

Thus, the only compartment not taken into account within the method of ecological scarcity is the compartment "fossil".

Halo-organic substances

This means all substances that contain Cl, F, Br or I that is connected to a hydrocarbon structure. Therefore, only a weighing factor for AOX can be found in Brand et al. (1998). Based on this factor, the weighting factors of the different halo-organic substances are calculated, based on their molar content of halogens. The amount of F, Br and I is converted into Cl, according to their respective molar masses – e.g. 1 F atom equals 0.536 Cl atom. In Tab. 7-3, the different halo-organic substances with their respective weighing factors are summarized.

Tab. 7-3 Halo-organic substances and their respective weighting factors used for the integration of the eco-scarcity method into the database ecoinvent

Emission to Water	Factor	Emission to Water	Factor
Benzene, chloro-	1	Ethene, chloro-	1
Chlorinated solvents, unspecified	1	Ethene, tetrachloro-	4
Chloroform	3	Ethene, trichloro-	3
Ethane, 1,1,1-trichloro-, HCFC-140	3	Methane, dichloro-, HCC-30	2
Ethane, 1,2-dichloro-	2	Methane, dichlorofluoro-, HCFC-21	2.536
Ethane, hexachloro-	6	Methane, tetrachloro-, CFC-10	4

Chromium compounds

Within the database ecoinvent, three different forms of chromium emissions to water are reported – chromium-III-ions, chromium-VI-ions as well as dichromate-ions. Brand et al. (1998) contains only a weighting factor for chromium-III-ions. Thus, for the ecoinvent implementation chromium-VI-ions are treated similar to these chromium-III-ions. The third form – dichromate-ions – is converted into chromium by using the molar masses of oxygen and chromium.

Nitrogen compounds

According to Tab. 7-8 and Tab. 7-9, several different weighing factors for nitrogen compounds are available. For the integration into the database ecoinvent the following assumptions have been used:

- *Nitrate (NO_3^-):* Assuming that this is not a persistent substance, no factors for the long-term emissions are integrated
- *Nitrite (NO_2^-):* No weighting factor has been attributed to this specific nitrogen compound in accordance with the general method for the integration of the different impact assessment methods (see table 2.2 in part I of this report).
- *Nitrogen:* Assuming that this is a persistent form, the same weighting factor is used for the emissions to the different compartments (exception: fossil, which is not included).
- *Nitrogen, organic bound:* The weighting factor for nitrogen is used, but it is assumed that this is not a persistent form and therefore no factors are attributed to the long-term emissions.

Phosphorus compounds

According to Tab. 7-8 only a weighing factor for elementary phosphorus is available. According to Brand et al. (1998), this factor is based on the critical flow of elementary P to lakes. Main sources therefore are agriculture and waste water treatment plants. Experience shows that in those two areas, most of the time the emissions of P to water are expressed as phosphate (PO_4^-) – thus the weighting factor for elementary phosphorus is also used for phosphate to water. Based on the mol weights of P and PO_4^-, the resulting weighting factor for phosphate is 653 UBP/g PO_4^-.

7.2.3 Emissions to soil

Pesticides

According to Tab. 7-9 in the appendix, this method has just one weighting factor for pesticides that are emitted. Following the rule for case 6 in Tab. 2-2 of part I of this report, this factor is assigned to all pesticides listed in Tab. 7-4.

Tab. 7-4 Emissions to top-soil/groundwater of the database ecoinvent that are weighted with the pesticide weighting factor from Brand et al. (1998)

Emission to soil	Emission to soil	Emission to soil
2,4-D	Ethephon	Napropamide
Abamectin	Ethofumesate	Nicosulfuron
Acephate	Ethoprop	Norflurazon
Acetamide	Etridiazole	Orbencarb
Acetochlor	Fenbuconazole	Oxadixyl
Aclonifen	Fenoxaprop	Oxamyl
Alachlor	Fenoxaprop ethyl ester	Oxydemeton-methyl
Aldicarb	Fenoxaprop-P ethyl ester	Oxyfluorfen
Aldrin	Fenpiclonil	Paraquat
Ametryn	Fenpropathrin	Parathion
Amidosulfuron	Fenpropidin	Pendimethalin
Anthraquinone	Fenpropimorph	Permethrin
Asulam	Fentin acetate	Phenmedipham
Atrazine	Fentin hydroxide	Phorate
Azinphos-methyl	Fipronil	Phosmet
Azoxystrobin	Florasulam	Picloram
Benazolin	Fluazifop-P-butyl	Picoxystrobin
Benomyl	Fluazinam	Piperonyl butoxide
Bensulfuron methyl ester	Flucarbazone sodium salt	Pirimicarb
Bentazone	Fludioxonil	Primisulfuron
Bifenox	Flufenacet	Prochloraz
Bifenthrin	Flumetsulam	Procymidone
Bitertanol	Flumioxazin	Profenofos
Bromoxynil	Fluometuron	Prohexadione-calcium
Bromuconazole	Fluorochloridone	Prometryn
Buprofezin	Fluoroglycofen-ethyl	Pronamide
Captan	Flupyrsulfuron-methyl	Propamocarb HCl
Carbaryl	Fluquinconazole	Propanil
Carbendazim	Fluroxypyr	Propaquizafop
Carbetamide	Flurtamone	Propargite
Carbofuran	Flusilazole	Propiconazole
Carboxin	Flutolanil	Propoxycarbazone-sodium
Carfentrazone ethyl ester	Fomesafen	Prosulfocarb
Chloridazon	Foramsulfuron	Prosulfuron
Chlorimuron-ethyl	Fuberidazole	Prothioconazol
Chlormequat	Glufosinate	Pymetrozine
Chlormequat Chloride	Glyphosate	Pyraclostrobin (prop)
Chlorothalonil	Halosulfuron-methyl	Pyridate
Chlorotoluron	Hexaconazole	Pyriproxyfen
Chlorpyrifos	Imazalil	Pyrithiobac sodium salt
Chlorsulfuron	Imazamox	Quinclorac
Choline chloride	Imazapyr	Quinmerac
Cinidon-Ethyl	Imazethapyr	Quinoxyfen
Clethodim	Imidacloprid	Quintozene
Clodinafop-propargyl	Indoxacarb	Quizalofop ethyl ester
Clomazone	Iodosulfuron	Quizalofop-P
Clopyralid	Iodosulfuron-methyl-sodium	Rimsulfuron
Cloquintocet-mexyl	Ioxynil	Sethoxydim
Cloransulam-methyl	Iprodion	Silthiofam

Tab. 7-4 (Cont.) Emissions to top-soil/groundwater of the database ecoinvent that are weighted with the pesticide weighting factor from Brand et al. (1998)

Emission to soil	Emission to soil	Emission to soil
Cyanazine	Isoproturon	Simazine
Cyclanilide	Isoxaflutole	Spinosad
Cycloxydim	Kresoxim-methyl	Spiroxamine
Cyfluthrin	Lactofen	Starane
Cymoxanil	Lamda-Cyhalothrin	Sulfentrazone
Cypermethrin	Lindane	Sulfosate
Cyproconazole	Linuron	Sulfosulfuron
Cyprodinil	Malathion	tau-Fluvalinate
Deltamethrin	Maleic hydrazide	TCMTB
Desmedipham	Mancozeb	Tebuconazole
Diazinon	Maneb	Tebufenozide
Dicamba	MCPA	Tebupirimphos
Dichlobenil	MCPB	Tebutam
Dichlorprop-P	Mecoprop	Teflubenzuron
Diclofop	Mecoprop-P	Tefluthrin
Diclofop-methyl	Mefenpyr	Terbufos
Dicofol	Mefenpyr-diethyl	Terbuthylazin
Dicrotophos	Mepiquat chloride	Thiamethoxam
Difenoconazole	Mesosulforon-methyl (prop)	Thidiazuron
Diflubenzuron	Mesotrione	Thifensulfuron-methyl
Diflufenican	Metalaxil	Thiobencarb
Diflufenzopyr-sodium	Metalaxyl-M	Thiophanat-methyl
Dimefuron	Metaldehyde	Thiram
Dimethachlor	Metamitron	Tralkoxydim
Dimethenamid	Metam-sodium	Tralomethrin
Dimethipin	Metazachlor	Triadimenol
Dimethoate	Metconazole	Tri-allate
Dimethomorph	Methabenzthiazuron	Triasulfuron
Dinoseb	Methamidophos	Tribenuron
Diquat	Methiocarb	Tribenuron-methyl
Disulfoton	Methomyl	Tribufos
Dithianon	Metiram	Trichlorfon
Diuron	Metolachlor	Triclopyr
DNOC	Metosulam	Tridemorph
DSMA	Metribuzin	Trifloxystrobin
Endosulfan	Metsulfuron-methyl	Trifluralin
Endothall	Molinate	Triflusulfuron-methyl
Epoxiconazole	Monocrotophos	Trinexapac-ethyl
EPTC	Monolinuron	Vinclozolin
Esfenvalerate	MSMA	
Ethalfluralin	Naled	

Chromium VI

Chromium VI has the same weighting factor as chromium III, as in Brand et al. (1998) it is not specified that the reported weighting factor is only valuable for one specific chromium type.

7.2.4 Resources and waste

Resources

Concerning the different resources reported within the database ecoinvent, Tab. 7-5 summarizes those of them that have a weighting factor within the eco-scarcity implementation into the database ecoinvent. All resources not mentioned within this table have no weighting factors within this method in ecoinvent, e.g. a factor for energy from waste is not implemented in ecoinvent data.

Tab. 7-5 Resources of the database ecoinvent and their respective weighting factors within the database ecoinvent

Resource	Factor	Remarks
Coal, brown, in ground	9.9	average upper heating value of lignite
Coal, hard, unspecified, in ground	19.1	upper heating value for coal
Energy, potential, stock, in barrage water	1	-
Gas, natural, in ground	38.3	upper heating value for natural gas
Oil, crude, in ground	45.8	upper heating value for oil
Uranium, in ground	5.60E+05	according to Dones et al. (2004)

Waste

According to Tab. 7-10, a similar weighting factor is applied within this method to each kilogram of landfilled waste[30]. But in the LCIA calculations of the ecoinvent database, direct valuation of technosphere processes is not possible nor pragmatic[31]. To be able, nevertheless, to fully assign this method, an approach via the landfill land area was chosen.

The landfill land area is inventoried within every landfill waste module. The necessary land area for the landfilling of one kilogram waste can be calculated from the landfill depth and the waste density. This area is inventoried in the database as a transformation to and from a landfill area (in m^2) and as an occupation of landfill area for the duration of the landfill operation (in m^2a) for each kilogram of waste. For land transformations and occupations associated with landfills the surface type with the CORINE code 132 ('dump site') is suitable. In the ecoinvent database this code is differentiated into several types for several near-surface landfill types (codes 132a-132e). This is not to suggest, that the ecological quality of these landfill types are significantly different[32].

Since the average depth and waste density is different for each landfill type, different areas per kilogram waste result. Since the concerned area is inventoried directly as a land transformation, it is possible to attach an adapted waste eco-factor in 'eco-points per m^2 landfill area' to the inventoried landfill area transformation[33]. The adapted eco-factor must be differentiated for the different landfill types (see Tab. 7-6). Using these modified eco-factors, each kilogram landfilled waste will be attributed a constant burden of 500 eco-points.

[30] There are however different ecofactors for wastes to underground deposits (salt mines) and for radioactive wastes.

[31] This would be not pragmatic because each time a *new* landfill waste module were created, the LCIA calculation matrix for Eco-scarcity would have to be expanded to include that module.

[32] Though a sanitary landfill with vermin and food wastes will have a different internal biodiversity and also a different impact on the biodiversity of the surrounding land than a inert material landfill. These effects are not quantified in this report.

[33] The area ecofactor is applied only to the 'transformation *to* dump site type Z' and not to 'transformation *from* dump site type Z'. Applying it to *both* would be double counting.

Tab. 7-6 Differentiated CORINE land types for landfills and ecofactors for landfill areas

CORINE code	Landfill type	Waste density	Landfill depth	Kilogram waste per m^2 landfill area	**Ecofactor per m^2 landfill area**
		kg/m^3	m	kg/m^2	eco-points/m^2
132b	dump site, sanitary landfill	1000	20	20'000	**10'000'000**
132c	dump site, slag compartment	1500	15	22'500	**11'250'000**
132d	dump site, residual material landfill	1600	10	16'000	**8'000'000**
132e	dump site, inert material landfill	1500	15	22'500	**11'250'000**

According to the general methodology used for the integration of the different impact assessment methods into the framework of the database ecoinvent (see part I of this report), factors have been applied only to the CORINE categories 132b to 132e. The CORINE types 132 (dump site, general) and 132a (dump side, benthos) have no weighting factor – and thus are also not shown in the table above.

7.2.5 EcoSpold Meta Information

Type	Field name	Entry			
ReferenceFunction	Category	ecological scarcity 1997	ecological scarcity 1997	ecological scarcity 1997	ecological scarcity 1997
ReferenceFunction	SubCategory	total	total	total	total
ReferenceFunction	Name	total	emission into air	emission into water	emission into top-soil/groundwater
Geography	Location	CH	CH	CH	CH
ReferenceFunction	Unit	UBP	UBP	UBP	UBP
DataSetInformation	Type	4	4	4	4
DataSetInformation	Version	1	1	1	1
DataSetInformation	energyValues	0	0	0	0
DataSetInformation	LanguageCode	en	en	en	en
DataSetInformation	LocalLanguageCode	de	de	de	de
DataEntryBy	Person	11	11	11	11
DataEntryBy	QualityNetwork	1	1	1	1
ReferenceFunction	DataSetRelatesToProduct	0	0	0	0
ReferenceFunction	Amount	1	1	1	1
ReferenceFunction	LocalName	Total	Emissionen in die Luft	Emissionen in die Oberflächengewässer	Emissionen in Boden und Grundwasser
ReferenceFunction	Synonyms	UBP//Umweltbelastungspunkte//Eco-factors//Eco-points//environmental scarcity	UBP//Umweltbelastungspunkte//Eco-factors//Eco-points//environmental scarcity	UBP//Umweltbelastungspunkte//Eco-factors//Eco-points//environmental scarcity	UBP//Umweltbelastungspunkte//Eco-factors//Eco-points//environmental scarcity
ReferenceFunction	GeneralComment	Swiss method	Swiss method	Swiss method. Hydrocarbons are accounted for only as COD.	Swiss method
ReferenceFunction	LocalCategory	Ökologische Knappheit 1997	Ökologische Knappheit 1997	Ökologische Knappheit 1997	Ökologische Knappheit 1997
ReferenceFunction	LocalSubCategory	Total	Total	Total	Total
TimePeriod	StartDate	1997	1997	1997	1997
TimePeriod	EndDate	1997	1997	1997	1997
TimePeriod	DataValidForEntirePeriod	1	1	1	1
TimePeriod	OtherPeriodText	year of reference for data used for the calculation of eco-factors	year of reference for data used for the calculation of eco-factors	year of reference for data used for the calculation of eco-factors	year of reference for data used for the calculation of eco-factors
Geography	Text	Values valuable for Swiss conditions	Values valuable for Swiss conditions	Values valuable for Swiss conditions	Values valuable for Swiss conditions

Type	Field name			
ReferenceFunction	Category	ecological scarcity 1997	ecological scarcity 1997	ecological scarcity 1997
ReferenceFunction	SubCategory	total	total	total
ReferenceFunction	Name	use of energy resources	deposited waste	radioactive waste
Geography	Location	CH	CH	CH
ReferenceFunction	Unit	UBP	UBP	UBP
DataSetInformation	Type	4	4	4
DataSetInformation	Version	1	1	1
DataSetInformation	energyValues	0	0	0
DataSetInformation	LanguageCode	en	en	en
DataSetInformation	LocalLanguageCode	de	de	de
DataEntryBy	Person	11	11	11
DataEntryBy	QualityNetwork	1	1	1
ReferenceFunction	DataSetRelatesToProduct	0	0	0
ReferenceFunction	Amount	1	1	1
ReferenceFunction	LocalName	Verbrauch von Energie-Ressourcen	Deponierte Abfälle	Radioaktive Abfälle
ReferenceFunction	Synonyms	UBP//Umweltbelastungspunkte//Eco-factors//Eco-points//environmental scarcity	UBP//Umweltbelastungspunkte//Eco-factors//Eco-points//environmental scarcity	UBP//Umweltbelastungspunkte//Eco-factors//Eco-points//environmental scarcity
ReferenceFunction	GeneralComment	Swiss method	Swiss method	Swiss method
ReferenceFunction	LocalCategory	Ökologische Knappheit 1997	Ökologische Knappheit 1997	Ökologische Knappheit 1997
ReferenceFunction	LocalSubCategory	Total	Total	Total
TimePeriod	StartDate	1997	1997	1997
TimePeriod	EndDate	1997	1997	1997
TimePeriod	DataValidForEntirePeriod	1	1	1
TimePeriod	OtherPeriodText	year of reference for data used for the calculation of eco-factors	year of reference for data used for the calculation of eco-factors	year of reference for data used for the calculation of eco-factors
Geography	Text	Values valuable for Swiss conditions	Values valuable for Swiss conditions	Values valuable for Swiss conditions

Appendices

Weighting factors reported in the original publication of the method (Brand et al. (1998))

Tab. 7-7 Weighting factors for emissions to air according to Brand et al. (1998)

emission to air	eco-points/g	emission to air	eco-points/g	emission to air	eco-points/g	emission to air	eco-points/g
NOx	67	R 11	2'000	R 23	2'300	Perfluormethan	1'300
SO2	53	R 12	2'000	R 32	130	Perfluorethan	1'800
NMVOC	32	R 13	2'000	R 41	30	Perfluorpropan	1'400
NH3	63	R 111	2'000	R 43-10mee	260	Perfluorbutan	1'400
HCl	47	R 112	2'000	R 125	560	Perfluorcyclobutan	1'700
HF	85	R 113	1'600	R 134	200	Perfluorpentan	1'500
PM10	110	R 114	2'000	R 134a	260	Perfluorhexan	1'500
CO2	0.2	R 115	1'200	R 152a	28	R 22	300
CH4	4.2	R 211	2'000	R 143	60	R 123	40
N2O	62	R 212	2'000	R 143a	760	R 124	94
R11-Äquivalents	2'000	R 213	2'000	R 227ea	580	R 141b	220
Pb	2'900	R 214	2'000	R 236fa	1'300	R 1,42b	360
Cd	120'000	R 215	2'000	R 245ca	110	Tetrachlorkohlenstoff	2'200
Zn	520	R 216	2'000	Halon 1211	6'000	Methylbromid	1'400
Hg	120'000	R 217	2'000	Halon 1301	20'000	Methylchlorofor m	200
				Halon 2402	12'000	Schwefelhexafluorid	4'800

Tab. 7-8 Weighting factors for emissions to water (surface water) according to Brand et al. (1998)

emission to surface water	eco-points/g	emission to surface water	eco-points/g	emission to surface water	eco-points/g	emission to surface water	eco-points/g
COD	5.9	N total	69	Zn	210	Pb	150
DOC	18	NH4+	54	Cu	1'200	Ni	190
TOC	18	NO3-	16	Cd	11'000	AOX	330
Phosphorus (P)	2'000	Cr	660	Kg	240'000		

Tab. 7-9 Weighting factors for emissions to top-soil/groundwater according to Brand et al. (1998)

emission to ground water	eco-points/g	emission to top-soil	eco-points/g	emission to top-soil	eco-points/g	emission to top-soil	eco-points/g
nitrate	27	Pb	2'900	Ni	1'900	Th	96'000
		Cu	1'900	Cr	1'300	Mo	19'000
		Cd	120'000	Co	3'800	Pesticides	800
		Zn	520	Hg	120'000		

Tab. 7-10 Weighting factors for waste according to Brand et al. (1998)

Wastes	eco-points/g	radioactive wastes	ecopoints/cm3
waste to inert, sanitary, residual material landfills	0.5	nuclear waste type B	3'300
waste to underground deposit	24	nuclear waste type C	46'000

Tab. 7-11 Weighting factors for resources according to Brand et al. (1998)

Resources	eco-points/MJ
primary energy sources	1

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8 EDIP'97 – Environmental Design of Industrial Products (Version 1997)

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Last changes: 2004

8.1 Introduction

The EDIP'97 method (EDIP is the abbreviation of "Environmental Design of Industrial Products") is the result of a four year effort in the Mid-1990s in Denmark, including the Technical University of Denmark, several Danish industry companies as well as the Danish Environmental Protection Agency. The final report of the project was published in 1997 (Wenzel et al. (1997)); a report with more detailed scientific information concerning the different impact factors one year later (Hauschild & Wenzel (1998)). The implementation is based on an updated version of the characterisation factors, available on the website of the Danish LCA center (DK LCA Center 2007).

In order to use this method together with the data from a database like ecoinvent, the equivalency factors from the EDIP'97 literature have to be linked to the respective elementary flows within ecoinvent. This Chapter describes this implementation procedure and lists all difficulties of assignment as well as all assumptions that have been made by the author of this implementation.

This should support the user of the ecoinvent database while using the EDIP'97 method and in the end lead to comparable results of different LCA studies that use the same database as well as the same impact assessment method (here: EDIP'97 method). Tab. 8-1 (see page 85) shows an overview of the impact categories of EDIP'97. All those categories shown with a grey background are not included into the present implementation of this method due to the fact that the inventories of ecoinvent do not contain the respective information needed for the calculation of each of these categories. All other categories are included on the first of the three levels distinguished within the EDIP'97 method – the level of the "environmental impact potentials".

For more details about the method itself as well as its various impact factors, the user is referred to the original literature of the EDIP'97 method (Wenzel et al. (1997), Hauschild & Wenzel (1998)) and DK LCA Center (2007).

8.2 Use of the method

According to Wenzel et al. (1997), the EDIP'97 method translates the cumulated inventory data of an examined system "into potential contributions to various impacts within the main groups environment, resources and working environment". Due to the already mentioned lack of one part of the required information, only two of these groups – environment and resources – are actually covered by the implementation. In order to have a maximum of transparency and reproducibility, the whole method distinguishes between three different steps:

1. **Environmental impact potentials.** Similar to most other methods (e.g. CML, Eco-indicator'99, ...), the contribution of each individual emission to the various impact categories is calculated by using the respective equivalency factors.

2. **Normalization with a common reference.** In order to see which of the various impact potentials rsp. resource consumptions are relevant compared with a common reference (e.g. total European values).

3. **Weighting of the normalized impact potentials.** According to Wenzel et al. (1997), "before the normalized impact potentials / resource consumptions are directly comparable, account must be

taken of the seriousness of each individual impact in relation to the others". Therefore, weighting factors have been calculated based on scientific, political and normative considerations.

Tab. 8-1 Impact categories of EDIP'97 method. The categories shown with a shaded background are not implemented in the ecoinvent database.

Name	Loc.	Unit	LocalCat.	LocalSubCategory	Cat.	SubCategory
accidents	GLO	h	EDIP	Einfluss auf Arbeitsumgebung	EDIP	impact on the working environment
acidification	GLO	kg SO2-Eq	EDIP	Umwelteinfluss	EDIP	environmental impact
allergy	GLO	h	EDIP	Einfluss auf Arbeitsumgebung	EDIP	impact on the working environment
cancer	GLO	h	EDIP	Einfluss auf Arbeitsumgebung	EDIP	impact on the working environment
damage to the nervous system	GLO	h	EDIP	Einfluss auf Arbeitsumgebung	EDIP	impact on the working environment
damage to the reproductive system	GLO	h	EDIP	Einfluss auf Arbeitsumgebung	EDIP	impact on the working environment
ecotoxicity, acute, in water	GLO	m3 water	EDIP	Umwelteinfluss	EDIP	environmental impact
ecotoxicity, chronic, in soil	GLO	m3 soil	EDIP	Umwelteinfluss	EDIP	environmental impact
ecotoxicity, chronic, in water	GLO	m3 water	EDIP	Umwelteinfluss	EDIP	environmental impact
ecotoxicity, in sewage treatment plants	GLO	m3 waste water	EDIP	Umwelteinfluss	EDIP	environmental impact
global warming, GWP 100a	GLO	kg CO2-Eq	EDIP	Umwelteinfluss	EDIP	environmental impact
global warming, GWP 20a	GLO	kg CO2-Eq	EDIP	Umwelteinfluss	EDIP	environmental impact
global warming, GWP 500a	GLO	kg CO2-Eq	EDIP	Umwelteinfluss	EDIP	environmental impact
hearing impairments	GLO	h	EDIP	Einfluss auf Arbeitsumgebung	EDIP	impact on the working environment
human toxicity, via air	GLO	m3 air	EDIP	Umwelteinfluss	EDIP	environmental impact
human toxicity, via groundwater	GLO	m3 water	EDIP	Umwelteinfluss	EDIP	environmental impact
human toxicity, via soil	GLO	m3 soil	EDIP	Umwelteinfluss	EDIP	environmental impact
human toxicity, via surface water	GLO	m3 water	EDIP	Umwelteinfluss	EDIP	environmental impact
land filling, bulk waste	GLO	kg waste	EDIP	Umwelteinfluss	EDIP	environmental impact
land filling, hazardous waste	GLO	kg waste	EDIP	Umwelteinfluss	EDIP	environmental impact
land filling, radioactive waste	GLO	kg waste	EDIP	Umwelteinfluss	EDIP	environmental impact
land filling, slag and ashes	GLO	kg waste	EDIP	Umwelteinfluss	EDIP	environmental impact
monotonous repetitive work	GLO	h	EDIP	Einfluss auf Arbeitsumgebung	EDIP	impact on the working environment
non-renewable resources, aluminium	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, antimony	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, beryllium	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, brown coal	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, cadmium	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, cerium	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, coal	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, cobalt	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, copper	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, gold	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, iron	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, lanthanum	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, lead	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, manganese	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, mercury	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, molybdenum	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, natural gas	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, nickel	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, oil	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, palladium	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, platinum	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, silver	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, tantalum	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, tin	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
non-renewable resources, zinc	GLO	kg	EDIP	Ressourcenverbrauch	EDIP	resource consumption
nutrient enrichment, combined potential	GLO	kg NO3-	EDIP	Umwelteinfluss	EDIP	environmental impact
nutrient enrichment, separate N potential	GLO	kg N	EDIP	Umwelteinfluss	EDIP	environmental impact
nutrient enrichment, separate P potential	GLO	kg P	EDIP	Umwelteinfluss	EDIP	environmental impact
photochemical ozone formation, high NOx POCP	RER	kg ethylene-Eq	EDIP	Umwelteinfluss	EDIP	environmental impact
photochemical ozone formation, low NOx POCP	RER	kg ethylene-Eq	EDIP	Umwelteinfluss	EDIP	environmental impact
renewable resources, wood	GLO	m3	EDIP	Ressourcenverbrauch	EDIP	resource consumption
stratospheric ozone depletion, ODP 100a	GLO	kg CFC-11-Eq	EDIP	Umwelteinfluss	EDIP	environmental impact
stratospheric ozone depletion, ODP 20a	GLO	kg CFC-11-Eq	EDIP	Umwelteinfluss	EDIP	environmental impact
stratospheric ozone depletion, ODP 5a	GLO	kg CFC-11-Eq	EDIP	Umwelteinfluss	EDIP	environmental impact
stratospheric ozone depletion, ODP steady state	GLO	kg CFC-11-Eq	EDIP	Umwelteinfluss	EDIP	environmental impact

Within the ecoinvent database, only the environmental impact potentials are implemented. For the next two steps, the respective normalization and weighting factors can be found in the Excel worksheet on the ecoinvent CD (/ecoinventTools/03_EDIP'97.xls) or in the original literature of this method (Wenzel et al. (1997): Tab.23.18a and 23.18b).

8.3 Project specific aspects of the implementation

Within the ecoinvent database, only factors for the first step – the environmental impact potentials – are linked to the emission list from ecoinvent. These equivalency factors are taken from chapter 23.2 to 23.9 in Wenzel et al. (1997); in case of CFC / HCFC, additional global warming factors are taken from chapter 1 in Hauschild & Wenzel (1998). Further developments of the EDIP method have not been taken into account within this ecoinvent implementation.

Within the EDIP'97 method, no subcategories (e.g. emissions to water, river) are distinguished within the three emissions types (air – water – soil) and no methodological restrictions are reported. Thus, for the integration case 1 in Tab. 2-2 of Part I of this report is used – e.g.

- **Emissions to air**: in general use of the factor for all subcategories
- **Emissions to water**: in general use of the factor for all subcategories
- **Emissions to soil**: in general use of the factor for all subcategories

The following chapters show the assumptions / approximations made during the integration of the EDIP'97 method into the framework of the ecoinvent database. Over all environmental impact potentials and resource consumption categories, only those factors from the EDIP publication are integrated where the respective emission / resource is mentioned in the ecoinvent database.

8.3.1 Global Warming (greenhouse gases)

In accordance with general guidelines, only fossil emissions have the respective equivalency factors – biogenic emissions as well as the CO_2 uptake are not assessed, they have no equivalency factors. The CO_2 emissions due to land transformation processes in primary forest areas (deforestation processes) are assessed as if they were fossil emissions.

Besides the direct contribution to the global warming, EDIP'97 takes into account also the so-called "indirect" contribution due to conversion into carbon dioxide. According to Hauschild & Wenzel (1998), this CO_2 formation potential is greatest for pure hydrocarbons and it declines with the degree of oxidation or substitution rsp. with the mass of the substituents. For the linking of these factors, the following rules have been applied:

- A factor of 3 kg CO_2-Eq/kg for "*Hydrocarbons (NMHC)*" is used for all hydrocarbons without a specific equivalency factor that don't contain other atoms than hydrogen or carbon.
- A factor of 2 kg CO_2-Eq/kg for "*partly oxidized hydrocarbons*" is used for all hydrocarbons without a specific equivalency factor that contain one or more oxygen atoms besides carbon and hydrogen.
- A factor of 1 kg CO_2-Eq/kg for "*partly halogenated hydrocarbons*" is used for all hydrocarbons without a specific equivalency factor that contain one or more halogen.

In cases of substances that fulfil more than one of these three criteria, the lower value is chosen.

8.3.2 Photochemical Ozone Formation

The same equivalency factor is used for biogenic and fossil emissions. For the various unspecified hydrocarbons emissions listed in the emission list of ecoinvent the respective average factors reported in DK LCA Center (2007) are used. The reported factor for alkanes is used for the following emissions from ecoinvent: "Hydrocarbons, aliphatic, alkanes, cyclic" / "Hydrocarbons, aliphatic, alkanes, unspecified" / "Hydrocarbons, aliphatic, unsaturated".

For the unspecified xylene emissions in ecoinvent, an average value based a mixture of 9% o-, 60% m- and 14% p-xylene and 17% ethylbenzene is calculated. This mixture represents the naturally occurring isotopes of xylene.

8.3.3 Acidification and Nutrient enrichment

According to Wenzel et al. (1997) the two effects are due not only emissions from air, but also due to emissions to water and soil.

Despite this information, only air emissions are included for the acidification due to the fact that neither the category "emissions to water" nor the category "emissions to soil" contain any of those substances listed in the list of equivalency factors for acidification in DK LCA Center (2007).

In case of "nutrient enrichment", the respective equivalency factors for N- rsp. P-containing substances are used for all types of emissions (to air, water, soil).

8.3.4 Ecotoxicity and Human Toxicity

In all toxicity categories, the equivalency factors for metal emissions to water are used for both cases – the metal form as well as the ionic form of the metals. All reported values for chromium refer only to Cr (VI) and thus, these factors are used only for Cr(VI) as well as sodium dichromate rsp. dichromate ions. This has been confirmed by a personal communication from the developers of the EDIP-method. In the case of sodium dichromate / dichromate ion, a correction factor based on the molar masses from (sodium) dichromate and chromium is added.

For hypochlorite the respective factors of sodium hypochlorite are used.

In the various human toxicity factors, NO_3^- and NO_2^- emissions to water got the factor for NO_x.

In case of ecotoxicity, the effluent to a waste water treatment plant (WWTP) has its own equivalency factors in the EDIP'97 method. These factors are included as "ecotoxicity, in sewage treatment plant". In practice, this factor has to be taken into account only in cases where WWTP effluents are examined – in all other cases only the remaining ecotoxicity factors are used.

8.3.5 Land filling (Waste)

As already mentioned in the respective chapter of the UBP method, in the LCIA calculations of the ecoinvent database, direct valuation of technosphere processes is not possible nor pragmatic[34]. To be able, nevertheless, to fully assign the different land filling categories, an approach via the respective landfill land area was chosen.

The landfill land area is inventoried within every landfill waste module. The necessary land area for the landfilling of one kilogram waste can be calculated from the landfill depth and the waste density. This area is inventoried in the database as a transformation to and from a landfill area (in m^2) and as an occupation of landfill area for the duration of the landfill operation (in m^2a) for each kilogram of waste. For land transformations and occupations associated with landfills the surface type with the CORINE code 132 ('dump site') is suitable. In the ecoinvent database this code is differentiated into

[34] This would be not pragmatic because each time a *new* landfill waste module were created, the LCIA calculation matrix for Eco-scarcity would have to be expanded to include that module.

several types for several near-surface landfill types (codes 132a-132e). This is not to suggest, that the ecological quality of these landfill types are significantly different[35].

Since the average depth and waste density is different for each landfill type, different areas per kilogram waste result. Since the concerned area is inventoried directly as a land transformation, it is possible to attach an adapted waste equivalency factor to the inventoried landfill area transformation[36]. The adapted eco-factor must be differentiated for the different landfill types (see Tab. 8-2). Within the integration work it is assumed, that bulk waste compromises all three main types of landfills distinguished – i.e. the inert, the sanitary and the residual material landfill.

Tab. 8-2 CORINE land types for landfills, used equivalency factors for landfill areas and assigned EDIP'97 land filling categories

Code	Landfill type	Waste density [kg/m^3]	Landfill depth [m]	Equivalency factors [kg/m^2]	**Assigned EDIP'97 land filling category**
132b	dump site, sanitary landfill	1000	20	20'000	**Land filling, bulk waste**
132c	dump site, slag compartment	1500	15	22'500	**Land filling, slag & ashes**
132d	dump site, residual material landfill	1600	10	16'000	**Land filling, bulk waste**
132e	dump site, inert material landfill	1500	15	22'500	**Land filling, bulk waste**

According to the general methodology used for the integration of the different impact assessment methods into the framework of the database ecoinvent (see part I of this report), factors have been applied only to the CORINE categories 132b to 132e. The CORINE types 132 (dump site, general) and 132a (dump side, benthos) have no weighting factor – and thus are also not shown in the table above.

With these transformation factors, only two of the four land filling types according to EDIP'97 methodology are covered. The remaining two types (land filling, hazardous waste & land filling, radioactive waste) are covered by attaching the respective equivalency factors to density of the inventoried landfill volume according to the following information:

- **Land filling, hazardous waste**: According to Doka (2007, part III, chapter 5.11) the underground deposit for hazardous waste is based on an average density of 1'600 kg/m^3.
- **Land filling, radioactive waste**: Within ecoinvent, two types of final repositories for radioactive waste are distinguished (low-active radioactive waste / radioactive waste). According to the nuclear energy chapter of ecoinvent (Dones 2007), the average density of these two types of final repositories is the following:
    - Low-active radioactive waste: 2'500 kg/m^3
    - Radioactive waste: 5'400 kg/m^3

8.3.6 Resources

The factor for natural gas is used not only for the resource "Gas, natural, in ground", but also for the resource "gas, mine, off-gas, process, coal mining". The respective factors of metals are used for all

[35] Though a sanitary landfill with vermin and food wastes will have a different internal biodiversity and also a different impact on the biodiversity of the surrounding land than a inert material landfill. These effects are not quantified in this report.

[36] The area ecofactor is applied only to the 'transformation *to* dump site type Z' and not to 'transformation *from* dump site type Z'. Applying it to *both* would be double counting.

different types of the respective metal – e.g. the factor for nickel is used for "Ni, Ni 2.3E+0%, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Cu 3.2E+0% in ore, in ground", "Ni, Ni 3.7E-2%, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Cu 5.2E-2% in ore, in round", "Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground" as well as "Nickel, 1.98% in silicates, 1.04% in crude ore, in ground". As all these resources refer to 1 kg of nickel, all of them have a factor of 1.

8.3.7 EcoSpold Meta Information

The full meta information of all impact categories of the EDIP'97 method can be assessed via the homepage www.ecoinvent.org. The following table shows only an example.

ReferenceFunction	Category	EDIP	EDIP	EDIP	EDIP
ReferenceFunction	SubCategory	environmental impact	environmental impact	environmental impact	resource consumption
ReferenceFunction	Name	acidification	ecotoxicity, chronic, in water	global warming, GWP 100a	non-renewable resources, aluminium
Geography	Location	GLO	GLO	GLO	GLO
ReferenceFunction	Unit	kg SO2-Eq	m3 water	kg CO2-Eq	kg
DataSetInformation	Type	4	4	4	4
DataSetInformation	Version	1	1	1	1
DataSetInformation	energyValues	0	0	0	0
DataSetInformation	LanguageCode	en	en	en	en
DataSetInformation	LocalLanguageCode	de	de	de	de
DataEntryBy	Person	11	11	11	11
DataEntryBy	QualityNetwork	1	1	1	1
ReferenceFunction	DataSetRelatesToProduct	0	0	0	0
ReferenceFunction	Amount	1	1	1	1
ReferenceFunction	LocalName	Versauerung	Ökotoxizität, chronisch, im Wasser	Treibhauseffekt, GWP 100a	Nicht-erneuerbare Ressourcen, Aluminium
ReferenceFunction	Synonyms				
ReferenceFunction	GeneralComment	Danish method. The factors here represent only the first step within the three steps of the method - i.e. the environmental impact potentials / ressource consumption potentials. The following normalization and weighting steps are not included in these factors here.	Danish method. The factors here represent only the first step within the three steps of the method - i.e. the environmental impact potentials / ressource consumption potentials. The following normalization and weighting steps are not included in these factors here.	Danish method. The factors here represent only the first step within the three steps of the method - i.e. the environmental impact potentials / ressource consumption potentials. The following normalization and weighting steps are not included in these factors here.	Danish method. The factors here represent only the first step within the three steps of the method - i.e. the environmental impact potentials / ressource consumption potentials. The following normalization and weighting steps are not included in these factors here.
ReferenceFunction	LocalCategory	EDIP	EDIP	EDIP	EDIP
ReferenceFunction	LocalSubCategory	Umwelteinfluss	Umwelteinfluss	Umwelteinfluss	Ressourcenverbrauch
TimePeriod	StartDate	1997	1997	1997	1997
TimePeriod	EndDate	1997	1997	1997	1997
TimePeriod	DataValidForEntirePeriod	1	1	1	1
TimePeriod	OtherPeriodText	year of reference for data used for the calculation of eco-factors	year of reference for data used for the calculation of eco-factors	year of reference for data used for the calculation of eco-factors	year of reference for data used for the calculation of eco-factors
Geography	Text	First step (potentials of envrionmental impact / resource consumption) is independent of geogrphical area - thus it is a GLOBAL factor.	First step (potentials of envrionmental impact / resource consumption) is independent of geogrphical area - thus it is a GLOBAL factor.	First step (potentials of envrionmental impact / resource consumption) is independent of geogrphical area - thus it is a GLOBAL factor.	First step (potentials of envrionmental impact / resource consumption) is independent of geogrphical area - thus it is a GLOBAL factor.

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9 EDIP 2003

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Review: Roland Hischier, Empa, St. Gallen
Last changes: 2007

9.1 Introduction

The EDIP03 is an evolution of the EDIP97 method and includes spatially differentiated characterisation modelling. EDIP97 is not replaced by EDIP03.

Compared to the EDIP97 methodology, the models underlying the EDIP03 characterisation factors take a larger part of the causality chain into account for all the non-global impact categories. The EDIP03 factors thus include the modelling of the dispersion of the substance and the subsequent exposure increase. For a number of impact categories, the modelling also includes the background exposure and vulnerability of the target systems to allow assessment of the exceedance of thresholds.

Therefore, the environmental relevance of the calculated impacts is higher – they are expected to be in better agreement with the actual environmental effects from the substances that are observed, and they are easier and more certain to interpret in terms of environmental damage.

New characterization factors and accompanying normalization references have been developed for each of the non-global impact categories:

- acidification
- terrestrial eutrophication
- photochemical ozone exposure of plants
- photochemical ozone exposure of human beings
- aquatic eutrophication
- human toxicity via air exposure
- ecotoxicity

For the global impact categories global warming and stratospheric ozone depletion, the characterization factors are updated with the latest recommendations from IPCC and WMO/UNEP.

The EDIP03 methodology Guideline (Hauschild & Potting, 2005). recommends that the EDIP03 characterisation methodology be used as an alternative to EDIP97 for performing site-generic characterisation (i.e. disregarding spatial information). For the non-global impact categories, the environmental relevance of the site-generic EDIP03 impact potentials is higher, and they provide the option to quantify and reduce the spatial variation not taken into account. EDIP97 can still be used if a new LCA should be compared with prior results based on EDIP97 methodology and factors.

9.2 Implementation

The purpose of this Chapter is not to fully describe the methodology. The reader is invited to refer to the EDIP03 methodology Guideline (Hauschild & Potting, 2005) for a detailed description on how the characterization factors are calculated. In addition some aspects of the implementation of this method in ecoinvent, is already described in the EDIP97 chapter. By the following we provide the additional specific aspects relative to the implementation of the 2003 version.

9.2.1 Global Warming (greenhouse gases)

EDIP03 and revised EDIP97 characterization factors are taken from the latest version of the IPCC consensus report. These are complemented by factors for hydrocarbons and partly oxidized or halogenated hydrocarbons of fossil origin, which are derived from the stoichiometrically determined formation of CO_2 by oxidation of the substance. Characterization factors are taken from Table 2.1 of the EDIP03 Methodological report. See chapter 8 for additional implementations details.

9.2.2 Ozone depletion

EDIP03 characterization factors are taken from recommendations of the latest version of the WMO status report. Characterization factors are taken from Table 3.1 of the EDIP03 Methodological report. See chapter 8 for additional implementations details.

9.2.3 Photochemical ozone formation

Ccharacterization factors of photochemical ozone formation are divided into two subcategories which represent the exposure of human beings and materials, and the exposure of vegetation above their respective thresholds. For each of these two subcategories, an impact potential is calculated.

The impact potential for vegetation exposure is expressed as the product of the area of vegetation exposed above the threshold of chronic effects, 40 ppb (m_2), the annual duration of the exposure above the threshold (hours), and the exceeding of the threshold concentration (ppb). The unit of the impact potential for vegetation is $m^2 \cdot$ ppm $\cdot$ hours. The impact potential for human exposure is expressed as the product of the number of persons exposed above the threshold of chronic effects, 60 ppb (pers), the annual duration of the exposure above the threshold (hours), and the exceeding of the threshold concentration (ppb). The unit of the impact potential for human exposure is pers $\cdot$ ppm $\cdot$ hours.

The photochemical ozone formation impacts on vegetation and human health are taken from Table 7.1, 7.2 and 7.3 of the EDIP03 Methodology report. See Chapter 8 for additional implementations details.

9.2.4 Acidification

EDIP03 acidification potentials are expressed as the area of ecosystem within the full deposition area which is brought to exceed the critical load of acidification as a consequence of the emission (area of unprotected ecosystem = m^2 UES/kg). Characterization factors are provided in Table 4.1 of the EDIP03 Methodology report.

9.2.5 Terrestrial Eutrophication

EDIP03 eutrophication potentials of an emission are expressed as the area of terrestrial ecosystem within the full deposition area that is brought to exceed the critical load of eutrophication as a consequence of the emission (area of unprotected ecosystem = m^2 UES). Characterization factors are taken from Table 6.1 and 6.2 of the EDIP03 Methodological report.

Similarly as per EDIP 2007 in case of “nutrient enrichment”, the respective equivalency factors for N- rsp. P-containing substances are used for all types of emissions (to air, water, soil). This therefore applies for Acrylonytrile, Ethylene diamine, Hydrazine and Nitrobenzene.

9.2.6 Human Toxicity

The EDIP03 exposure factors have been established to evaluate spatially determined variations in the increase of human exposure through inhalation resulting directly from air emissions. EDIP03 factors therefore do not replace the EDIP97 characterization factors. Rather, they should be considered as exposure factors to be used in combination with the EDIP97 factors which are maintained to characterize the site-generic impact on human toxicity from emissions. See chapter 8 for additional implementations details.

9.2.7 Ecotoxicity

The EDIP03 factors do not replace the EDIP97 characterization factors Rather, they should be considered as exposure factors to be used in combination with the EDIP97 factors which are maintained to characterize the site-generic impact on ecotoxicity from emissions. This means that the parts of the fate and effect factors which are not spatially differentiated are maintained as they were defined in EDIP97. For see chapter 8 for additional implementation details.

9.2.8 Land filling (Waste) and Resources

No updates have been made in respect to the EDIP 2007 version.

9.2.9 Normalization and weighting

Within the ecoinvent database, only the environmental impact potentials are implemented. If the practitioner would like to include these two steps, the respective normalization and weighting factors can be found in Tab. 9-1 and Tab. 9-2.

Tab. 9-1: EDIP03 normalization and weighting factors: global and regional impact categories

Impact category	Normalization reference Unit		Weighting factor	Reference year	Reference region
Environmental impacts					
Global					
Global warming	kg CO_2-eq/pers/year	8.70E+03	1.1	1994	World
Ozone depletion	kg CFC-11-eq/pers/ar	0.103	63	1994	World
Regional and local					
photochemical ozone formation - vegetation	m2.ppm.hours/pers/yr	1.40E+05		1995	EU-15
photochemical ozone formation - human health	pers.ppm.hours/pers/yr	10		1995	EU-15
Acidification	m2/pers/year	2.20E+03		1990	EU-15
terrestrial eutrophication		2.10E+03			
aquatic eutrophication	kg NO_3^--eq/pers/year	58		1995	EU-15
-N-equivalents	kg N-eq/pers/year	12		1995	EU-15
-P-equivalents	kg P-eq/pers/year	0.41		1995	EU-15
Ecotoxicity					
- water acute	m^3 water/pers/year	2.91E+04	1.1	1994	EU-15
- water chronic	m^3 water/pers/year	3.52E+05	1.2	1994	EU-15
- soil chronic	m^3 soil/pers/year	9.64E+05	1	1994	EU-15
Human toxicity					
- via air	m^3 air/pers/year	3.06E+09	1.1	1994	EU-15
- via water	m^3 water/pers/year	5.22E+04	1.3	1994	EU-15
- via soil	m^3 soil/pers/year	1.27E+02	1.2	1994	EU-15
Waste					
-bulk Waste	kg/pers/year	1350	1.1	1991	Denmark
-hazadous waste	kg/pers/year	20.7	1.1	1991	Denmark
-slag and ashes	kg/pers/year	350	1.1	1991	Denmark
-nuclear waste	kg/pers/year	0.035	1.1	1989	Sweden

Tab. 9-2: EDIP03 normalization and weighting factors for resource consumption

Resource consumption	Normalization reference		Weighting	1 / pers.-reserve	Reference	Reference
	Unit		factor (year-1)	(pers/kg)	year	region
Non-renewable	**RR_{90}**		**WF**	**WF/RR_{90}**		
Aluminium	kg/pers/year	3.4	0.0051	0.0015	1990	World
Antimony	kg/pers/year			1	1990	World
Beryllium	kg/pers/year			26	1990	World
Brown coal	kg/pers/year	250	0.0026	0.00001	1991	World
Cadmium	kg/pers/year			4.4	1990	World
Cerium	kg/pers/year			0.17	1990	World
Coal	kg/pers/year	570	0.0058	0.00001	1991	World
Cobalt	kg/pers/year			0.98	1990	World
Copper	kg/pers/year	1.7	0.028	0.016	1990	World
Gold	kg/pers/year			87	1990	World
Iron	kg/pers/year	100	0.0085	0.000085	1990	World
Lanthanum	kg/pers/year			0.31	1990	World
Lead	kg/pers/year	0.64	0.048	0.075	1990	World
Manganese	kg/pers/year	1.8	0.012	0.0067	1990	World
Mercury	kg/pers/year			9.1	1990	World
Molybdenum	kf/pers/year			0.25	1990	World
Natural gas	kg/pers/year	310	0.016	0.000052	1991	World
Nickel	kg/pers/year	0.18	0.019	0.11	1990	World
Oil	kg/pers/year	590	0.023	0.000039	1991	World
Palladium	kg/pers/year			140	1990	World
Platinum	kg/pers/year			120	1990	World
Silver	kg/pers/year			6.9	1990	World
Tantalum	kg/pers/year			21	1990	World
Tin	kg/pers/year	0.04	0.037	0.93	1990	World
Zinc	kg/pers/year	1.4	0.05	0.036	1990	World

Appendix

EcoSpold Meta Information

The full meta information of all impact categories of the EDIP03 method can be assessed via the homepage www.ecoinvent.org.

Original factors

The EDIP03 method description and the original damage factors might be found on the following web page: http://www2.mst.dk/Udgiv/publications/2005/87-7614-579-4/pdf/87-7614-580-8.pdf

References

Hauschild & Potting 2005 — Hauschild M. and Potting J. (2005) Background for spatial differentiation in LCA impact assessment: The EDIP03 methodology. 2005. Institute for Product Development Technical University of Denmark. Environmental Project No. 996, Denmark.

10 EPS 2000

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Last changes: 2004

Important notice

This method was not extended to the new elementary flows introduced with ecoinvent data v2.0. Thus, EPS 2000 was removed from the ecoinvent data v2.0 contents. The extended version will be provided with ecoinvent data v2.1, scheduled for late 2008.

Acknowledgement

The kindest assistance of the originator of the Method, Bengt Steen, has been instrumental for its implementation into ecoinvent v1.1, and it is herewith highly esteemed.

Summary

The Environmental Priority Strategy in product design (EPS) is an environmental-accounting method, which describes impacts (changes) to the (current, global) environment as impacts to specific safeguards subjects: biodiversity, production, human health, resources, and aesthetic values. These impacts are valued on a relative scale in Environmental Load Units (ELU) according to the willingness to pay (WTP) to avoid negative effects on the safeguard subjects. Raw material resources are evaluated by the WTP for alternative renewable processes to produce comparable services. One ELU corresponds to one Euro. EPS was intended as a tool for product development within companies; applications for other purposes require knowledge of its features and limitations. This chapter shortly describes the general approach and the implementation of the version 2000 of the default method into ecoinvent.

10.1 Introduction

The ESP method has been developed in 1990-1991 as a conceptual tool for LCA (Ryding & Steen 1991). The version 2000 (Steen 1999a; Steen 1999b; Steen 2001), implemented in ecoinvent v.1.1 and herewith described, is an update of the 1996 version (Steen 1996) and the 1994 version (Ryding & al. 1995). EPS system's rules and terminology comply with the ISO standards for LCA. The following information has been retrieved from the EPS website[37] and only slightly modified (own additions are within parentheses).

Goal: To assess the added value from all types of impacts (accounted for); to communicate an understanding of the magnitude of the impact (in monetary terms, for easy weighting against other items that must be considered for product development); to provide a forum for the growth of the environmental strategy of a product.

Scope: The EPS system was developed as a tool for designers for product development within companies; use for other purposes like environmental declarations, purchasing decisions, education or environmental accounting requires knowledge of its features and limitations, because the models used to give a measure of impacts may not apply in different contexts; EPS cannot discriminate violations of an emission or quality standards.

[37] http://eps.esa.chalmers.se

10.2 The EPS default method

EPS was developed following a *top-down approach*, starting from what the designers would like to know in order to be able to decide which environmental concerns to follow in a choice between two concepts of a product. From this basis, the methodology was gradually developed to use to the extent possible the existing knowledge from environmental sciences. The input to the models was data on use of abiotic resources and on emissions from processes involved in life cycle of products, as well as risk assessment and valuation models for resulting environmental effects.

The application of the EPS default method to an LCI assessment is by mean of indexes, which are ready made weighted factors describing the impacts of resources and emissions. The inventory results of individual flows for the activity under examination shall be multiplied by the corresponding indexes and thus summed up to give one total value.

The impacts or changes to the current, global environment are described as impacts to specific safeguards subjects: biodiversity, production, human health, resources, and aesthetic values. These impacts are valued in EPS on a relative scale in Environmental Load Units (ELU) according to the willingness to pay (WTP) today of a fictive global society consisting of OECD-economies to avoid negative effects (changes) on the safeguard subjects. Hence, a monetary measure is produced, where one ELU is assumed equal to 1 Euro (originally, ECU). To estimate the WTP for preserving lives, given the prevailing circumstances in the current society, the Contingent Valuation Method (CVM) is used when applicable. Tab. 10-1 shows the monetary values for the key safeguards subjects considered in EPS. They were determined on the basis of various European and US studies as described in (Steen 1999b).

Tab. 10-1 EPS default method safeguard subjects and related impact categories and weighting factors (Steen 1999b)

Safeguard subject	Impact category	Category indicator	Indicator unit	Weighting factor (ELU/Indicator unit)	Uncertainty factor [a]
Human health	Life expectancy	YOLL	Person-year	$8.5 \cdot 10^{4}$	3
	Severe morbidity	Severe morbidity	Person-year	$1.0 \cdot 10^{5}$	3
	Morbidity	Morbidity	Person-year	$1.0 \cdot 10^{4}$	3
	Severe nuisance	Severe nuisance	Person-year	$1.0 \cdot 10^{4}$	3
	Nuisance	Nuisance	Person-year	$1.0 \cdot 10^{3}$	3
Ecosystem production capacity	Crop growth capacity	Crop	kg	$1.5 \cdot 10^{-1}$	2
	Wood growth capacity	Wood	kg	$4.0 \cdot 10^{-2}$	1.4
	Fish and meat production capacity	Fish and meat	kg	$1.0 \cdot 10^{0}$	2
	Soil acidification	Base cat-ion capacity of soils	Mole H^{+}-equivalents	$1.0 \cdot 10^{-2}$	2
	Production capacity for irrigation water	Irrigation water	kg	$3.0 \cdot 10^{-3}$	4
	Production capacity for drinking water	Drinking water	kg	$3.0 \cdot 10^{-2}$	6
Biodiversity	Species extinction	NEX	---	$1.10 \cdot 10^{11}$	3

[a] Not implemented in ecoinvent v1.1.

For the weighting factors for abiotic resources, the CVM cannot be applied directly to estimate the relevant WTP: as a matter of facts, those concerned for resource depletion are future generations. A market scenario is then defined where all future generations are considered. As resource are depleting, the costs for extraction will increase until reaching an almost constant value representing the “cost for a sustainable production”, i.e., extraction of relatively large resources at very diluted concentrations or by means of renewable processes. It is assumed that the WTP curve will intersect the cost curve at this value.

Impacts on aesthetic shall be valued from case to case. Therefore, no default value is given.

In the appendix, one example for emissions to air and one for abiotic resources are provided from (Steen 1999b) in order to illustrate how the indexes have been quantified.

10.3 Implementation

10.3.1 General

Tab. 10-2 shows an overview of the EPS implementation into ecoinvent v1.1. In the following sections, each compartment (corresponding to “Name” in Tab. 10-2) is addressed separately. These sections are basically providing only the list of the items accounted for in ecoinvent. The ecoinvent users are strongly recommended to refer to the original publications for deeper understanding of the details of the EPS default method.

Tab. 10-2 Categories implemented in the database ecoinvent to represent the EPS 2000 default method

Category	SubCategory	Name	Unit	Location
EPS 2000	total	abiotic stock resources	ELU	GLO
		emissions into air		
		emissions into water		
		emissions into soil		
		land occupation		
		total		

10.3.2 Abiotic stock resources

Tab. 10-3 and Tab. 10-4 show the impact categories and indexes for the abiotic stock resources in the EPS default method and their implementation into ecoinvent v1.1. In particular for the energy resources, ecoinvent has two gas resources: "Gas, natural, in ground" and "Gas, mine, off-gas, process, coal mining". EPS includes explicitly only the first, but the factor is applied to both, along with the philosophy of the method. EPS deals only with generic coal for which the closest in ecoinvent is hard coal. For the application to lignite, the EPS factor for coal has been scaled down by the ratio of the average low heating values in ecoinvent v1.1, i.e. 9.9/19.1, to give 0.0258 ELU/kg.

Tab. 10-3 and Tab. 10-4 include only elemental resources, along with EPS. In case of ores considered as resources in ecoinvent v1.1, the EPS index for a specific element has been applied consistently to the element content in the ore including it. Thus, the mol ratio of the element contained in the ore has been used to calculate the EPS factor associated with the ore resource. This applies to the following ores (within parentheses is the corresponding element): barite (Ba), borax (B), cinnabar (Hg), colemanite (B), fluorspar (F), kaolinite (Al), magnesite (Mg – for which the EPS index is zero), pyrolusite (Mn), rutile (Ti), spodumene (Li), stibnite (Sb), sylvite (Cl – for which the EPS index is zero), TiO_2 (Ti), ulexite (B), zirconia (Zr).

The database ecoinvent v1.1 includes two processes for gravel-making, namely "gravel, crushed, at mine" and "gravel, round, at mine", and a sort of summary dataset "gravel, unspecified, at mine" using the share of natural round gravel to total gravel extracted/processed in Switzerland of 0.79. Both use the resource "Gravel, in ground". EPS considers the resource "natural gravel". The corresponding factor is calculated from the crushing rock gravel mining. Therefore, EPS index of 0.02 ELU/kg has been weighted by the above reported share.

Tab. 10-3 Impact categories and factors for the abiotic stock resources in the EPS default method (Steen 1999b; and EPS website)

Impact category: Depletion of "X" reserves	Category indicator: "X" reserves	Impact index (ELU/kg)	Implemented in ecoinvent v1.1 under "Abiotic stock resources"	Uncertainty factor [a]
oil	Fossil oil	$5.06 \cdot 10^{-1}$	√	1.4
coal	Fossil coal	$4.98 \cdot 10^{-2}$	√	2
natural gas	Natural gas	$1.10 \cdot 10^{0}$	√	2
		(ELU/kg of element)		
Ag	Ag	$5.40 \cdot 10^{4}$	√	2.2
Al	Al	$4.39 \cdot 10^{-1}$	√	2
Ar	Ar	0	√	1
As	As	$1.49 \cdot 10^{3}$	-	2.2
Au	Au	$1.19 \cdot 10^{6}$	-	3
B	B	$5.0 \cdot 10^{-2}$	√	10
Ba	Ba	$4.45 \cdot 10^{0}$	√	3
Bi	Bi	$2.41 \cdot 10^{4}$	-	2.2
Be	Be	$9.58 \cdot 10^{2}$	-	3
Br	Br	0	-	1
Cd	Cd	$2.91 \cdot 10^{4}$	-	2.2
Ce	Ce	$4.52 \cdot 10^{1}$	√	3
Cl	Cl	0	-	1
Co	Co	$2.56 \cdot 10^{2}$	-	3
Cr	Cr	$8.49 \cdot 10^{1}$	√	3
Cs	Cs	$5.12 \cdot 10^{2}$	-	3
Cu	Cu	$2.08 \cdot 10^{2}$	√	3
Dy	Dy	$1.02 \cdot 10^{3}$	-	3
Er	Er	$1.41 \cdot 10^{3}$	-	3
Eu	Eu	$3.13 \cdot 10^{3}$	-	3
F	F	$4.86 \cdot 10^{0}$	√	3
Fe	Fe	$9.61 \cdot 10^{-1}$	√	2.2
Ga	Ga	$2.12 \cdot 10^{2}$	-	3
Gd	Gd	$1.06 \cdot 10^{3}$	-	3
Ge	Ge	$2.12 \cdot 10^{3}$	-	3
H	H	0	-	1
He	He	0	-	1
Hf	Hf	$5.12 \cdot 10^{2}$	-	3
Hg	Hg	$5.30 \cdot 10^{4}$	√	2.2
Ho	Ho	$4.79 \cdot 10^{3}$	-	3
I	I	0	-	1
In	In	$4.87 \cdot 10^{4}$	-	3
Ir	Ir	$5.94 \cdot 10^{7}$	-	3
K	K	$1.00 \cdot 10^{-2}$	-	10
La	La	$9.20 \cdot 10^{1}$	√	3
Li	Li	$1.00 \cdot 10^{-1}$	√	10
Lu	Lu	$1.11 \cdot 10^{4}$	-	3
Mg	Mg	0	√	1
Mn	Mn	$5.64 \cdot 10^{0}$	√	3
Mo	Mo	$2.12 \cdot 10^{4}$	√	3
N	N	0	-	1
Na	Na	0	-	1
Nb	Nb	$1.14 \cdot 10^{2}$	-	3
Nd	Nd	$1.15 \cdot 10^{2}$	-	3
Ne	Ne	0	-	1
Ni	Ni	$1.60 \cdot 10^{2}$	√	2.2
O	O	0	-	1
Os	Os	$5.94 \cdot 10^{7}$	-	3
P	P	$4.47 \cdot 10^{0}$	√	3
Pb	Pb	$1.75 \cdot 10^{2}$	√	2.2
Pd	Pd	$7.43 \cdot 10^{6}$	√	3
Pr	Pr	$4.71 \cdot 10^{2}$	-	3
Pt	Pt	$7.43 \cdot 10^{6}$	√	3

[a] Not implemented in ecoinvent v1.1.

Tab. 10-4 Impact categories and factors for the abiotic stock resources in the EPS default method (Steen 1999b; and EPS website) contd.

Impact category: Depletion of "X" reserves	Category indicator: "X" reserves	Impact index (ELU/kg of element)	Implemented in ecoinvent v1.1 under "Abiotic stock resources"	Uncertainty factor [a]
Rb	Rb	$2.70 \cdot 10^{1}$	-	3
Re	Re	$7.43 \cdot 10^{6}$	√	3
Rh	Rh	$4.95 \cdot 10^{7}$	-	3
Ru	Ru	$2.97 \cdot 10^{7}$	√	3
S	S	$1.00 \cdot 10^{-1}$	√	5
Sb	Sb	$9.58 \cdot 10^{3}$	√	3
Sc	Sc	$4.24 \cdot 10^{2}$	-	3
Se	Se	$3.58 \cdot 10^{4}$	-	3
Sm	Sm	$6.32 \cdot 10^{2}$	-	3
Sn	Sn	$1.19 \cdot 10^{3}$	√	2.2
Sr	Sr	$9.40 \cdot 10^{0}$	-	3
Ta	Ta	$1.98 \cdot 10^{3}$	-	3
Tb	Tb	$5.94 \cdot 10^{3}$	-	3
Te	Te	$5.94 \cdot 10^{5}$	-	3
Th	Th	$2.88 \cdot 10^{2}$	-	3
Ti	Ti	$9.53 \cdot 10^{-1}$	√	3
Tl	Tl	$3.96 \cdot 10^{3}$	-	3
Tm	Tm	$9.90 \cdot 10^{3}$	-	3
U	U	$1.19 \cdot 10^{3}$	√	3
V	V	$5.60 \cdot 10^{1}$	-	3
W	W	$2.12 \cdot 10^{3}$	√	---
Y	Y	$1.43 \cdot 10^{2}$	-	3
Yb	Yb	$1.98 \cdot 10^{3}$	-	3
Zn	Zn	$5.71 \cdot 10^{1}$	√	2.2
Zr	Zr	$1.25 \cdot 10^{1}$	√	3

[a] Not implemented in ecoinvent v1.1.

10.3.3 Emissions into air

In ecoinvent all species emitted to air are divided into five subcategories, depending on the key characteristic of the compartment where they occur: high population density; low population density; low population density, long-term; lower stratosphere + upper troposphere; and, unspecified. EPS ignores this aspect, but deals with emissions anywhere in the world. Therefore, in first approximation it can be assumed that EPS factor for one species is applied to the five subcategories without adjustments. Tab. 10-5 through Tab. 10-8 show the impact categories and indexes for the emissions into air in the EPS default method and their implementation into ecoinvent v1.1.

The emission species CO, CO_2, and methane are categorized in ecoinvent as "biogenic" or "fossil". For the application of any LCIA method, the net emissions shall be considered, to correctly assess the systems using biomass. To achieve this in the present case, the EPS factor for CO_2 is applied positively to all ecoinvent CO_2 elementary emission flows, and negatively to the ecoinvent "resource in air" "Carbon dioxide, in air". This implementation corresponds to applying the EPS factor for CO_2 to the net emission of CO_2 from the system.

The EPS impact index given in (Steen 1999b) for PM_{10} is 36 ELU/kg. However, $PM_{2.5}$ is considered to be the responsible for almost all the impacts, and the EPS index for $PM_{2.5}$ is estimated in (Steen 1999b; Steen 2001) as the double of PM_{10}. Considering the way the particle emissions have been split in ecoinvent, starting from all sorts of information sources available for inventorying them, this implementation of the EPS default method assumes the index 72 ELU/kg for $PM_{2.5}$ and 0.23 ELU/kg (which is the nuisance part of the total impact) for PM of size between 2.5 and 10 µm.[38]

[38] Email exchange with Bengt Steen, June 2004. Also discussed were the indexes for Cr and NMVOC species.

Tab. 10-5 EPS default factors for inorganic emissions into air (Steen 2001, Steen 1999b, EPS website)

Substance flow group	Impact index (ELU/kg)	Implemented in ecoinvent v1.1 under "emissions into air"
CO	$3.31 \cdot 10^{-1}$	√
CO_2	$1.08 \cdot 10^{-1}$	√
H_2S	$4.96 \cdot 10^{0}$	√
HCl	$2.13 \cdot 10^{0}$	√
HF	$2.07 \cdot 10^{0}$	√
N_2O	$3.83 \cdot 10^{1}$	√
NH_3	$1.96 \cdot 10^{0}$	√
NO_x as NO_2	$2.13 \cdot 10^{0}$	√
PM_{10}	$3.60 \cdot 10^{1}$	√
$PM_{2.5}$	$7.20 \cdot 10^{1}$	√
SO_2	$3.27 \cdot 10^{0}$	√
As	$9.53 \cdot 10^{1}$	√
Cd	$1.02 \cdot 10^{1}$	√
Cr	$2.00 \cdot 10^{1}$	√
Hg	$6.14 \cdot 10^{1}$	√
Cu	0	√
Ni	0	√
Pb	$2.91 \cdot 10^{3}$	√
Zn	0	√

The EPS for generic chromium emitted to air is 20 ELU/kg. However, the health effects are caused by the active component Cr-VI (carcinogenic), which in ecoinvent v1.1 has been inventoried separately from Cr-III. Therefore, the EPS index has been adapted for this implementation taking into account its share (26%) to 76.9 ELU/kg. However, in order to keep the balance for total chromium, the other component of total chromium is given 0 (zero) ELU/kg. To be consistent with other implementations of LCIA methods in ecoinvent, "Sodium dichromate" is attributed the same factor for Cr-VI multiplied by 52*2/(52*2+23*2+16*7) = 0.397.

The two sets of NMVOC in EPS – whose impact factors were individually estimated for selected compounds – and in ecoinvent Data v1.1 do not fully match. Applying a general rule within the implementation of LCIA methods into ecoinvent, whenever a specific index existed, it has been used. However, those NMVOC species in ecoinvent not explicitly modelled in EPS have been given the average impact factor for NMVOC of 2.14 ELU/kg. For some of the latter species the real impacts might be probably larger (e.g. for contribution to acidification and toxic effects). However, considering that the actual emissions of these NMVOC species are commonly small, the difference for total EPS score may be relatively small as well.

No model was made for the EPS default method for dioxins because of lack of quantitative risk information. "Ethylene oxide" is known to be a potent carcinogen; however, no modelling was done in (Steen 1999b). Also for "Ethane, 1,1,2-trichloro", "Ethane, 1,2-dichloro-", "Ethane, hexafluoro-, HFC-116", and "Halogenated hydrocarbons, chlorinated" no specific EPS index could be established for lack of information on ODP or GWP. Therefore, for all the emission species mentioned in this paragraph the average EPS factor for NMVOC is applied, although it is acknowledged that it may be (sometimes strongly) underestimated.[39]

[39] Personal communication of Bengt Steen, June 2004.

Tab. 10-6 EPS default factors for organic emission into air (Steen 1999b; and EPS website)

Substance flow group	Impact index (ELU/kg)	Implemented in ecoinvent v1.1 under "emissions into air"
1,2,3-trimethyl benzene	$2.41 \cdot 10^0$	-
1,2,4-trimethyl benzene	$2.38 \cdot 10^0$	-
1,3,5-trimethyl benzene	$2.40 \cdot 10^0$	-
1,3-butadiene	$1.07 \cdot 10^1$	√
1-butene	$2.59 \cdot 10^0$	-
1-pentene	$2.46 \cdot 10^0$	-
2-butene	$2.57 \cdot 10^0$	-
2-methyl 1-butene	$2.40 \cdot 10^0$	-
2-methyl 2-butene	$2.84 \cdot 10^0$	-
2-methyl pentane	$2.43 \cdot 10^0$	-
2-metylheptane	$2.40 \cdot 10^1$	-
2-metyloktane	$2.36 \cdot 10^0$	-
2-methylnonane	$2.45 \cdot 10^0$	-
2-pentene	$2.54 \cdot 10^0$	-
3-methyl pentane	$2.32 \cdot 10^0$	-
acetaldehyde	$2.11 \cdot 10^0$	√
acetone	$1.46 \cdot 10^0$	√
acetylene	$1.64 \cdot 10^0$	as ethine
acrolein	$3.32 \cdot 10^0$	√
allyl chloride	$2.16 \cdot 10^0$	-
Benzene	$3.65 \cdot 10^0$	√
butadiene	$1.07 \cdot 10^1$	√
butane	$2.15 \cdot 10^0$	√
butanol	$2.33 \cdot 10^0$	-
butene	$2.58 \cdot 10^0$	√
butyraldehyde	$2.30 \cdot 10^0$	-
decane	$2.45 \cdot 10^0$	-
Dichlorvos (DDVP)	$7.13 \cdot 10^0$	-
Dieldrin	$7.13 \cdot 10^1$	-
dimethyl ether	$1.66 \cdot 10^0$	-
dodecane	$2.19 \cdot 10^0$	-
ethane	$1.46 \cdot 10^0$	√
ethanol	$1.95 \cdot 10^0$	√
ethylacetate	$1.68 \cdot 10^0$	-
ethylene (ethene)	$3.54 \cdot 10^0$	√
ethylbenzene	$2.11 \cdot 10^0$	-
formaldehyde (CH_2O)	$6.47 \cdot 10^0$	√
heptane	$2.58 \cdot 10^0$	√
hexachlorobenzene	$4.46 \cdot 10^0$	√
hexane	$2.57 \cdot 10^0$	√
i-butane	$1.74 \cdot 10^0$	-
i-butanol	$1.85 \cdot 10^0$	-
i-butylacetate	$1.66 \cdot 10^0$	-
i-butyraldehyde	$2.20 \cdot 10^0$	-
i-pentane	$1.80 \cdot 10^0$	-

Tab. 10-7 EPS default factors for organic emission into air (Steen 1999b; and EPS website) contd.

Substance flow group	Impact index (ELU/kg)	Implemented in ecoinvent v1.1 under "emissions into air"
i-propanol	$1.46 \cdot 10^0$	-
i-propyl benzene	$2.07 \cdot 10^0$	-
isoprene	$2.11 \cdot 10^0$	-
methane	$2.72 \cdot 10^0$	√
methanol	$1.44 \cdot 10^0$	√
methyl chloroform	$1.15 \cdot 10^0$	As Ethane, 1,1,1-trichloro-, HCFC-140
metyl-cyclohexane	$1.87 \cdot 10^0$	-
methyl ethyl ketone	$1.85 \cdot 10^0$	-
methyl i-butyl ketone	$2.37 \cdot 10^0$	-
m-ethyl toluene	$2.28 \cdot 10^0$	-
m-xylene	$2.20 \cdot 10^0$	√
n-butyl acetate	$1.94 \cdot 10^0$	-
nonane	$2.29 \cdot 10^0$	-
n-propyl benzene	$2.07 \cdot 10^0$	-
octane	$2.41 \cdot 10^0$	-
o-ethyl toluene	$2.23 \cdot 10^0$	-
o-xylene	$1.91 \cdot 10^0$	-
pentane	$2.25 \cdot 10^0$	√
p-ethyl toluene	$2.28 \cdot 10^0$	-
PAH (PAC)	$6.43 \cdot 10^4$	√ [a]
propane	$2.24 \cdot 10^0$	√
propene	$2.64 \cdot 10^0$	√
Propionaldehyde	$2.33 \cdot 10^0$	As Propanal
propylene (propene)	$2.64 \cdot 10^0$	√
propylene glycol methyl ether	$2.54 \cdot 10^0$	-
propylene glycol methyl ether acetate	$1.70 \cdot 10^0$	-
p-xylene	$2.25 \cdot 10^0$	-
toluene	$1.95 \cdot 10^0$	√
undecane	$2.34 \cdot 10^0$	-
Valeraldehyde	$2.26 \cdot 10^0$	-
Xylene [b]	$2.17 \cdot 10^0$	-
NMVOC average	$2.14 \cdot 10^0$	Applied to generic NMVOC and specific NMVOC species not modelled in (Steen 1999b) [c]

[a] Index also applied to Benzo(a)pyrene.

[b] Not in (Steen 1999b). Calculated as 60% m-xylene, 9% o-xylene, 14% p-xylene, 17% ethylbenzene, using the corresponding EPS factors, in compliance with other applications of LCIA methods into ecoinvent.

[c] Namely: Acetic acid; Acetic acid, trifluoro-; Aldehydes, unspecified; Benzaldehyde; Benzene, hexachloro-; Benzene, pentachloro-; Carbon disulfide; Chloroform; Epichlorohydrin; Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin; Ethane thiol; Ethane, 1,1,2-trichloro-; Ethane, 1,2-dichloro-; Ethane, hexafluoro-, HFC-116; Ethene, chloro-; Ethene, tetrachloro-; Ethene, trichloro-; Ethylene diamine; Ethylene oxide; Halogenated hydrocarbons, chlorinated; Hydrocarbons, aliphatic, alkanes, cyclic; Hydrocarbons, aliphatic, alkanes, unspecified; Hydrocarbons, aliphatic, unsaturated; Hydrocarbons, aromatic; Isocyanic acid; Monoethanolamine; Nitrobenzene; Paraffins; Phenol; Phenol, pentachloro-; Polychlorinated biphenyls; Propionic acid; Propylene oxide; t-Butyl methyl ether.

Impacts of generic aldehydes emission are not modelled in EPS. Although a weighted average of aldehydes for which individual EPS indexes exist might be defined, due to lack of a generic composition and relevant documentation, the average NMVOC index was used.

Tab. 10-8 EPS default factors for freons and other similar substances to air (Steen 1999b; and EPS website)

Substance flow group		Impact index (ELU/kg) [a]	Implemented in ecoinvent v1.1 under "emissions into air"
CFC's	CFC-11	$5.41 \cdot 10^{2}$	√
	CFC-12	$1.04 \cdot 10^{3}$	√
	CFC-13	$1.39 \cdot 10^{3}$	√
	CFC-113	$6.59 \cdot 10^{2}$	√
	CFC-114	$1.11 \cdot 10^{3}$	√
	CFC-115	$1.08 \cdot 10^{3}$	√
	Arithmetic average for the above CFC's (after (Steen 1999b))	$9.70 \cdot 10^{2}$	Used for: CFC-10
HCFC's	HCFC-22	$1.94 \cdot 10^{2}$	√
	HCFC-123	$1.23 \cdot 10^{1}$	√
	HCFC-124	$5.53 \cdot 10^{1}$	√
	HCFC-141b	$8.06 \cdot 10^{1}$	√
	HCFC-142b	$2.28 \cdot 10^{2}$	as HCFC-142
	HCFC-225ca	$2.13 \cdot 10^{1}$	-
	HCFC-225cb	$6.19 \cdot 10^{1}$	-
	Arithmetic average for the above HCFC's (after (Steen 1999b))	$8.62 \cdot 10^{1}$	Used for: HCFC-21 HCFC-31 HCC-30 [a] R-40 [a]
Bromocarbons	H-1301	$2.20 \cdot 10^{3}$	also used for H-1001, H-1211 [b]
Others	HFC-23	$1.34 \cdot 10^{3}$	√
	HFC-32	$6.42 \cdot 10^{1}$	√
	HFC-43-10mee	$1.77 \cdot 10^{2}$	-
	HFC-125	$3.54 \cdot 10^{2}$	√
	HFC-134	$1.33 \cdot 10^{2}$	-
	HFC-134a	$1.44 \cdot 10^{2}$	√
	HFC-152a	$1.55 \cdot 10^{1}$	√
	HFC-143	$3.21 \cdot 10^{1}$	√
	HFC-143a	$4.87 \cdot 10^{2}$	√
	HFC-227ea	$3.65 \cdot 10^{2}$	√
	HFC-236fa	$8.85 \cdot 10^{2}$	√
	HFC-245ca	$6.75 \cdot 10^{1}$	√
	SF6	$2.76 \cdot 10^{3}$	√
	CF4	$6.97 \cdot 10^{2}$	√
	C2F6	$1.38 \cdot 10^{3}$	√
	c-C4F8	$1.01 \cdot 10^{3}$	-
	C6F14	$7.52 \cdot 10^{2}$	-

[a] Although it is no HCFC, its impacts should be in the approximate range of HCFC's.

[b] This assumption may be affected by high uncertainty.

10.3.4 Emissions into water

Tab. 10-9 shows the impact categories and indexes for the emissions into water in the EPS default method and their implementation into ecoinvent v1.1. Only the EPS factor for BOD is considered while the factor for COD is discarded, in order to prevent double counting. This assumption is applied consistently throughout the implementation of LCIA methods in ecoinvent v1.1.

Tab. 10-9 EPS default factors for emissions into water (Steen 1999b; and EPS website)

Substance flow group	Impact index (ELU/kg)	Implemented in ecoinvent v1.1 under "emissions into water" [a]
BOD	$2.01 \cdot 10^{-3}$	√
COD [b]	$1.01 \cdot 10^{-3}$	-
N-tot	$-3.81 \cdot 10^{-1}$	√ [c]
P-tot	$5.50 \cdot 10^{-2}$	√ [d]
Hg	$1.80 \cdot 10^{2}$	√

[a] For the five ecoinvent Sub-categories: lake; ocean; river; river; long-term; and, unspecified. Not included in the three ecoinvent Sub-categories: fossil water; groundwater; and, groundwater, long-term.

[b] Non implemented in ecoinvent to prevent double counting.

[c] Applied to Nitrogen, organic bound, and Nitrogen. Adapted to Nitrate and Nitrite using the mol relative weight of N in NO_3^- (0.226) and NO_2^- (0.304), respectively.

[d] Applied to Phosphorus. Adapted to Phosphate using the mol relative weight of P in PO_4^{3-} (0.326).

10.3.5 Emissions into soil

Tab. 10-10 shows the impact categories and indexes for the emissions into soil in the EPS default method, pesticides first, then metals, and their implementation into ecoinvent v1.1. Some ecoinvent emissions species to soil are given for four subcategories: soil agricultural; soil forestry; soil industrial; and, soil unspecified. The two given EPS indexes for heavy metals (Cd and Hg) are applied to all of them.

Only a few pesticides included in the EPS list have a corresponding item in the ecoinvent database v1.1 (see Tab. 10-10). Since the published EPS reports do not include explicitly an index for average pesticides, the several un-matching pesticides in ecoinvent v1.1, which is a large fraction of the total, have no index attributed to them (see Section 10.3.7 for further discussion). The relevant list is not included for being too long, but the full pesticides list is easily retrievable from the ecoinvent website. Therefore, the total EPS score for agricultural products and other datasets linked to them should be considered with great prudence, because the total effects from all inventoried pesticides would be possibly somewhat underestimated.

Tab. 10-10 EPS default factors for emissions into soil (Steen 1999b; and EPS website)

Substance flow group	Impact index (ELU/kg)	Implemented in ecoinvent v1.1 under "emissions into soil"
2,4,5, Trichlorophenoxyacetic acid (2,4,5-T)	$3.57 \cdot 10^{-1}$	-
2,4-Dichlorophenoxyacetic acid (2,4-D)	$3.57 \cdot 10^{-1}$	√
Alachlor	$3.57 \cdot 10^{-1}$	-
Aldicarb	$3.57 \cdot 10^{0}$	-
Aldrin	$1.19 \cdot 10^{2}$	-
Atrazine	$1.02 \cdot 10^{-1}$	√
Benomyl	$7.13 \cdot 10^{-2}$	As Carbendazim
Captan	$2.74 \cdot 10^{-2}$	√
Carbaryl	$3.57 \cdot 10^{-2}$	-
Carbofuran	$7.13 \cdot 10^{-1}$	-
Chlordane	$7.13 \cdot 10^{0}$	-
Chlorpyrifos	$1.19 \cdot 10^{0}$	√
Cypermethrin	$3.57 \cdot 10^{-1}$	√
Demeton	$8.92 \cdot 10^{1}$	-
Dichlorvos (DDVP)	$7.13 \cdot 10^{0}$	-
Dieldrin	$7.13 \cdot 10^{1}$	-
Diflubenzuron	$1.78 \cdot 10^{-1}$	-
Dimethoate	$8.92 \cdot 10^{0}$	-
Diquat	$1.62 \cdot 10^{0}$	√
Disulfoton	$8.92 \cdot 10^{1}$	-
Endosulfan	$5.94 \cdot 10^{-1}$	-
Endrin	$1.19 \cdot 10^{1}$	-
Fenamiphos	$1.43 \cdot 10^{1}$	-
Glyphosate	$3.57 \cdot 10^{-2}$	√
Heptachlor	$7.13 \cdot 10^{0}$	-
Hexachlorbenzene	$4.46 \cdot 10^{0}$	-
Lindane	$1.19 \cdot 10^{1}$	√
Malathion	$1.78 \cdot 10^{-1}$	-
Methomyl	$1.43 \cdot 10^{-1}$	-
Methoxychlor	$7.13 \cdot 10^{-1}$	-
Naled	$1.78 \cdot 10^{0}$	-
Oxamyl	$1.43 \cdot 10^{-1}$	-
Paraquat	$7.93 \cdot 10^{-1}$	-
Permethrin	$7.13 \cdot 10^{-2}$	-
Phosphine	$1.19 \cdot 10^{1}$	-
Pirimifos-methyl	$3.57 \cdot 10^{-1}$	-
Propachlor	$2.74 \cdot 10^{-1}$	-
Resmethrin	$1.19 \cdot 10^{-1}$	-
Sodium fluoracetate	$1.78 \cdot 10^{2}$	-
Thallium sulfate	$4.46 \cdot 10^{1}$	-
Thiram	$7.13 \cdot 10^{-1}$	-
Warfarin	$1.19 \cdot 10^{1}$	-
Zinc phosphide	$1.19 \cdot 10^{1}$	-
Cd	$5.00 \cdot 10^{0}$	√
Hg	$1.80 \cdot 10^{2}$	√

10.3.6 Land occupation

Tab. 10-11 shows the impact categories and indexes for land use activities in the EPS default method and their implementation into ecoinvent v1.1. The impacts depend on a reference state and a use type. Reference states in EPS are forests, agricultural areas, and impediments. Use types are hard making (i.e., nothing grows), forestry, and agriculture. If an activity (e.g., a dumpsite) for which there is some form of hard making is located in areas originally forested, hard making of forest areas is relevant. If the activity is located on agricultural land it should ideally be hard making of agricultural land, but no such models were made in (Steen 1999b). In ecoinvent the information on the original status of land can be included as “transformation” and therefore is decoupled from “occupation” figures. Therefore, an allocation of results for occupation classes to EPS reference states cannot be done. However, considering that at some point of time there was forest, it is reasonable to use the index for hard making of forest land for all categories related to transport systems, industrial (built) sites, dump sites on land, and urban built areas.[40]

No factors are given in EPS for water surfaces and sea ground occupation. EPS default method does not valuate land transformation.

Tab. 10-11 EPS default factors for land use activities (Steen 1999b; and EPS website)

Activity	Unit	Impact index (ELU/unit)	Implemented in ecoinvent v1.1 under “land occupation”
Arable land use	m^2a	$1.562 \cdot 10^{-3}$	√ [a]
Forestry	m^2a	$5.50 \cdot 10^{-4}$	√ [b]
Forestry	m^3	$6.25 \cdot 10^{0}$	-
Hard making of forest land	m^2a	$4.55 \cdot 10^{-2}$	√ [c]
Littering	m^2	$1.39 \cdot 10^{1}$	-

[a] Applied to the ecoinvent Sub-categories for Occupation: arable; arable, non-irrigated; arable, non-irrigated, diverse-intensive; arable, non-irrigated, fallow; arable, non-irrigated, monotone-intensive; heterogeneous, agricultural; pasture and meadow; pasture and meadow, extensive; pasture and meadow, intensive; permanent crop; permanent crop, fruit ; permanent crop, fruit, extensive ; permanent crop, fruit, intensive; permanent crop, vine; permanent crop, vine, extensive; permanent crop, vine, intensive; and, shrub land, sclerophyllous.

[b] Applied to the ecoinvent Sub-categories for Occupation: forest, extensive; forest, intensive; forest, intensive, clear-cutting; forest, intensive, normal; and, forest, intensive, short-cycle.

[c] Applied to the ecoinvent Sub-categories for Occupation: traffic area, rail embankment; traffic area, rail network; traffic area, road embankment; traffic area, road network; construction site; dump site; industrial area; industrial area, built up; mineral extraction site; urban, continuously built; and, urban, discontinuously built.

10.3.7 Indexes not included

Steen valuated the health effects of radioactive emissions to air, water, and soil from the nuclear system as $7.67 \cdot 10^{-4}$ ELU/MJe (i.e., $2.76 \cdot 10^{-3}$ ELU/kWh), after the assessment of YOLL made in (Edlund 2001).[41] However, in ecoinvent on the one hand the radioactive emissions have been inventoried in terms of kBq for individual isotopes or classes of isotopes, and on the other hand they originate not only from the nuclear system (primarily) but also from coal and oil/gas energy systems. They enter the LCI results of every ecoinvent datasets predominantly through electricity consumptions. Therefore, an application of the EPS estimation into ecoinvent would require the conversion of the given index into ELU/kBq isotope by isotope, which is not possible in a straightforward manner but it would require a major task. Anyway, the above summary factor may be

[40] Email exchange with Bengt Steen, June 2004.

[41] Personal communication of Bengt Steen, June 2004.

used case by case to have a rough estimation of the consequence of the inclusion of radioactivity into EPS through the use of nuclear electricity in the datasets of interest.

Other not included indexes concern non documented ones. They could not be implemented into ecoinvent v1.1 because of the general internal rule that requires availability of published data, although the items shortly addressed in the following were proposed by and discussed with the author of the EPS methodology. This list may serve future updates of the EPS implementation.

The EPS impact index for “Benzaldehyde” has been recently estimated as 3.64 ELU/kg, but in ecoinvent it has been given the average for NMVOC of 2.14 ELU/kg. “Benzo(a)pyrene” is the major contributor to the PAH index, with a share of about 10%. Along with the EPS index definition, a value 10 times the PAH value, i.e. 643000 ELU/kg, was suggested. However, also due to consistency problem with the index for total PAH, the EPS index for generic PAH has been assumed in ecoinvent. The index for “Chloroform” (Trichloromethane) has been calculated as 8.59 ELU/kg, but it has been given the average for NMVOC of 2.14 ELU/kg. Carbon disulfide is not modelled in EPS. Although the index for H_2S of 6.89 ELU/kg might be used, due to lack of specific documentation, also for this species the average NMVOC index was attributed.

An EPS average factor for pesticides of 16.61 ELU/kg can be calculated from the data in (Steen 1999b). This average index is obtained considering WHO data on total health effects (mainly excess mortality) and the total mass of pesticides as a whole. The model for determining EPS indexes for the individual pesticides selected in (Steen 1999b) allocates the impacts on the basis of their toxicity. Because of lack of statistics on the use of individual compounds, equal amounts were assumed in the EPS default method for each of them. In other words, the average EPS index would not change just because of the inclusion of further individual pesticides. For lack of specific documentation, this index has not been used for those many pesticides in ecoinvent v1.1 that have no corresponding individual EPS index.

10.4 Quality considerations

Only 26% of the elementary flows in the ecoinvent database have been given a corresponding index in EPS 2000, according to the described implementation. On the other hand, some of the items in EPS 2000 do not have a corresponding ecoinvent elementary flow, as illustrated in the tables in the previous sections. Therefore, the user of EPS results contained in ecoinvent v1.1 should carefully consider the characteristics and limitations of this implementation before drawing conclusions.

Abbreviations

CVM	Contingent Valuation Method
ECU	European Currency Unit (now: Euro)
ELU	Environmental Load Units
EPS	Environmental Priority Strategy in product design
GWP	Greenhouse Warming Potential
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
NEX	Normalized Extinction of Species
NMVOC	Non-Methane Volatile Organic Compounds
ODP	Ozone Depletion Potential
OECD	Organisation for Economic Cooperation and Development
PAC	Polycyclic Aromatic Compounds
PAH	Polycyclic Aromatic Hydrocarbons
WHO	World Health Organization
WTP	Willingness To Pay
YOLL	Years of Life Lost

Appendices

Examples of estimation of EPS Indexes for Emissions and Resources

Emission example: CO_2 to air

The possible effects of CO_2 emissions to air and the corresponding pathways included in the EPS default method are shown in Tab. 10-12 as an example of the application of the WTP approach. The impact group is global due to the nature of the emission and its long residence time in the atmosphere. Only the estimation of the first item "life expectancy–heat stress" is described. The assumed scenario (IS92A) is taken from (IPCC 1990), which gives the total emission of carbon dioxide over 100 years (14 Pg-C). The time for the integration of the effects is also assumed 100 years. Excess mortality due to an average temperature increase of 1.5ºC is estimated in (Steen 1999b) as 5.9 million YOLL per year over 100 years. The above items combined give the characterization factor $7.43 \cdot 10^{-8}$ YOLL/kgCO_2. This factor multiplied by the weighting factor of $8.5 \cdot 10^{4}$ ELU/YOLL from Tab. 10-12 gives the contribution of the effects (YOLL) of heat stress from 1 kg of CO_2 to the total EPS factor for CO_2. The factor of $8.5 \cdot 10^{4}$ ELU/YOLL was determined in (Steen 1999b) by taking the value of the statistical life in the ExternE project (1995) of 2.6 million EUR (1990 value), modifying it to 3.2 million EUR (1998 value) and assuming an average shortening of life of 37.5 years due to random accidents over 75 years average lifetime in the OECD countries.

Tab. 10-12 Characterization of CO_2 air emissions for the estimation of the corresponding EPS index (Steen 1999b)

Impact category (Indicator) [a]	Pathway	Pathway specific characterization factor (Indicator/kg)	Indicator's contribution to EPS default impact index (ELU/kg)	EPS default impact index (ELU/kg)
Life expectancy (YOLL) [b]	Heat stress	$7.43 \cdot 10^{-8}$		
	Starvation	$6.80 \cdot 10^{-7}$		
	Flooding	$5.70 \cdot 10^{-9}$		
	Malaria	$3.30 \cdot 10^{-8}$		
	All pathways	$7.93 \cdot 10^{-7}$	$6.74 \cdot 10^{-2}$	
Severe morbidity	Starvation	$3.15 \cdot 10^{-7}$		
	Malaria	$3.80 \cdot 10^{-8}$		
	All pathways	$3.53 \cdot 10^{-7}$	$3.53 \cdot 10^{-2}$	
Morbidity	Starvation	$3.15 \cdot 10^{-7}$		
	Malaria	$3.40 \cdot 10^{-7}$		
	All pathways	$6.55 \cdot 10^{-7}$	$6.55 \cdot 10^{-3}$	
Crop production capacity (Crop)	Desertification	$7.56 \cdot 10^{-4}$	$1.13 \cdot 10^{-4}$	
Wood production capacity (Wood)	Global warming	$-1.16 \cdot 10^{-3}$		
	CO_2 fertilization	$-3.93 \cdot 10^{-2}$		
	All pathways	$-4.05 \cdot 10^{-2}$	$-8.09 \cdot 10^{-4}$	
Extinction of species (NEX) [c]	Climate change	$1.26 \cdot 10^{-14}$	$1.39 \cdot 10^{-3}$	
All	All			$1.08 \cdot 10^{-1}$

[a] When the parentheses are missing, the name of the Indicator equals the name used for the Impact category.

[b] Years Of Life Lost.

[c] Normalized Extinction of Species.

Abiotic resource example: Aluminium

For the production of aluminium using current technology, aluminium oxide is leached by NaOH to give sodium aluminate, which is then neutralized with sulphuric acid to give aluminium hydroxide. In (Steen 1999b) the energy resource use (natural gas, lignite, coal, and oil) and the emissions (CH_4, CO_2, NMVOC, NO_x and SO_x) for the entire process, including the production of NaOH and H_2SO_4, are accounted for to calculate the total ELU/kg-Al, using the EPS factors for individual energy resources and emissions. The EPS weighting factor for Al is then estimated from the previous assuming that only wood energy is used instead of fossil, NMVOC emission is entirely avoided, and NO_x and SO_x are reduced by 50% and 90%, respectively. Therefore, the total external cost for this sustainable process is calculated as 0.439 ELU/kg-Al, which is used as EPS default method value for elemental Al.

EcoSpold Meta Information

The full meta information can be assessed via the homepage www.ecoinvent.org/. The following table shows only an excerpt for illustration.

Type	ID	Field name			
ReferenceFunction	495	Category	EPS 2000	EPS 2000	EPS 2000
	496	SubCategory	total	total	total
	401	Name	abiotic stock resources	emissions into air	total
Geography	662	Location	GLO	GLO	GLO
ReferenceFunction	403	Unit	ELU	ELU	ELU
DataSetInformation	201	Type	4	4	4
	202	Version	1.1	1.1	1.1
	203	energyValues	0	0	0
	205	LanguageCode	en	en	en
	206	LocalLanguageCode	de	de	de
DataEntryBy	302	Person	51	51	51
	304	QualityNetwork	1	1	1
ReferenceFunction	400	DataSetRelatesToProduct	0	0	0
	404	Amount	1	1	1
	490	LocalName	Abiotische Ressourcen	Luftemissionen	Total
	491	Synonyms	Environmental Priority Strategy in product design//EPS default method	Environmental Priority Strategy in product design//EPS default method	Environmental Priority Strategy in product design//EPS default method
	492	GeneralComment	The Environmental Priority Strategy in product design (EPS) is an environmental-accounting method, which describes impacts (changes) to the environment as impacts to specific safeguards objects: biodiversity, production, human health, resources, and aesthetic values. These impacts are valued on a relative scale in Environmental Load Units (ELU; 1 ELU = 1 Euro) according to the willingness to pay to avoid negative effects on the safeguard objects. The EPS default method, herewith applied, focuses on damage or end point effects. This dataset provides the contribution from abiotic stock resurces to the total EPS score.	The Environmental Priority Strategy in product design (EPS) is an environmental-accounting method, which describes impacts (changes) to the environment as impacts to specific safeguards objects: biodiversity, production, human health, resources, and aesthetic values. These impacts are valued on a relative scale in Environmental Load Units (ELU; 1 ELU = 1 Euro) according to the willingness to pay to avoid negative effects on the safeguard objects. The EPS default method, herewith applied, focuses on damage or end point effects. This dataset provides the contribution from emissions into air to the total EPS score.	The Environmental Priority Strategy in product design (EPS) is an environmental-accounting method, which describes impacts (changes) to the environment as impacts to specific safeguards objects: biodiversity, production, human health, resources, and aesthetic values. These impacts are valued on a relative scale in Environmental Load Units (ELU; 1 ELU = 1 Euro) according to the willingness to pay to avoid negative effects on the safeguard objects. The EPS default method, herewith applied, focuses on damage or end point effects. This dataset provides the total EPS score.
	497	LocalCategory	EPS 2000	EPS 2000	EPS 2000
	498	LocalSubCategory	Total	Total	Total
TimePeriod	601	StartDate	1990	1990	1990
	602	EndDate	1999	1999	1999
	603	DataValidForEntirePeriod	1	1	1
	611	OtherPeriodText	Time of publication.	Time of publication.	Time of publication.
Geography	663	Text	Modelling for a global situation.	Modelling for a global situation.	Modelling for a global situation.
DataGenerator AndPublication	751	Person	51	51	51
	756	DataPublishedIn	2	2	2
	757	ReferenceToPublishedSource	3	3	3
	758	Copyright	1	1	1
	759	AccessRestrictedTo	0	0	0
	760	CompanyCode			
	761	CountryCode			
	762	PageNumbers			

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Ryding & Steen 1991	Ryding S.-O. and Steen B. (1991) The EPS System. A PC-based System for Development and Application of Environmental Priority Strategies in Product Design - From Cradle to Grave. IVL-report Nr B 1022 (In Swedish). IVL, Gothenburg, Sweden.
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Steen 1999b	Steen B. (1999b) A systematic approach to environmental priority strategies in product development (EPS). Version 2000 - Models and data of the default method. CPM Report 1999b. Technical Environmental Planning, Chalmers University of Technology, Gothenburg, Sweden, retrieved from: http://eps.esa.chalmers.se/download.htm#item2.
Steen 2001	Steen B. (2001) Identification of significant environmental aspects and their indicators. NORDEPE, CPM Report Nr 2001:7. Chalmers University of Technology, Gothenburg, Sweden.

11 IMPACT 2002+

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Review: Thomas Nemecek

Last changes: 2007

Summary

IMPACT 2002+ is an impact assessment methodology originally developed at the Swiss Federal Institute of Technology, - Lausanne (EPFL), with current developments carried out by the same team of researchers now under the name of ecointesys-life cycle systems (Lausanne). The present methodology proposes a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results (elementary flows and other interventions) via 14 midpoint categories to four damage categories (Jolliet et al., 2003b). This takes advantages both from midpoint-based indicators such as CML (Guinée et al., 2001) and from damage based methodologies as Eco-indicator 99 (Goedkoop & Spriensma, 2000).

The characterization factors for Human Toxicity and Aquatic & Terrestrial Ecotoxicity are taken from the methodology IMPACT 2002 - IMPact Assessment of Chemical Toxics (Pennington et al., 2005). The characterization factors for other categories are adapted from existing characterizing methods, i.e. Eco-indicator 99, CML 2001, IPCC and the Cumulative Energy Demand (see chapter 1).

For IMPACT 2002+ new concepts and methods have been developed, especially for the comparative assessment of human toxicity and ecotoxicity. Human Damage Factors are calculated for carcinogens and non-carcinogens, employing intake fractions, best estimates of dose-response slope factors, as well as severities. The transfer of contaminants into the human food is no more based on consumption surveys, but accounts for agricultural and livestock production levels. In addition, the intermittent character of rainfall is considered. Both human toxicity and ecotoxicity effect factors are based on mean responses rather than on conservative assumptions.

The IMPACT 2002+ method (version 2.1) presently provides characterization factors for almost 1500 different LCI-results, which can be downloaded at http://www.epfl.ch/impact

11.1 Introduction

In order to use the impact assessment method IMPACT 2002+ (Jolliet et al., 2003b), it is necessary to link elementary flows of the life cycle inventory data to the respective characterization factors of this impact assessment method. This background paper describes the implementation of IMPACT 2002+ including difficulties in the assignment and how these have been overcome by assumptions. Tab. 11-1 shows an overview of IMPACT 2002+ method implemented in the ecoinvent database.

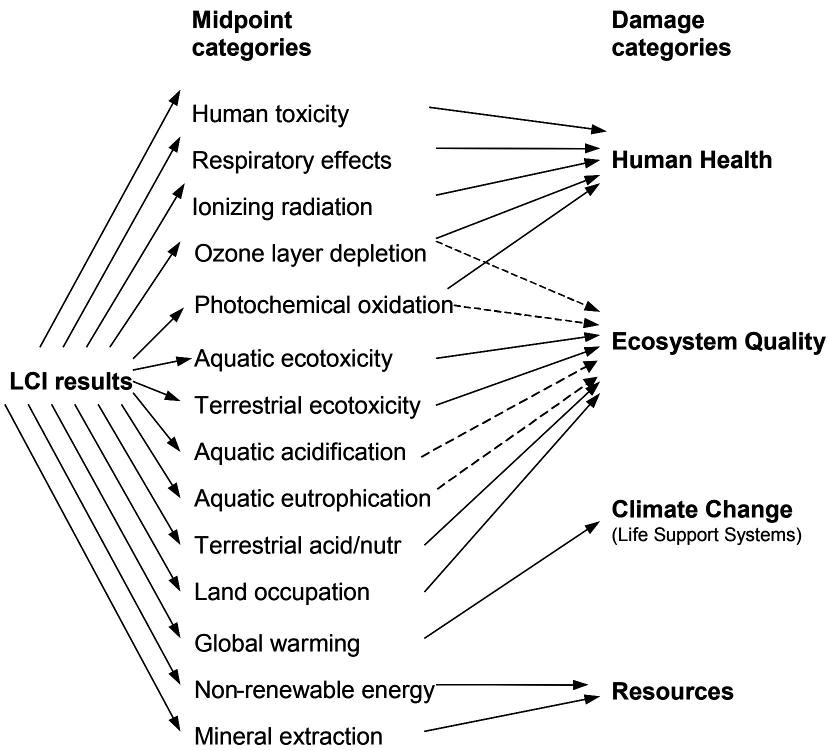
Tab. 11-1 Impact Assessment Methods implemented in the database ecoinvent

Name	LocalName	Locati	Unit	LocalCategory	LocalSubCategory	Category	SubCategory
aquatic acidification	Aquatische Versauerung	RER	kg SO2-Eq	IMPACT 2002+ (Zwischenpunkt)	Ökosystemqualität	IMPACT 2002+ (Midpoint)	ecosystem quality
aquatic eutrophication	Aquatische Eutrophierung	RER	kg PO4-Eq	IMPACT 2002+ (Zwischenpunkt)	Ökosystemqualität	IMPACT 2002+ (Midpoint)	ecosystem quality
aquatic ecotoxicity	Aquatische-Ökotoxizität	RER	points	IMPACT 2002+ (Endpunkt)	Ökosystemqualität	IMPACT 2002+ (Endpoint)	ecosystem quality
terrestrial ecotoxicity	Boden-Ökotoxizität	RER	points	IMPACT 2002+ (Endpunkt)	Ökosystemqualität	IMPACT 2002+ (Endpoint)	ecosystem quality
terrestrial acidification & nutrification	Boden Versauerung & Eutrophierung	RER	points	IMPACT 2002+ (Endpunkt)	Ökosystemqualität	IMPACT 2002+ (Endpoint)	ecosystem quality
land occupation	Landnutzung	RER	points	IMPACT 2002+ (Endpunkt)	Ökosystemqualität	IMPACT 2002+ (Endpoint)	ecosystem quality
human toxicity	Humantoxizität	RER	points	IMPACT 2002+ (Endpunkt)	Menschliche Gesundheit	IMPACT 2002+ (Endpoint)	human health
respiratory effects (inorganics)	Atemwegserkrankungen (inorganisch)	RER	points	IMPACT 2002+ (Endpunkt)	Menschliche Gesundheit	IMPACT 2002+ (Endpoint)	human health
ionising radiation	Ionisierende Strahlung	RER	points	IMPACT 2002+ (Endpunkt)	Menschliche Gesundheit	IMPACT 2002+ (Endpoint)	human health
ozone layer depletion	Ozonabbau	RER	points	IMPACT 2002+ (Endpunkt)	Menschliche Gesundheit	IMPACT 2002+ (Endpoint)	human health
photochemical oxidation	Photochemische Oxidation	RER	points	IMPACT 2002+ (Endpunkt)	Menschliche Gesundheit	IMPACT 2002+ (Endpoint)	human health
climate change	Klimawandel	RER	points	IMPACT 2002+ (Endpunkt)	Klimawandel	IMPACT 2002+ (Endpoint)	climate change
non-renewable energy	Nicht-erneuerbare Energie	RER	points	IMPACT 2002+ (Endpunkt)	Ressourcen	IMPACT 2002+ (Endpoint)	resources
mineral extraction	Mineralien	RER	points	IMPACT 2002+ (Endpunkt)	Ressourcen	IMPACT 2002+ (Endpoint)	resources
total	Total	RER	points	IMPACT 2002+ (Endpunkt)	Ökosystemqualität	IMPACT 2002+ (Endpoint)	ecosystem quality
total	Total	RER	points	IMPACT 2002+ (Endpunkt)	Menschliche Gesundheit	IMPACT 2002+ (Endpoint)	human health
total	Total	RER	points	IMPACT 2002+ (Endpunkt)	Klimawandel	IMPACT 2002+ (Endpoint)	climate change
total	Total	RER	points	IMPACT 2002+ (Endpunkt)	Ressourcen	IMPACT 2002+ (Endpoint)	resources

IMPACT 2002+ impact assessment methodology is strongly based on preliminary outcomes from the LCIA (life cycle impact assessment) definition study of the SETAC-UNEP Life Cycle Initiative (Jolliet et al., 2003a). The present methodology is based on a structured midpoint- and damage-oriented approach of LCIA.

LCIA methods aim to connect, as far as possible, and desired, each LCI result to the environmental damages caused. As shown in Fig. 11.1, LCI results with similar impact pathways (e.g. all elementary flows influencing stratospheric ozone concentrations) are grouped into impact categories at midpoint level, also called midpoint categories. A midpoint indicator characterizes the elementary flows and other environmental exchanges that contribute to the same midpoint category.

Fig. 11.1 Overall scheme of the IMPACT 2002+ framework, linking LCI results via the midpoint categories to damage categories. Based on Jolliet et al. (2003a)



The term 'midpoint' expresses the view that this point is located somewhere on the impact pathway as an intermediate point between the LCI results and the damage or endpoint of the pathways. In consequence, a further step may allocate these midpoint categories to one or more damage categories, the latter representing quality changes of the environment. A damage indicator result is the quantified representation of this quality change. In practice, a damage indicator result is always a simplified model of a very complex reality, giving only a coarse approximation of the result.

Fig. 11.1 shows the overall scheme of the IMPACT 2002+ framework, linking all types of LCI results via the 14 midpoint categories (human toxicity, respiratory effects, ionising radiation, ozone layer depletion, photochemical oxidation, aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acidification/nutrification, aquatic acidification, aquatic eutrophication, land occupation, global warming, non-renewable energy, mineral extraction) to the damage categories (human health, ecosystem quality, climate change, resources). An arrow symbolizes that a relevant impact pathway is known or assumed to exist between the two corresponding elements. Uncertain impact pathways between midpoint and damage levels are shown as dotted arrows.

In the current version (2.1) of IMPACT 2002+, endpoint and midpoint factors are all normalized in respect to the overall endpoint results. Only the two midpoint categories aquatic acidification and eutrophication are expressed in kg-equivalents of reference substance, because the link to the endpoint is still not scientifically established (see also Tab. 11-1). A more comprehensive and complete version of the method can be downloaded at http://www.epfl.ch/impact. This version includes many additional characterization factors for inventory flows not included in ecoinvent, especially for human and ecotoxicological impact categories, and midpoint. This is because ecoinvent is only interested in assessing the impact of inventory flows included in its database and not in providing comprehensive LCIA methodologies.

We strongly recommend all users to refer to the original publication (Jolliet et al., 2003b) and to the user guide (Humbert et al., 2005) for a better understanding of the IMPACT 2002+ methodology, which can be found on the aforementioned web site.

11.1.1 Normalization and weighting

The damage factor reported in ecoinvent are normalized by dividing the impact per unit of emission by the total impact of all substances of the specific category for which characterization factors exist, per person per year (for Europe). The unit of all normalized midpoint/damage factors is therefore [pers·year/unit$_{emission}$][42], i.e. the number of equivalent persons affected during one year per unit of emission. An overview of normalization factors for the four damage categories is given in Tab. 11-2.

Tab. 11-2 Normalization factors for the four damage categories for Western Europe

Damage categories	Normalization factors	Unit
Human health	0.0071	DALY/pers/yr
Ecosystem Quality	13700	PDF.m^2.yr/pers/yr
Climate Change	9950	kg CO_2/pers/yr
Resources	152000	MJ/pers/yr

The authors suggest to analyze normalized scores at damage level considering the four-damage oriented impact categories human health, ecosystem quality, climate change, and resources or, alternatively, the 14 midpoint indicators separately for the interpretation phase of LCA. However, if aggregation is needed, one could use self-determined weighting factors or a default weighting factor of one, unless other social weighting values are available.

11.2 Implementation

Long Term emissions (LT emissions). In the life cycle impact assessment (LCIA) we are evaluating as a default LT emissions equal to present emissions (same characterization factor), as there is little reason that a pollutant emission in 2000 years is less harmful than in the present. However, the developers of IMPACT 2002+ strongly recommend that long and short term emissions should never be directly added up. This is particularly the case for persistent chemicals as heavy metals.

Short-term emissions shall be first evaluated and not added up with the obtained impact scores of LT emissions. These latter - for which the same characterization factors as for short-term emissions are used in ecoinvent – should only be considered within a sensitivity study to check if these pollutants could potentially represent a problem for future generations, being however conscious that uncertainty on those estimations might be extremely important. In addition it is not clear if these LT

[42] The units can be [kg$_{emitted}$], [Bq$_{emitted}$], or [m$^2_{used}$·year]

emissions+exposure are higher than the LT natural emissions+exposure, which could have occurred anyway without human intervention (as a substitution principle). If stabilisation can be considered comparable to nature, in some respect there is no increase in emission levels. See also Chapter 2.1.3 for a wider discussion on LT emissions.

Emission of metals. The user should be aware that current LCIA methods have problems in modelling speciation, bioavailability and bioconcentration of metals, both for short term and long term emissions. Current characterization factors of IMPACT 2002+ only apply for metals emitted in dissolved and bioavailable form (ions). Therefore, metal emissions have to be appropriately specified in the life cycle inventory analysis. If this distinction is not specified and the CF are applied to the total metal emission, the overall assessment is definitely overestimated.

11.2.1 Emissions to air

Introduced subcategories are: *low population density, long-term low population density*, *lower stratosphere + upper troposphere*, *high population density* and *unspecified*.

Characterization factors are the same for *high population density*, *low population density, long-term low population density* and *unspecified*.

For emissions in *lower stratosphere + upper troposphere* characterization factors are only available for ozone layer depletion and global warming. It is assumed that these emissions don't have any effects on human health outside of the depletion of the ozone layer and on ecosystems quality.

Particulate matter:

PM respiratory effects are determined based on epidemiological studies and includes both carcinogenic and non-carcinogenic effects. Ecoinvent clearly distinguish 3 categories of particle emissions. IMPACT 2002+ only assign a characterization factor for "Particulates < 2.5 µm". According to *Dockery and Pope (1994)* particles above 2.5 µm have no adverse effects, thus for "Particulates, > 2.5 µm, and < 10µm" and "Particulates, > 10 µm" a characterization factor equals 0 is assigned.

"Carbon dioxide, biogenic" and *"Carbon monoxide, biogenic"* and *"Methane, biogenic"* have been assigned a GWP of 0.

"Hydrocarbons, aromatic" are considered as *"PAH, polycyclic aromatic hydrocarbons"*.

Characterization factor for *"PAH, polycyclic aromatic hydrocarbons"* is set to 10% of the value of the characterization factor for "*Benzo(a)pyrene"*.

"Hydrocarbons, aliphatic, alkanes, cyclic" and *"Hydrocarbons, aliphatic, alkanes, unspecified"* have been assigned the same characterization factor, equal to the one of *"Alkanes"* in IMPACT 2002+ v2.1.

11.2.2 Emissions to water

Introduced subcategories are: *lake*, *river long-term river* and *unspecified*.

Omitted subcategories in the impact assessment method are: *groundwater, long-term groundwater*, *ocean* and *fossil-water*.

Characterization factors are the same for *river*, *long-term river, lake* and *unspecified*.

Impacts caused by emissions in *ocean water* and *groundwater* could not yet be estimated due to the lack of the appropriate models.

Characterization factor for aquatic eutrophication for BOD_5 is estimated to be the same as the one for *COD*.

11.2.3 Emissions to soil

All subcategories of the inventories in ecoinvent 2000 have been introduced: *agriculture*, *forestry*, *industrial* and *unspecified*.

Characterization factors are the same for emissions to *forestry*, *industrial* and *unspecified*. Impacts on human health caused by emissions to *agricultural* soil are higher than impacts for the same emission into another type of soil. This is because only 22%[43] (1/4.6) of the European surface is used as agricultural soil. As this compartment is directly linked with chemical exposure via agricultural produce, one has to take into account that an emission to *agricultural* soil is not spread out over all Europe, but concentrates by a factor 4.6 in the area where the food is produced. This multiplicative factor is taken into account in the CFs, by multiplying all the food exposure pathways by 4.6.

11.2.4 Resource uses

Introduced subcategories are: *in ground* and *land*.

Omitted subcategories in IMPACT 2002+ (for which no CF are given) are: *in air*, *biotic* and *in water.*

Land transformation and occupation

IMPACT 2002+ only takes into account land occupation (called *land* in the database). Land transformation is not considered.

Energy resources

Basic non-renewable energies have been introduced for energy consumption (called *resource/ground* in the database) and are in line with the cumulative energy demand methodology adopted by ecoinvent. Non-renewable cumulative energy demand for fossil fuel and nuclear resources are directly taken into account from Table 1.4 (Chapter 1, Part II) of this document . These basic non-renewable energies are: "Coal, brown, in ground" (lignite), "Coal, hard, unspecified, in ground", "Gas, mine, off-gas, process, coal mining", "Gas, natural, in ground", "Uranium, in ground", "Oil, crude, in ground" and "Peat, in ground"

11.3 Quality considerations

The uncertainty of the characterisation factors is not addressed. A discussion on this topic can be found in the User Guide of IMPACT 2002+ (to be found at http://www.epfl.ch/impact). Generally speaking, uncertainties on global warming and resources are low compared to the ones on human health and ecosystem quality. When assessing impacts in those two latter categories, one should consider all inventory flows that have a contribution over 1% to the total damage score as potentially important, as uncertainties are estimated being about two orders of magnitude.

[43] Value used in IMPACT 2002+.

Appendices

EcoSpold Meta Information

The full meta information can be accessed via the homepage www.ecoinvent.org. The following table shows an example.

Type	ID	Field name						
ReferenceFunctio	495	Category	IMPACT 2002+ (Midpoint)	IMPACT 2002+ (Midpoint)	IMPACT 2002+ (Endpoint)	IMPACT 2002+ (Endpoint)	IMPACT 2002+ (Endpoint)	IMPACT 2002+ (Endpoint)
	496	SubCategory	ecosystem quality	ecosystem quality	ecosystem quality	human health	climate change	resources
	401	Name	aquatic acidification	aquatic eutrophication	total	total	total	total
Geography	662	Location	RER	RER	RER	RER	RER	RER
ReferenceFunctio	403	Unit	kg SO2-Eq	kg PO4-Eq	points	points	points	points
DataSetInformatic	201	Type	4	4	4	4	4	4
	202	Version	2.0	2.0	2.0	2.0	2.0	2.0
	203	energyValues	0	0	0	0	0	0
	205	LanguageCode	en	en	en	en	en	en
	206	LocalLanguageCode	de	de	de	de	de	de
DataEntryBy	302	Person	20	20	20	20	20	20
	304	QualityNetwork	1	1	1	1	1	1
ReferenceFunctio	400	DataSetRelatesToProduc	0	0	0	0	0	0
	404	Amount	1	1	1	1	1	1
	490	LocalName	Aquatische Versauerun	Aquatische Eutrophieru	Total	Total	Total	Total
	491	Synonyms						
	492	GeneralComment	Methodology based on a structured midpoint- and damage-oriented approach of LCIA	Methodology based on a structured midpoint- and damage-oriented approach of LCIA	Methodology based on a structured midpoint- and damage-oriented approach of LCIA. Normalization factor = 13700 [PDF*m2*yr/pers-yr]	Methodology based on a structured midpoint- and damage-oriented approach of LCIA. Normalization factor = 0.068 [DALY/pers-yr]	Methodology based on a structured midpoint- and damage-oriented approach of LCIA. Normalization factor = 9950 [kgCO2eq/pers-yr]	Methodology based on a structured midpoint- and damage-oriented approach of LCIA. Normalization factor = 152000 [MJ/pers-yr]
	497	LocalCategory	IMPACT 2002+ (Zwischenpunkt)	IMPACT 2002+ (Zwischenpunkt)	IMPACT 2002+ (Endpunkt)	IMPACT 2002+ (Endpunkt)	IMPACT 2002+ (Endpunkt)	IMPACT 2002+ (Endpunkt)
	498	LocalSubCategory	Ökosystemqualität	Ökosystemqualität	Ökosystemqualität	Menschliche Gesundheit	Klimawandel	Ressourcen
TimePeriod	601	StartDate	2002	2002	2002	2002	2002	2002
	602	EndDate	2004	2004	2004	2004	2004	2004
	603	DataValidForEntirePeriod	1	1	1	1	1	1
	611	OtherPeriodText						
Geography	663	Text	Midpoint value based on a reference substance, as the link with endpoint damage factors is not still available	Midpoint value based on a reference substance, as the link with endpoint damage factors is not still available	Normalization factors based on European emissions	Normalization factors based on European emissions	Normalization factors based on European emissions	Normalization factors based on European emissions
DataGeneratorAn	751	Person	18	18	18	18	18	18
	756	DataPublishedIn	2	2	2	2	2	2
	757	ReferenceToPublishedSo	3	3	3	3	3	3
	758	Copyright	1	1	1	1	1	1
	759	AccessRestrictedTo	0	0	0	0	0	0
	760	CompanyCode						
	761	CountryCode						
	762	PageNumbers	IMPACT 2002+	IMPACT 2002+	IMPACT 2002+	IMPACT 2002+	IMPACT 2002+	IMPACT 2002+

Original factors

The IMPACT 2002+ method description and the original damage factors can be found and are downloadable from the following web page: http://www.epfl.ch/impact.

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12 IPCC 2001 (climate change)

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Last changes: 2007

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Summary

This chapter describes the implementation for the characterisation of the global warming potential. Only the up-to-date figures of the Intergovernmental Panel on Climate Change (IPCC) for direct contributions to the problem of climate change have been used.

12.1 Introduction

The characterisation of different gaseous emissions according to their global warming potential and the aggregation of different emissions in the impact category climate change is one of the most widely used methods in life cycle impact assessment (LCIA). Characterisation values for greenhouse gas emissions are normally based on global warming potentials published by the IPCC (Intergovernmental Panel on Climate Change) (Albritton & Meira-Filho 2001; Houghton et al. 1996; IPCC 1997; 2001). The figures given in these publications are used not only for the characterisation of greenhouse gases (Guinée et al. 2001a; b; Heijungs et al. 1992a; b) but also within impact assessment methods like Eco-indicator 99 (Goedkoop et al. 1998) or environmental scarcity 1997 (Brand et al. 1998). All these methods evaluate the emissions of greenhouse gases due to anthropogenic activities investigated for the inventory table.

Three time horizons are used to show the effects of atmospheric lifetimes of the different gases. Tab. 12-1 shows an overview about the impact assessment methods implemented in the database.

Tab. 12-1 Impact Assessment Methods implemented in the database ecoinvent

Name	LocalName	Location	Unit	LocalCategory	LocalSubCategory	Category	SubCategory
GWP 20a	GWP 20a	GLO	kg CO2-	IPCC 2001	Klimawandel	IPCC 2001	climate change
GWP 100a	GWP 100a	GLO	kg CO2-	IPCC 2001	Klimawandel	IPCC 2001	climate change
GWP 500a	GWP 500a	GLO	kg CO2-	IPCC 2001	Klimawandel	IPCC 2001	climate change

12.2 Use of the method

Direct global warming potentials (GWPs) are relative to the impact of carbon dioxide. GWPs are an index for estimating relative global warming contribution due to atmospheric emission of a kg of a particular greenhouse gas compared to the emission of a kg of carbon dioxide (Albritton & Meira-Filho 2001).

12.3 Implementation

12.3.1 Emissions to air

Direct emissions of greenhouse gases

The factors have been directly taken from (IPCC 2001:Tables 6.7, 6.8, 6.10). A factor of 1.57 for CO has been calculated assuming a transformation to CO_2. Characterisation factors for further emissions have been published by (UNEP 1999:Appendix L). They are not taken into account for the implementation of the IPCC method (see Tab. 12-4).

Emissions due to deforestation

CO_2 emissions due to deforestation of primary forests and land transformation are registered with the elementary flow "Carbon dioxide, land transformation". This elementary flow has the same Global Warming Potential like fossil CO_2 emissions and thus the same factor is assigned to these emissions. This is line with reporting guidelines of the IPCC which take also emissions due to deforestation into account (Jungbluth et al. 2007).

Biogenic CO_2 emissions

The characterisation factor of biogenic CO_2 and CO emissions is zero. Biogenic methane emissions have the same factor as fossil methane emissions. If impact assessment results are to be used in the context of carbon sequestration in biomass, biogenic CO and CO_2 emissions as well as the CO_2-resource uptake from air need to be assigned the corresponding characterisation factors.

Indirect effects of hydrocarbons

The minimum and maximum values for indirect effects of the selected hydrocarbons given in (IPCC 2001:Table 6.10) are not considered. The ranges are quite large and it is not simply possible to determine one relevant figure. It is also not possible to assign an uncertainty or min/max values to the LCIA methods in the database.

Lower stratosphere + upper troposphere emissions

There are several specific effects of emissions in high altitude, which lead to a comparable higher contribution of aviation to the problem of climate change. The following pathways are discussed (Penner et al. 2000):

- NOx emissions leading to O_3 formation and CH_4 degradation
- Stratospheric H_2O
- Contrails
- Sulphate aerosols
- Soot aerosols

Nevertheless, it is difficult to find GWP characterisation factors for the different emissions that contribute to the problem and (Penner et al. 2000) states:

"GWP has provided a convenient measure for policymakers to compare the relative climate impacts of two different emissions. However, the basic definition of GWP has flaws that make its use questionable, in particular, for aircraft emissions. For example, impacts such as contrails may not be directly related to emissions of a particular greenhouse gas. Also, indirect RF (radiative forcing) from O_3 produced by NO_x emissions is not linearly proportional to the amount of NO_x emitted but depends

also on location and season. Essentially, the build-up and radiative impact of short-lived gases and aerosols will depend on the location and even the timing of their emissions. Furthermore, the GWP does not account for an evolving atmosphere wherein the RF from a 1-ppm increase in CO_2 is larger today than in 2050 and the efficiency of NO_x at producing tropospheric O_3 depends on concurrent pollution of the troposphere. In summary, GWPs were meant to compare emissions of long-lived, well-mixed gases such as CO_2, CH_4, N_2O, and hydrofluorocarbons (HFC) for the current atmosphere; they are not adequate to describe the climate impacts of aviation. In view of all these problems, we will not attempt to derive GWP indices for aircraft emissions in this study. The history of radiative forcing (Fig. 12.1), calculated for the changing atmosphere, is a far better index of anthropogenic climate change from different gases and aerosols than is GWP."

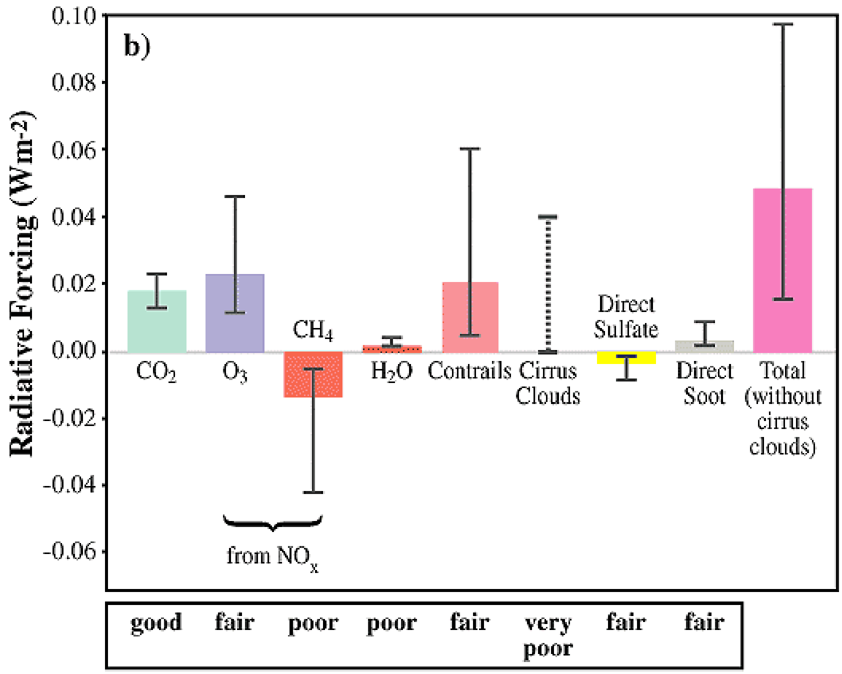

Fig. 12.1 Radiative forcing from aircraft movements in 1992

The relevance of the emissions from aviation is still the subject of scientific debate. Some relevant emissions have a very short life time. Thus the concept of GWP, which has been developed for long-living emissions, is not very useful. Calculations for NO_x show a high variation. The effect of the emissions depends considerably on the exact location of the emission. And for contrails there is no direct dependency between emissions and effect. Today experts judge the contribution of clouds higher while the importance of induced contrails gets less attention.[44]

RCEP (2002) states that recent estimates supported the IPCC's best estimate for the positive impact of ozone, but suggested that the negative impact of methane loss should be at the small end of the range given in Fig. 12.1. According to this publication a recent study suggested a much smaller best estimate for the contrail impact. In summary it is stated in this report that the IPCC figures are more likely to be an under-estimate rather than over-estimate the impacts due to aircraft movements.

The available information has been used to estimate global warming potentials for these emissions roughly in Tab. 12-2. The radiative forcing due to aviation estimated by (Penner et al. 2000) for

[44] Personal communication with Prof. Dr. Robert Sausen, DLR-Institut fuer Physik der Atmosphaere, Oberpfaffenhofen, DE and Prof. J. Stählin, ETH Zurich, CH, in July 2003.

aircraft movements in 1992 has been taken as a basis. It has to be noted that these figures have an uncertainty of 2 to 3 as shown in Fig. 12.1. The emission of the responsible pollutant has been taken from the assumptions in this project (Spielmann et al. 2007). Water emissions are not directly related to the formation of condense trails, but for reasons of simplification this effect has been allocated to these emissions. Further on it has to be considered that only a part of the aircraft emissions goes to the sensitive layer of the atmosphere while all CO_2 contributes to the effect. Thus the caused effect for radiative forcing has to be related only to the emissions taking place in high altitude.

The GWP of CO_2 is set to one regardless of the subcategory of emissions. The other GWP have been calculated with (example for NOx, ozone formation):

$$GWP(NO_x) = Emission(CO_2)/Emission(NO_x)/Share(NO_x)* RadiativeForcing(NO_x, \text{ozone formation})/RadiativeForcing(CO_2)$$

Different effects have been summed up for the pollutants. The calculation for NO_x is in the same order of magnitude as a study referred to in (IPCC 2001: chapter 6.12.3.4) that has calculated a GWP in the order of 450. The factors in Tab. 12-2 are not implemented in the database as this would mean a new development.

In the moment emissions to the stratosphere are characterised in the same way as other emissions without taking their specific contribution into account. Impacts of tropospheric ozone, NO_x, CO, water and aerosol emissions are not considered so far. Thus only a smaller part of the effect caused by aviation is addressed with this method. This estimation of GWP might be used in a sensitivity analysis of aircraft movements.

Tab. 12-2 Estimation for the global warming potential for emissions in lower stratosphere + upper troposphere for sensitivity analysis. Not implemented in ecoinvent for the calculation of IPCC 2001 GWP

	radiative forcing	Pollutant	Emission	Share troposphere	GWP	Sum GWP
	W/m^2		g/kg	%	kg-CO2-eq	kg-CO2-eq
carbon dioxide (CO_2)	0.018	Carbon dioxide, fossil	3150		1.0	1.0
ozone formation via NO_x	0.023	Nitrogen oxides	14	30%	958	375
decomposition of methane via NO_x	-0.014	Nitrogen oxides	14	30%	-583	-
condense trails	0.02	Water	1240	30%	9.4	10.3
water in the stratosphere	0.002	Water	1240	30%	0.9	-
sulfate (reflexion)	-0.003	Sulfate	1	30%	-1'750	-1'750
soot	0.003	Particulates	0.038	39%	35'425	35'425
total	**0.049**					

Indirect dinitrogen monoxide emissions

Dinitrogen monoxide can develop due to natural degradation processes after previous emissions of nitrogen in different types of chemical bindings, e.g. as ammonia or nitrogen dioxide and to different environmental compartments, i.e. air, water and soil. The originally emitted, nitrogen containing substances do not contribute directly to the problem of climate change.

These indirect emissions are also shown in the national greenhouse gas inventories (e.g. BUWAL 1999). A recent report of the (IPCC 2000) updates the proposal for the calculation of indirect emissions of N_2O for the national greenhouse gas inventories.

An application of the IPCC guidelines for the agricultural sector in Switzerland showed that the indirect emissions of N_2O lead to a considerable rise of the total nitrous oxide emissions due to human activities (Schmid et al. 2000). The indirect emissions due to deposition and nitrate leaching might be as high as 38% of the total direct and indirect emissions of N_2O.

Most LCA studies do consider only the direct emissions from the system under analysis to the environment. Thus in inventories for agricultural products, for example, direct emissions of N_2O, NO_x, NH_3, etc. from the field are included in the inventory (Brentrup et al. 2000). Emissions which follow these direct emissions outside the system boundaries are not further followed up.

Within the ecoinvent project, indirect emissions of N_2O induced by conversion from ammonia and nitrate emissions in agriculture have been included (Nemecek et al. 2007), using the conversion factors of 1% from NH_3 and 2.5% from nitrate (NO_3^-) (on the basis of N, factors from Schmid et al. 2000). Also Doka (2007) has considered the indirect emissions from treated waste water. But, for other inventories (e.g. direct emissions of effluents from a production process) these indirect emissions have not been included in the inventories in all cases.

Indirect emissions are not taken into account because this would result in a double counting.

Nitrous oxide and particle emissions

Experts discuss further on the contribution of ozone induced due to the emissions of nitrous oxide from emissions near the ground, e.g. from vehicles. The effect is not the same as for emissions from aviation, but it might be as well important. A GWP of the order of 5 has been cited in (IPCC 2001: chapter 6.12.3.4). Also particle emissions and their contribution to climate change are debated in the scientific community.[45] Also these effects are not taken into account because official factors are not available.

12.3.2 Resource uses

Carbon dioxide, in air

The characterisation factor of CO_2 uptake by plants is '0' (zero). If impact assessment results are to be used in the context of carbon sequestration in biomass, CO_2-resource uptake from air (and biogenic CO and CO_2 emissions as well) need to be assigned the corresponding characterisation factors.

12.3.3 List of impact assessment factors in ecoinvent

Tab. 12-3 shows the impact factors for the global warming potential implemented in ecoinvent. They are used for all subcategories of air emissions.

[45] Personal communication with Prof. J. Stählin, ETH Zurich, CH, in July 2003.

Tab. 12-3 Impact factors for the global warming potential implemented in ecoinvent. Factors for subcategory unspecified are used for all subcategories of air emissions.

Name SubCategory Name Location Unit	Cat egor	SubCategory	Unit	IPCC 2001 climate change GWP 20a GLO kg CO2-Eq	IPCC 2001 climate change GWP 100a GLO kg CO2-Eq	IPCC 2001 climate change GWP 500a GLO kg CO2-Eq
Carbon dioxide, fossil	air	unspecified	kg	1.00E+0	1.00E+0	1.00E+0
Carbon dioxide, land transformation	air	unspecified	kg	1.00E+0	1.00E+0	1.00E+0
Carbon monoxide, fossil	air	unspecified	kg	1.57E+0	1.57E+0	1.57E+0
Chloroform	air	unspecified	kg	1.00E+2	3.00E+1	9.00E+0
Dinitrogen monoxide	air	unspecified	kg	2.75E+2	2.96E+2	1.56E+2
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	air	unspecified	kg	3.30E+3	1.30E+3	4.00E+2
Ethane, 1,1,1-trifluoro-, HFC-143a	air	unspecified	kg	5.50E+3	4.30E+3	1.60E+3
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	unspecified	kg	6.10E+3	6.00E+3	2.70E+3
Ethane, 1,1-dichloro-1-fluoro-, HCFC-141b	air	unspecified	kg	2.10E+3	7.00E+2	2.20E+2
Ethane, 1,1-difluoro-, HFC-152a	air	unspecified	kg	4.10E+2	1.20E+2	3.70E+1
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-11	air	unspecified	kg	7.50E+3	9.80E+3	8.70E+3
Ethane, 1-chloro-1,1-difluoro-, HCFC-142b	air	unspecified	kg	5.20E+3	2.40E+3	7.40E+2
Ethane, 2,2-dichloro-1,1,1-tri-fluoro-, HCFC-123	air	unspecified	kg	3.90E+2	1.20E+2	3.60E+1
Ethane, 2-chloro-1,1,1,2-tetra-fluoro-, HCFC-124	air	unspecified	kg	2.00E+3	6.20E+2	1.90E+2
Ethane, chloropentafluoro-, CFC-115	air	unspecified	kg	4.90E+3	7.20E+3	9.90E+3
Ethane, hexafluoro-, HFC-116	air	unspecified	kg	8.00E+3	1.19E+4	1.80E+4
Ethane, pentafluoro-, HFC-125	air	unspecified	kg	5.90E+3	3.40E+3	1.10E+3
Methane, biogenic	air	unspecified	kg	6.20E+1	2.30E+1	7.00E+0
Methane, bromo-, Halon 1001	air	unspecified	kg	1.60E+1	5.00E+0	1.00E+0
Methane, bromochlorodifluoro-, Halon 1211	air	unspecified	kg	3.60E+3	1.30E+3	3.90E+2
Methane, bromotrifluoro-, Halon 1301	air	unspecified	kg	7.90E+3	6.90E+3	2.70E+3
Methane, chlorodifluoro-, HCFC-22	air	unspecified	kg	4.80E+3	1.70E+3	5.40E+2
Methane, chlorotrifluoro-, CFC-13	air	unspecified	kg	1.00E+4	1.40E+4	1.63E+4
Methane, dichloro-, HCC-30	air	unspecified	kg	3.50E+1	1.00E+1	3.00E+0
Methane, dichlorodifluoro-, CFC-12	air	unspecified	kg	1.02E+4	1.06E+4	5.20E+3
Methane, dichlorofluoro-, HCFC-21	air	unspecified	kg	7.00E+2	2.10E+2	6.50E+1
Methane, difluoro-, HFC-32	air	unspecified	kg	1.80E+3	5.50E+2	1.70E+2
Methane, fossil	air	unspecified	kg	6.20E+1	2.30E+1	7.00E+0
Methane, monochloro-, R-40	air	unspecified	kg	5.50E+1	1.60E+1	5.00E+0
Methane, tetrachloro-, R-10	air	unspecified	kg	2.70E+3	1.80E+3	5.80E+2
Methane, tetrafluoro-, R-14	air	unspecified	kg	3.90E+3	5.70E+3	8.90E+3
Methane, trichlorofluoro-, CFC-11	air	unspecified	kg	6.30E+3	4.60E+3	1.60E+3
Methane, trifluoro-, HFC-23	air	unspecified	kg	9.40E+3	1.20E+4	1.00E+4
Sulfur hexafluoride	air	unspecified	kg	1.51E+4	2.22E+4	3.24E+4

12.4 Quality considerations

The impact inventory table in ecoinvent uses most of the elementary flows contributing to the problem of climate change. The quality of implementation is good as published factors could be used without adoption or alteration.

A bias exists for the indirect emissions of dinitrogen monoxide. They are only considered in case of nitrogen emission in agriculture and from waste treatment services, but not for some other emissions in the database.

The uncertainty of the characterisation factors itself cannot be addressed. It has to be noted that the list of substances would be longer if specific problems of aviation would be taken into account.

The characterisation of the global warming potential covers only a part of the problem climate change. Many important aspects like emissions from aviation, indirect and induced effects are not included in the assessment.

Appendices

Additional weighting factors

Tab. 12-4 shows characterisation factors for the global warming potential from different other publications. They are not implemented in the database in order to do not mix different methodologies.

Tab. 12-4 Characterisation factors based on the global warming potential for greenhouse gases (Albritton & Meira-Filho 2001; UNEP 1999) and for the formation of N_2O due to the emission of nitrogen (IPCC 2000).

	Unit	global warming potential 100a 2001 kg CO2-equiv.	global warming potential 100a 2001, incl. indirect N2O kg CO2-equiv.	Remarks
Ammonia (NH3)	kg		7.66	1% emitted as N2O
Butane (C4H10)	kg	3	3	
Carbon dioxide (CO2)	kg	1	1	
Carbon monoxide (CO)	kg	1.58	1.58	
Chloroform (CHCl3)	kg	4	4	
Dinitrogen monoxide (N2O)	kg	296	296	
Ethane, 1,1,1-trichloro- (C2H3Cl3, HCFC-140)	kg	-204	-204	
Ethane, 1,1,1-trifluoro- (C2H3F3, CFC-143a)	kg	4300	4300	
Ethane, 1,1,2-trichloro-1,2,2-trifluoro- (C2Cl3F3, CFC-113)	kg	3060	3060	
Ethane, 1,1-dichloro-1-fluoro- (C2H3Cl2F, HCFC-141b)	kg	250	250	
Ethane, 1,1-difluoro- (C2H4F2, HFC-152a)	kg	120	120	
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro- (C2Cl2F4, CFC-114)	kg	5690	5690	
Ethane, 1-chloro-1,1-difluoro- (C2H3ClF2, HCFC-142)	kg	1650	1650	
Ethane, 2,2-dichloro-1,1,1-tri-fluoro- (C2HCl2F3, HCFC-123)	kg	32	32	
Ethane, 2-chloro-1,1,1,2-tetra-fluoro- (C2HClF4, HCFC-124)	kg	410	410	
Ethane, chloropentafluoro- (C2ClF5, CFC-115)	kg	5690	5690	
Ethane, hexafluoro- (C2F6, HFC-116)	kg	11900	11900	
Ethane, pentafluoro- (C2HF5, HFC-125)	kg	3400	3400	
Ethane,1,1,1,2-tetrafluoro- (C2H2F4, HFC-134a)	kg	1300	1300	
Hydrochlorofluorocarbon (HCFC-R502)	kg	3570	3570	
Hydrofluorcarbon (HFC-Isceon 59)	kg	1950	1950	
Hydrofluorcarbon (HFC-R404A)	kg	3260	3260	
Hydrofluorcarbon (HFC-R407C)	kg	1530	1530	
Hydrofluorcarbon (HFC-R410A)	kg	1730	1730	
Methane (CH4)	kg	23	23	
Methane, bromochlorodifluoro- (CBrClF2, Halon 1211)	kg	1300	1300	
Methane, bromotrifluoro- (CBrF3, Halon 1301)	kg	-34700	-34700	
Methane, chlorodifluoro- (CHClF2, HCFC-22)	kg	1350	1350	
Methane, chlorotrifluoro- (CClF3, CFC-13)	kg	9130	9130	
Methane, dichloro- (CH2Cl2, HCC-30)	kg	9	9	
Methane, dichlorodifluoro- (CCl2F2, CFC-12)	kg	6640	6640	
Methane, dichlorofluoro- (CHCl2F, HCFC-21)	kg	210	210	
Methane, difluoro- (CH2F2, HFC-32)	kg	550	550	
Methane, tetrachloro- (CCl4, CFC-10)	kg	-1530	-1530	
Methane, tetrafluoro- (CF4, FC-14)	kg	5700	5700	
Methane, trichlorofluoro- (CCl3F, CFC-11)	kg	1070	1070	
Methane, trifluoro- (CHF3, HFC-23)	kg	12000	12000	
Nitrogen oxides (NOx as NO2)	kg		2.83	1% emitted as N2O
Propane (C3H8)	kg	3	3	
Sulfur hexafluoride (SF6)	kg	22200	22200	
Ammonium, ion (NH4+)	kg		23.26	2.5% emitted as N2O
Nitrate (NO3 -)	kg		5.25	2.5% emitted as N2O
Nitrite (NO2 -)	kg		7.08	2.5% emitted as N2O
Nitrogen (organic bound)	kg		23.26	2.5% emitted as N2O
Nitrogen (total)	kg		23.26	2.5% emitted as N2O

EcoSpold Meta Information

ReferenceFunction	495	Category	IPCC 2001	IPCC 2001	IPCC 2001
	496	SubCategory	climate change	climate change	climate change
	401	Name	GWP 20a	GWP 100a	GWP 500a
Geography	662	Location	GLO	GLO	GLO
ReferenceFunction	403	Unit	kg CO2-Eq	kg CO2-Eq	kg CO2-Eq
	490	LocalName	GWP 20a	GWP 100a	GWP 500a
	491	Synonyms	GHG//Treibhausgaspotential//global warming potential//radiative forcing	GHG//Treibhausgaspotential//global warming potential//radiative forcing	GHG//Treibhausgaspotential//global warming potential//radiative forcing
	492	GeneralComment	IPCC characterisation factors for the direct global warming potential of air emissions. Not including indirect formation of dinitrogen monoxide from nitrogen emissions. Not accounting for radiative forcing due to emissions of NOx, water, sulphate, etc. in the lower stratosphere + upper troposphere. Not considering the range of indirect effects given by IPCC. Including CO2 formation from CO emissions. Biogenic CO2 uptake and biogenic CO2 emissions are not characterised. CO2 emissions due to deforestation and land	IPCC characterisation factors for the direct global warming potential of air emissions. Not including indirect formation of dinitrogen monoxide from nitrogen emissions. Not accounting for radiative forcing due to emissions of NOx, water, sulphate, etc. in the lower stratosphere + upper troposphere. Not considering the range of indirect effects given by IPCC. Including CO2 formation from CO emissions. Biogenic CO2 uptake and biogenic CO2 emissions are not characterised. CO2 emissions due to deforestation are included	IPCC characterisation factors for the direct global warming potential of air emissions. Not including indirect formation of dinitrogen monoxide from nitrogen emissions. Not accounting for radiative forcing due to emissions of NOx, water, sulphate, etc. in the lower stratosphere + upper troposphere. Not considering the range of indirect effects given by IPCC. Including CO2 formation from CO emissions. Biogenic CO2 uptake and biogenic CO2 emissions are not characterised. CO2 emissions due to deforestation are included
	497	LocalCategory	IPCC 2001	IPCC 2001	IPCC 2001
	498	LocalSubCategory	Klimawandel	Klimawandel	Klimawandel
TimePeriod	601	StartDate	2001	2001	2001
	602	EndDate	2001	2001	2001
	603	DataValidForEntirePeriod	1	1	1
	611	OtherPeriodText	Time of publication.	Time of publication.	Time of publication.
Geography	663	Text	Global impact category.	Global impact category.	Global impact category.

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13 TRACI

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Last changes: 2007

13.1 Introduction

From 1996 to 2003, the US EPA has focused on determining and developing the best impact assessment tool for Life Cycle Impact Assessment (LCIA), Pollution Prevention (P2), and Sustainability Metrics for the US. A literature survey was conducted to ascertain the applicability, sophistication, and comprehensiveness of all existing methodologies. When the development of TRACI began, the state of the practice involved nearly all US practitioners utilizing European methodologies when conducting comprehensive impact assessments for US conditions simply because similar simulations had not been conducted within the US. Since no tool existed which would allow the sophistication, comprehensiveness, and applicability to the US which was desired, the US EPA decided to begin development of a tool which could be utilized to conduct impact assessment with the best applicable methodologies within each category. This research effort was called TRACI - the Tool for the Reduction and Assessment of Chemical and other environmental Impacts.

The methodology has been developed specifically for the US using input parameters consistent with US locations. Site specificity is available for many of the impact categories, but in all cases a US average value exists when the location is undetermined. The average values were implemented in the ecoinvent data.

A complete description of the TRACI method is given in Bare et al., (2002). Characterization factors can be obtained directly by Bare.Jane@epamail.epa.gov.

13.1.1 Impact categories

TRACI is a midpoint oriented LCIA method including the impact categories as per Tab. 13-1:

Tab. 13-1 Midpoint impact categories of TRACI

Impact category	Midpoint level	Level of site specificity	Comments on implementation into ecoinvent data
Ozone depletion	Potential to destroy ozone based on chemical's reactivity and lifetime	Global	
Global warming	Potential global warming based on chemical's radiative forcing and lifetime	Global	See chapter 13.2.1
Acidification	Potential to cause wet or dry acid deposition	U.S.	See chapter 13.2.1
Eutrophication	Potential to cause eutrophication	U.S.	
Photochemical oxidation (smog)	Potential to cause photochemical smog	U.S.	See chapter 13.2.1
Ecotoxicity	Potential of a chemical released into an evaluative environment to cause ecological harm	U.S	
Human health: criteria air pollutants	Exposure to criteria air pollutants. Distinguished in Air-Point source and Air-Mobile source impact categories	U.S.	Air-Point sources and Air-Mobile sources have been grouped into a single impact category in ecoinvent database, see chapter 13.2.1

Impact category	Midpoint level	Level of site specificity	Comments on implementation into ecoinvent data
Human health: carcinogenics	Potential of a chemical released into an evaluative environment to cause human cancer effects	U.S.	
Human health: non-carcinogenics	Potential of a chemical released into an evaluative environment to cause human noncancer effects	U.S.	
Fossil fuel			Refer to Ecoindicator 99
Land use			Not available
Water use			Not available

The TRACI methodology does not take into account resource consumption related impact categories. The land use and the water use impact categories have been removed from TRACI, as it has been acknowledged that further research was needed in these fields.

For the fossil fuel depletion impact category, the developers of TRACI suggest to refer to Eco-indicator 99 (Bare, 2007, personal communication). The user is therefore invited to follow Eco-indica-[46]tor 99 guidance in this category.

13.1.2 Normalization and weighting

TRACI is a midpoint oriented life cycle impact assessment methodology, consistently with EPA's decision not to aggregate between environmental impact categories.

Arguing that normalization and valuation is still very much under debate and because of possible misinterpretation and misuse, the authors of TRACI determined that the state of the art for the normalization and valuation processes did not yet support inclusion in TRACI.

13.2 Implementation

The implementation has been made following the general rules for the assignment of factors to the elementary flows developed in the ecoinvent database (see chapter 1: Introduction). However, as these rules cannot solve all implementation problems, below we will give a detailed description of the specific implementation. An overview of the implementation in the ecoinvent database is shown in Tab. 13-2.

Tab. 13-2 TRACI Method implemented in the ecoinvent database

Name	LocalName	Location	Unit	LocalCategory	LocalSubCategory	Category	SubCategory
global warming	Treibhauseffekt	GLO	kg CO2-Eq	TRACI	Umwelteinfluss	TRACI	environmental impact
acidification	Versauerung	US	moles of H+-Eq	TRACI	Umwelteinfluss	TRACI	environmental impact
carcinogenics	Krebserregende Stoffe	US	kg benzene-Eq	TRACI	Menschliche Gesundheit	TRACI	human health
non-carcinogenics	Nicht Krebserregende Stoffe	US	kg toluene-Eq	TRACI	Menschliche Gesundheit	TRACI	human health
respiratory effects, average	Atemwegserkrankungen, Durchschnitt	US	kg PM2.5-Eq	TRACI	Menschliche Gesundheit	TRACI	human health
eutrophication	Eutrophierung	US	kg N	TRACI	Umwelteinfluss	TRACI	environmental impact
ozone depletion	Ozonabbau	GLO	kg CFC-11-Eq	TRACI	Umwelteinfluss	TRACI	environmental impact
ecotoxicity	Ökotoxizität	US	kg 2,4-D-Eq	TRACI	Umwelteinfluss	TRACI	environmental impact
photochemical oxidation	Photochemische Oxidation	US	kg NOx-Eq	TRACI	Umwelteinfluss	TRACI	environmental impact

46

13.2.1 Characterization factors assignment to elementary flows

The assignment of TRACI characterization factors to ecoinvent elementary flows was mostly done through their CAS number. Few of them were otherwise identified individually. Tab. 13-3 describes the choices made for the assignment.

Tab. 13-3 Choices made for the assignment of TRACI characterization factor to ecoinvent elementary flows

ecoinvent name	TRACI name	Note
Carbon dioxide, biogenic	CARBON DIOXIDE	
Carbon dioxide, fossil	CARBON DIOXIDE	
Carbon monoxide, biogenic	CARBON MONOXIDE	
Carbon monoxide, fossil	CARBON MONOXIDE	
Chromium	CHROMIUM	TRACI does not provide characterization factor for chromium VI. It would be a severe mistake to ignore this substance, therefore we implemented the chromium CF, being aware that this underestimates the effect of chromium VI.
Chromium VI	CHROMIUM	
Methane, biogenic	METHANE	
Methane, fossil	METHANE	
Nitrogen oxides	NITROGEN OXIDES	
--	NITROGEN DIOXIDE	The TRACI characterization factors for NO_2 are not implemented into the ecoinvent database, which does not list nitrogen dioxide as a separate elementary flow.
Particulates, < 2.5 μm	PM2.5	TRACI provides CFs for PM2.5, PM10 and TSP being 1, 0.6 and 0.33 $kg_{PM2.5}$eq./kg, respectively. The ratio between these CFs suggests that the respective fractions above 2.5 μm are harmless.
--	PM10	
--	TSP	
Sulfur dioxide	SULFUR DIOXIDE	

Global Warming (greenhouse gases)

In accordance with general assignments for the implementation of the LCIA methodologies (see Chapter 2 of this document), different characterization factors are used for carbon dioxide and carbon monoxide biogenic and fossil emissions (see Tab. 13-4).

Tab. 13-4 Biogenic and fossil characterization factors for CO and CO_2

ecoinvent name	GWP characterization factor (kg CO_2-Eq)
Carbon dioxide, biogenic	0
Carbon dioxide, fossil	1.00
Carbon monoxide, biogenic	0
Carbon monoxide, fossil	1.57
Methane, biogenic	23
Methane, fossil	23

Note that, in ecoinvent data, CO emissions are subtracted from the theoretical CO_2 emissions. Thus, a GWP factor is calculated for CO (1.57 kg CO_2-eq per kg CO). This is done because otherwise, processes with higher CO emissions would benefit from this gap. This is especially important for biomass combustion: neglecting the formation of CO_2 from CO would lead in this case to a negative sum of the global warming potential score (see general assignments in chapter 2).

Indirect contribution due to conversion into carbon dioxide of other organic compounds is not taken into account.

Acidification

Acidification by emissions to water is not considered in TRACI. Therefore, only emissions to air are considered.

Human Health Air criteria pollutants

TRACI provides the distinction between *mobile* and *point* sources. Such a distinction is not possible within the structure of the ecoinvent data: there is no assignment of the source to the pollutants' names (For instance, particulates emitted by lorries are added up to particulates from boilers etc.).

Hence, it was chosen to implement an average value of the two categories, as described in Tab. 13-5. The average value was chosen to reflect the average environmental impacts that are related to the different functions implied in air pollutant emissions. The "worst-case estimates" are therefore not applied.

Tab. 13-5 Human Health Air criteria implementation

	TRACI category (in human health)		Implemented category
	Criteria Air-Point Source (kg PM2.5 eq / kg)	Criteria Air-Mobile (kg PM2.5 eq / kg)	Respiratory effects, average (kg PM2.5 eq / kg)
Nitrogen oxides	0.04151	0.05019	0.04585
Particulates, < 2.5 μm	1	1	1
Sulfur dioxide	0.2407	0.2415	0.2411

As TRACI explicitly provides the characterization factor for PM2.5, this is assigned to the ecoinvent category particulates, < 2.5 μm elementary flow. Particle fractions, > 2.5 μm are considered harmless and therefore characterization factors for PM10 and TSP given by TRACI are not considered.

13.2.2 Characterization factors assignment to emission categories

Emissions to soil

TRACI distinguishes two types of emissions to soil: *Ground-Surface Soil* and *Root-Zone Soil*. The following correspondence was adopted in the ecoinvent database implementation (see Tab. 13-6).

Tab. 13-6 Soil categories correspondence

ecoinvent compartment category and sub-category	TRACI characterization factor	Note
Soil, agricultural	Root-Zone Soil	We consider that agricultural activities would mix the pollutant in the whole root-soil layer, contrary to an emission on the other type of soil, which is likely to be made in the first thin ground-surface soil layer.
Soil, forestry	Ground-Surface Soil	
Soil, industrial	Ground-Surface Soil	
Soil, unspecified	Ground-Surface Soil	

Emissions to air

TRACI only distinguishes one type of emissions to air (with two types of exposure: *mobile* and *point* source, which are merged into one category, as mentioned above). The following correspondence was adopted in the ecoinvent database implementation (see Tab. 13-7).

Tab. 13-7 Air categories correspondence

ecoinvent compartment category and sub-category	TRACI compartment category	Note
Air, high population density	Air	TRACI does not have factors for emissions into lower stratosphere or upper troposphere.
Air, low population density	Air	
Air, low population density, long-term	Air	
Air, lower stratosphere + upper troposphere	--	
Air, unspecified	Air	

Emissions to water

TRACI only distinguishes one type of emissions to water. The following correspondence was adopted in the ecoinvent database implementation (see Tab. 13-8).

Tab. 13-8 Water categories correspondence

ecoinvent compartment category and sub-category	TRACI compartment category	Note
Water, fossil-	--	TRACI does not have factors for emissions into fossil water, groundwater or ocean.
Water, ground-	--	
Water, ground-, long-term	--	
Water, lake	Water	
Water, ocean	--	
Water, river	Water	
Water, river, long-term	Water	
Water, unspecified	Water	

The characterization factors of the metals shown in Tab. 13-9 have been assigned to ecoinvent elementary flows under the assumption that they all dissociate into ions when emitted into water. Therefore one should be aware that the overall assessment in this case is overestimated:

Tab. 13-9 Substances differently mapped because of their ionic form

ecoinvent name	TRACI name
Arsenic, ion	ARSENIC
Cadmium, ion	CADMIUM
Chromium, ion	CHROMIUM
Copper, ion	COPPER
Cyanide	HYDROCYANIC ACID
Nickel, ion	NICKEL
Silver, ion	SILVER
Tin, ion	TIN
Vanadium, ion	VANADIUM (FUME OR DUST)
Zinc, ion	ZINC

13.2.3 Normalization

The TRACI version implemented in ecoinvent data 2.0 is the one provided by Jane Bare in 2007, which does not contain Normalizaiton factors. The normalization factors recently published in ES&T (Bare and Gloria, 2007) will be integrated in the new version of TRACI (among many other improvements) to be expected per beginning 2008.

13.3 Quality of implementation

The ecoinvent database contains 826 different elementary flows (not including radioactive emissions or heat emissions). For only 206 chemicals of the ecoinvent data (25%) characterization factors are available in TRACI, which contains characterization for 960 elementary flows.

Appendices

EcoSpold Meta Information

The full meta information can be accessed via the homepage www.ecoinvent.org. The following table shows an example.

Type	ID	Field name							
ReferenceFunctio	495	Category	TRACI	TRACI	TRACI	TRACI	TRACI	TRACI	TRACI
	496	SubCategory	environmental	environmental	human health	human health	human health	environmental	environmental
	401	Name	global warming	acidification	carcinogenics	non-carcinogenics	respiratory effects, average	eutrophication	ozone depletion
Geography	662	Location	GLO	US	US	US	US	US	GLO
ReferenceFunctio	403	Unit	kg CO2-Eq	moles of H+-Eq	kg benzene-Eq	kg toluene-Eq	kg PM2.5-Eq	kg N	kg CFC-11-Eq
DataSetInformati	201	Type	4	4	4	4	4	4	4
	202	Version	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	203	energyValues	0	0	0	0	0	0	0
	205	LanguageCode	en	en	en	en	en	en	en
	206	LocalLanguageCode	de	de	de	de	de	de	de
DataEntryBy	302	Person	61	61	61	61	61	61	61
	304	QualityNetwork	1	1	1	1	1	1	1
ReferenceFunctio	400	DataSetRelatesToProduc	0	0	0	0	0	0	0
	404	Amount	1	1	1	1	1	1	1
	490	LocalName	Treibhauseffekt	Versauerung	Krebs erregende Stoffe	Nicht Krebs erregende Stoffe	Atemwegserkrankungen, Durchschnitt	Eutrophierung	Ozonabbau
	491	Synonyms							
	492	GeneralComment	Potential global warming based on chemical's radiative forcing and lifetime	Potential to cause wet or dry acid deposition	Potential of a chemical released into an evaluative environment to cause human cancer effects	Potential of a chemical released into an evaluative environment to cause human noncancer effects	Exposure to elevated particulate matter less than 2.5 micrometers; average between mobile and point sources	Potential to cause eutrophication	Potential to destroy ozone based on chemical's reactivity and lifetime
	497	LocalCategory	TRACI	TRACI	TRACI	TRACI	TRACI	TRACI	TRACI
	498	LocalSubCategory	Umwelteinfluss	Umwelteinfluss	Menschliche Gesundheit	Menschliche Gesundheit	Menschliche Gesundheit	Umwelteinfluss	Umwelteinfluss
TimePeriod	601	StartDate	2002	2002	2002	2002	2002	2002	2002
	602	EndDate	2004	2004	2004	2004	2004	2004	2004
	603	DataValidForEntirePeriod	1	1	1	1	1	1	1
	611	OtherPeriodText							
Geography	663	Text							
DataGeneratorAr	751	Person	61	61	61	61	61	61	61
	756	DataPublishedIn	2	2	2	2	2	2	2
	757	ReferenceToPublishedSo	3	3	3	3	3	3	3
	758	Copyright	1	1	1	1	1	1	1
	759	AccessRestrictedTo	0	0	0	0	0	0	0
	760	CompanyCode							
	761	CountryCode							
	762	PageNumbers	TRACI	TRACI	TRACI	TRACI	TRACI	TRACI	TRACI

Original factors

The TRACI method description can be found on the following web page: http://www.epa.gov/nrmrl/std/sab/traci. Characterization factors can be obtained directly from Bare.Jane@epamail.epa.gov.

References

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14 Selected Life Cycle Inventory Indicators

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Last changes: 2007

Summary

This chapter describes the implementation of selected life cycle inventory indicators. In most cases it is the summation of selected substances emitted to all different subcompartments. In some cases, different substances are added up to quantify frequently used parameters such as non-methane volatile organic carbon (NMVOC), selected radioactive species or particulate matter. According to ISO 14044 (International Organization for Standardization (ISO) 2006, clause 4.4.2.5), a set of elementary flows may be part of the results after characterisation. This is the reason why we present the selected LCI indicators within the life cycle impact assessment methods section of the ecoinvent database.

14.1 Introduction

The list of selected LCI indicators is divided in two: The first list contains the common set of elementary flows shown in the results discussion of the ecoinvent reports. One example is "fossil CO_2 emissions to air". The second one contains additional elementary flows used in at least one of the ecoinvent reports. One example of this extended list are "actinides emitted to water".

The selection does not necessarily reflect the environmental importance of the listed pollutants and resources. The pollutants and resources are selected in view of a better characterisation of the analysed products and services.

The factors applied in the LCI indicators reflect a mere physical addition without any effect or damage assessment and without final active weighting. Nevertheless, the addition on the basis of physical properties contains an implicit weighting.

The selection helps practitioners to get a more convenient access to a selection of LCI results of products and services. It does not replace the use of the complete set of LCI results and the application of LCIA methods.

14.2 Overview

Most LCI indicators represent the sum of all pollutants emitted to one compartment, thus aggregating the emissions to different sub-compartments. Tab. 14-1 shows the list of elementary flows. The indicators that simply represent the sum of all subcompartments are indicated with an 'x'.

Tab. 14-1 list of selected life cycle inventory indicators implemented in ecoinvent data v2.0; x: sum of emissions to all subcompartments

SubCategory		Name	Location	Unit	Used in ecoinvent report
resource		land occupation	GLO	m^2a	all
resource		water	GLO	m^3	No. 6 VIII
resource		carbon, biogenic, fixed	GLO	kg	No. 17
air	x	carbon monoxide	GLO	kg	No. 11 II
air		CO_2, fossil	GLO	kg	all
air	x	lead	GLO	kg	No. 6 VI
air	x	methane	GLO	kg	No. 6 IV
air	x	N_20	GLO	kg	No. 6 VI
air	x	nitrogen oxides	GLO	kg	all
air		NMVOC	GLO	kg	all

SubCategory		Name	Location	Unit	Used in ecoinvent report
air	x	particulates, <2.5 µm	GLO	kg	all
air	x	particulates, >2.5 µm and <10 µm	GLO	kg	No. 6 VI
air	x	particulates >10 µm	GLO	kg	No. 6 VI
air		particulates	GLO	kg	No. 11 II
air	x	sulphur dioxide	GLO	kg	all
air	x	zinc	GLO	kg	No. 6 VI
air, radioactive		radon (+ radium)	GLO	kBq	No. 6 VII
air, radioactive		noble gas	GLO	kBq	No. 6 VII
air, radioactive		aerosole	GLO	kBq	No. 6 VII
air, radioactive		actinides	GLO	kBq	No. 6 VII
soil	x	cadmium	GLO	kg	all
water	x	BOD	GLO	kg	all
water, radioactive	x	radium	GLO	kBq	No. 6 VII
water, radioactive	x	tritium	GLO	kBq	No. 6 VII
water, radioactive		nuclides	GLO	kBq	No. 6 VII
water, radioactive		actinides	GLO	kBq	No. 6 VII
total		oils, unspecified	GLO	kg	No. 6 IV
total		heat, waste	GLO	MJ	No. 6 VII

The aggregation procedure of all those simple indicators is not described any further. The aggregation procedure of all other indicators is described in Section 14.3.

14.3 Specific summations

14.3.1 Land occupation

The summation of land occupation includes all land cover types recorded within the ecoinvent data v2.0. This indicator is comparable to the land competition indicator of CML 2001 except that land use of the sea bed or of rivers and lakes are additionally included.

14.3.2 Water

The summation of water includes all water extractions (rivers, lakes, ocean, sole, from wells) except for the water used for cooling and used in turbines in hydroelectric power production.

14.3.3 Carbon, biogenic fixed

The indicator "carbon, biogenic, fixed" calculated the amount of biogenic carbon extracted from the air minus releases of biogenic carbon emitted with CO_2, CO and CH_4. A positive value indicates that a certain amount of the biogenic carbon is fixed in the product at issue. Products based on renewable sources are expected to have a levelled-out balance (Carbon, biogenic fixed = zero) in case the incineration of the product is included.

14.3.4 CO_2, fossil

The indicator "CO_2, fossil" includes all fossil CO_2 emissions and the emissions of CO_2 due to land transformation (elementary flow "Carbon dioxide, land transformation").

14.3.5 Non methane volatile organic compounds

The indicator "NMVOC" includes all organic compounds except methane.

14.3.6 Particulates

The indicator "Particulates" includes the three individual elementary flows of PM2.5, 2.5 to 10 and >10 µm.

14.3.7 Radioactive Substances

Radionuclides emitted to air are grouped according to the following list: "radon + radium" included Rn-222 and Ra-226, "noble gases" includes all Kr and Xe isotopes, Ar-41 and the non-noble gases H-3 and C-14), "aerosole" includes the isotopes of Ag, Ba, Ce, Co, Cr, Cs, Fe, I, La, Mn, Nb, Pb, Pm, Po, Ru, Sb, Sr, Tc, Te, Zn and Zr – plus K-40 from the coal chain), and "actinides" includes all isotopes of U, Th, Pa, Pu, Am, Cm, and Np.

Radionuclides emitted to water are grouped according to the following list: "radium" includes the Ra isotopes; "tritium" includes "tritium", "nuclides" includes the isotopes of Ag, Ba, C, Cd, Ce, Co, Cr, Cs, Fe, I, La, Mn, Mo, Na, Nb, Pb, Po, Ru, Sb, Sr, Tc, Te, Y, Zn and Zr — plus K-40 washed out from piles of coal ash); and "actinides" includes all isotopes of U, Th, Pa, Pu, Am, Cm, and Np.

All substances are summed up on a kBq basis, hence without any health related weighting factor.

14.3.8 Oils, unspecific

The indicator "oils, unspecific" includes biogenic and unspecific oils emitted to water and soil.

14.3.9 Waste heat

The indicator "waste heat" includes all waste heat released to air, water and soil.

14.4 Quality considerations

The implementation of life cycle inventory summations is rather straightforward. Thus the uncertainty in the indicators is quite low.

Appendices

EcoSpold Meta Information

The full meta information can be accessed via the homepage www.ecoinvent.org.

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