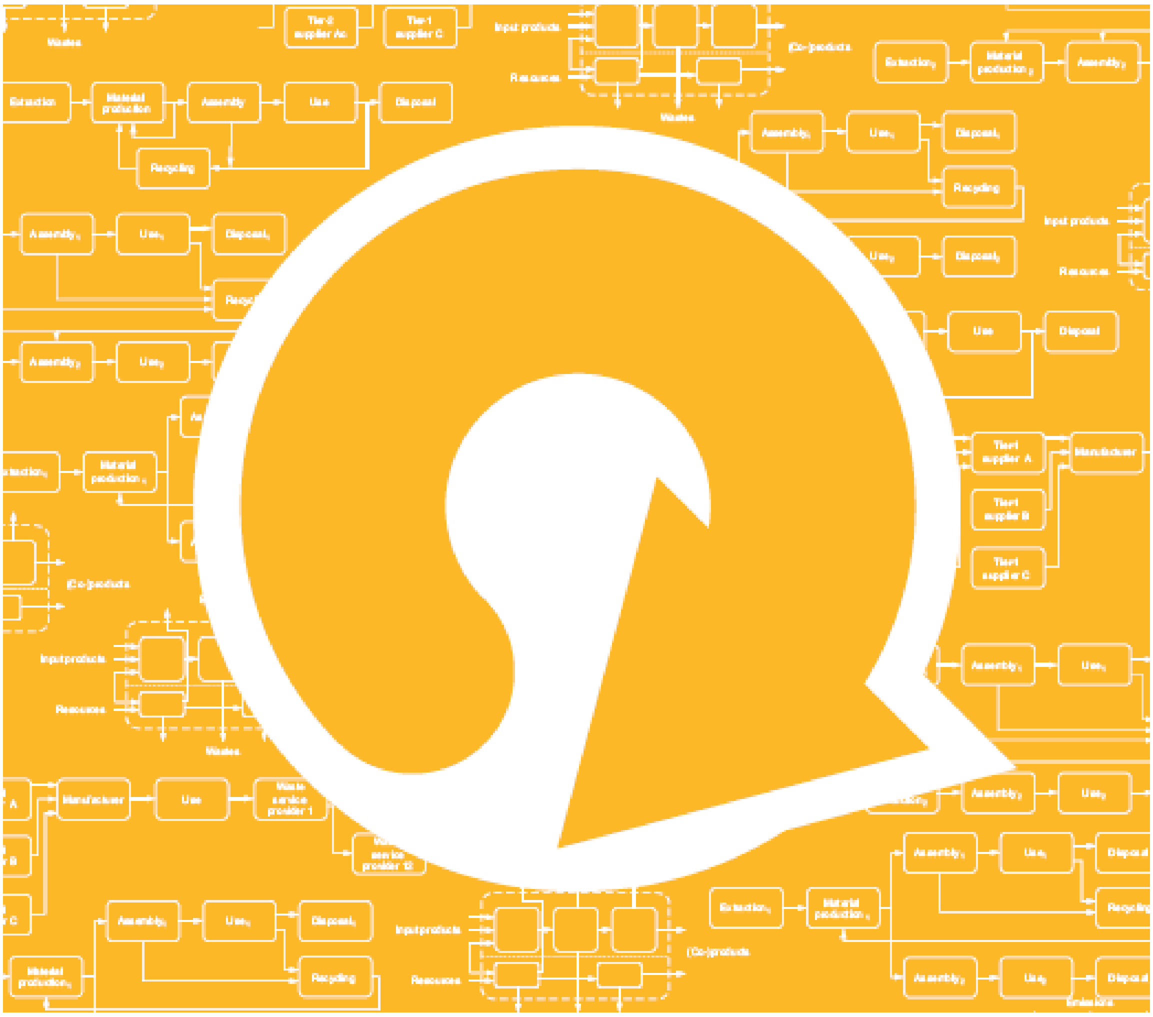
JRC Technical Notes

Characterisation factors of the ILCD Recommended Life Cycle Impact Assessment methods

Database and supporting information



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Executive Summary

Overview on Life Cycle Impact Assessment (LCIA)

Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) are scientific approaches behind a growing number of environmental policies and business decision support in the context of Sustainable Consumption and Production (SCP). The International Reference Life Cycle Data System (ILCD) provides a common basis for consistent, robust and quality-assured life cycle data, methods and assessments.

In Life Cycle Assessment, the emissions and resources consumed linked to a specific product are compiled and documented in a Life Cycle Inventory (LCI). An impact assessment is then performed, generally considering three areas of protection: human health, natural environment, and issues related to natural resource use.Impact categories typically covered in a Life Cycle Impact Assessment include climate change, ozone depletion, eutrophication, acidification, human toxicity (cancer and non-cancer related), respiratory inorganics, ionizing radiation, ecotoxicity, photochemical ozone formation, land use, and resource depletion (materials, energy, water). The emissions and resources of the inventory are assigned to the corresponding impact categories and then converted into quantitative impact indicators using characterisation factors.

Approach and key issues addressed in this supporting document

This document supports the correct use of the characterisation factors for impact assessment as recommended in the ILCD guidance document "Recommendations for Life Cycle Impact Assessment in the European context - based on existing environmental impact assessment models and factors" (EC-JRC, 2011). The characterisation factors are provided in a separate database in ILCD-formatted xml files and as Excel files. This document focuses on how to use the database and highlights existing limitations of the database and models/factors. These factors take into account the models available and sufficiently documented when the ILCD document on Analysis of existing methods was released (mid 2009).

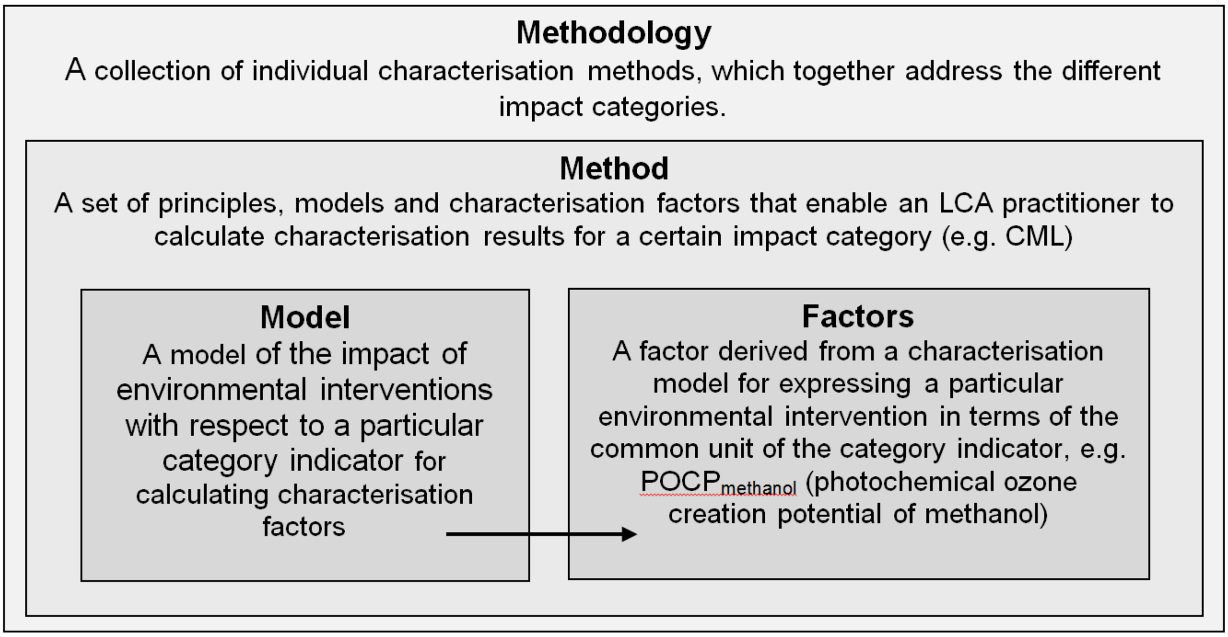
Contents

LIST OF ACRONYMS

AG	Advisory Group of the European Platform on LCA
AoP	Area of Protection
CFs	Characterisation Factors
DALY	Disability Adjusted Life Year
GWP	Global Warming Potential
ICRP	International Commission on Radiological Protection
ILCD	International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non-Methane Volatile Organic Compound
PAF	Potentially Affected Fraction of species
PDF	Potentially Disappeared Fraction of species
SETAC	Society of Environmental Toxicology and Chemistry
UNEP	United Nations Environment Programme
VOC	Volatile Organic Compound
WHO	World Health Organisation
WMO	World Metereological Organisation

GLOSSARY

Definiendum	**Definition**
Area of protection (AOP)	A cluster of category endpoints of recognisable value to society, viz. human health, natural resources, natural environment and sometimes man-made environment (Guinée et al., 2002)
Cause-effect chain	or environmental mechanism.System of physical, chemical and biological processes for a given impact category, linking the life cycle inventory analysis result to the common unit of the category indicator (ISO 14040) by means of a characterisation model.
Characterisation	A step of the Impact assessment, in which the environmental interventions assigned qualitatively to a particular impact category (in classification) are quantified in terms of a common unit for that category, allowing aggregation into one figure of the indicator result (Guinée et al., 2002)
Characterisation factor	Factor derived from a characterisation model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the impact category indicator (ISO 14040)
Characterisation methodology, methods, models and factors	Throughout this document an “LCIA methodology” refers to a collection of individual characterisation “methods” or characterisation “models”, which together address the different impact categories, which are covered by the methodology. “Method” is thus the individual characterisation model while “methodology” is the collection of methods. The characterisation factor is, thus, the factor derived from characterisation model which is applied to convert an assigned life cycle inventory result to the common unit of the category indicator.



Definiendum	**Definition**
Classification	A step of Impact assessment, in which environmental interventions are assigned to predefined impact categories on a purely qualitative basis (Guinee et al 2002)
Elementary flow	Material or energy entering the system being studied has drawn from the environment without previous human transformation (e.g. timber, water, iron ore, coal) , or material or energy leaving the system being studied that is released into the environment without subsequent human transformation (e.g. CO_2 or noise emissions, wastes discarded in nature) (ISO 14040)
Endpoint method/model	The category endpoint is an attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern (ISO 14040). Hence, endpoint method (or damage approach)/model is a characterisation method/model that provides indicators at the level of Areas of Protection (natural environment's ecosystems, human health, resource availability) or at a level close to the Areas of Protection level.
Environmental impact	A consequence of an environmental intervention in the environment system (Guinee et al 2002)
Environmental intervention	A human intervention in the environment, either physical, chemical or biological; in particular resource extraction, emissions (incl. noise and heat) and land use; the term is thus broader than “elementary flow” (Guinee et al 2002)
Environmental profile	The result of the characterisation step showing the indicator results for all the predefined impact categories, supplemented by any other relevant information (Guinee et al 2002)
Impact category	Class representing environmental issue of concern (ISO 14040). E.g. Climate change, Acidification, Ecotoxicity etc.
Impact category indicator	Quantifiable representation of an impact category (ISO 14040). Eg Kg CO_2-equivalents for climate change
Life cycle impact assessment (LCIA)	"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a given product system throughout its life cycle." (ISO 14040) The third phase of an LCA, concerned with understanding and evaluating the magnitude and significance of the potential environmental impacts of the product system(s) under study
Midpoint method	The midpoint method is a characterisation method that provides indicators for comparison of environmental interventions at a level of cause-effect chain between emissions/ (resource consumption) towards endpoint level.
Sensitivity analysis	A systematic procedure for estimating the effects of choices made regarding methods and data on the outcome of the study (ISO 14044)

1 Overview

This document supplements information with respect to the ILCD Handbook - "Recommendations for Life Cycle Impact Assessment in the European context - based on existing environmental impact assessment models and factors". The supplementing information is based on the structure and content of the database in which characterisation factors (CFs) related to the recommended methods are compiled.

The database is meant to be used mainly in order to integrate the CFs of the International Reference Life Cycle Data System (ILCD) (EC-JRC, 2011) methodology into existing LCA software and database systems. Hence, this supporting document explains, where necessary, the choices made in adapting the source methods into ILCD elemenatary flows and current limitations and methodological advice related to the CFs' use. This is meant to support the correct use of these factors, but also to stimulate potential improvement by developers of LCIA methods and factors.

Documentation of the LCIA methods as ILCD formatted data set, mapping to the ILCD elementary flows, and additional quality checks were performed by the EC's JRC-IES and with contractual support projects.

The CFs database consists of a database of ILCD-formatted xml files[1] to allow electronic import into LCA software. With help of the included ILCD2HTML xslt-style sheet they can also be displayed in web browsers[2]; additionaly al LCIA method data sets are made available as html files for direct and stable display in web browers. The LCIA methods are each implemented as separate data sets which contain all the descriptive metadata documentation and the characterisation factors. The database contains moreover data sets of all elementary flows, flow properties and unit groups as well as the source and contact data sets (e.g. of the referenced data sources and publications as well as authors, data set developers, and so on).

In addition to the ILCD-formatted xml files, the data sets are available also as 2 MS Excel files[3], to ease extraction of the factors until major LCA software have implemented import interfaces to allow for a more efficient and error-free transfer[4].

The two MS Excel files are:

- "ILCD2011-LCIA-method-documentation-FILE-1- v1.0.2_17Jan2012.xlsx" *
- "ILCD2011-LCIA-method-documentation-FILE-2- v1.0.2_17Jan2012.xlsx" *

Within these files, the worksheets "LCIA Documentation page "1 and "2" are of interest for the practitioner.

The first worksheet gives the condensed documentation of the recommended LCIA methods. It comprises details and metadata (see Annex 1) on:

[1] Downloadable, from http://lct.jrc.ec.europa.eu/
[2] Simply by doubleclicking the LCIA methods' xml files after unzipping the database when saved on the hard disk
[3] Downloadable, from http://lct.jrc.ec.europa.eu/
[4] Please note that, for technical reasons, the Excel files show identifier numbers (UUIDs) for all data sources and contacts and not the clear text. The clear text and full source and contact details can be found in the downloadable database in the files with the respective UUID as filename or by opening the above mentioned html files of the LCIA method data set.

- Name, source and information on the background models used to calculate the characterization factors
- Characteristics of the indicators (e.g. reference unit, applicability, time and geographical representativness, etc)
- Validation of models and review process leading to the recommendation of each model
- Administrative information (commissioner of the data set, ownership of the data, accessibility etc)

The second worksheet gives the individual characterisation factors in relation to the ILCD reference elementary flows.

This documentation accompanies the recommendation (EC-JRC, 2011) based on models and factors identified in the "ILCD Handbook - Analysis of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment" (EC-JRC, 2010a).

The content of the present technical report document is:

- a synthesis, recalling general considerations or decisions, which were applied for all impact categories and technical details with respect to each impact category, documenting specific choices made when implementing the characterization factors as well as problems/solutions encountered in the course of this implementation.
- a summary of the issues that have not yet been solved in this present version of the characterisation factors related to recommend LCIA methods. This document list also recommendations for method developers, who are to update the documentation in the future. Actually, many LCIA methods and related factors are under development.

Not necessarily all LCIA methods and characterisation factors that are recommended are currently fully compliant with all ILCD requirements, especially related to the requirements for review. However the recommendation reflects that they were seen as being of sufficient quality.

Any feedback and comment from method developers and practitioners is crucial for identifying potential errors and further improving the quality of data and for supporting further development of methods. Therefore any input is welcome. Please send your input to lca@jrc.ec.europa.eu.

1.1 Summary of Recommended Methods

The recommended characterisation models and associated characterisation factors in ILCD are classified according to their quality into three **levels: "Level I"** (recommended and satisfactory), "**Level II"** (recommended but in need of some improvements) or "**Level III**" (recommended, but to be applied with caution). Note that in some cases individual charcaterisation factors are classified lower (down-rated) compared to the general level of the method per se (e.g. a method may be "Level II" but several flows only be "Level III" or "Interim", e.g. due to lack of some substance data). A mixed classification (e.g. Level I/II) is related to the application of the classified method to different types of substances, whose level of recommendation is differentiated. The first level refers to level of recommendation of the method and the second level refers to a downgrade of recommandations for certain characterisation factors calculated with that method. In the database, a specific indication of which factors are downgraded is indicated.

In the summary table "**Interim**" indicates that a method was considered the most promising among others for the same impact category, but still immature to be recommended. This does not indicate that the impact category would not be relevant, but that further efforts are needed before any recommendation can be given.

In the CFs database, factors are reported for levels I, II, and III. Interim factors are also reported but are to be considered only as optional factors, not as recommended ones.

The tables below present the summary of recommended methods (models and associated characterisation factors) and their classification both at midpoint and at endpoint. Indicators and related unit are also reported for each recommended and interim methods.

For more information on the recommended methods, the reader is referred to the "ILCD Handbook - Recommendations for Life Cycle Impact Assessment in the European context - based on existing environmental impact assessment models and factors" (EC-JRC, 2011) and to the references of the methods themselves.

Table 1 LCIA method data set names, reccomandation level, reference quantities (aka "Flow properties" of the impact indicators), and associated unit groups for recommended and interim CFs in ILCD dataset

LCIA method	Rec Level	Flow property*	Unit group data set (with reference unit)
ILCD2011; Climate change; midpoint; GWP_{100}; IPPC2007	I	Mass CO_2-equivalents	Units of mass (kg)
ILCD2011; Climate change; endpoint - human health; DALY; ReCiPe2008	interim	Disability Adjusted Life Years (DALY)	Units of time (a)
ILCD2011; Climate change; endpoint - ecosystems; PDF; ReCiPe2008	interim	Potentially Disappeared number of species*time[5]	Units of items*time (1*a) §
ILCD2011; Ozone depletion; midpoint; ODP; WMO1999	I	Mass CFC-11-equivalents	Units of mass (kg)
ILCD2011; Ozone depletion; endpoint - human health; DALY; ReCiPe2008	interim	Disability Adjusted Life Years (DALY)	Units of time (a)
ILCD2011; Cancer human health effects; midpoint; CTUh; USEtox	II/III	Comparative Toxic Unit for human (CTUh)	Units of items (cases)

LCIA method	Rec Level	Flow property*	Unit group data set (with reference unit)
ILCD2011; Non-cancer human health effects; midpoint; CTUh; USEtox	II/III	Comparative Toxic Unit for human (CTUh)	Units of items (cases)
ILCD2011; Cancer human health effects; endpoint; DALY; USEtox	II/interim	Disability Adjusted Life Years (DALY)	Units of time (a)
ILCD2011; Non-cancer human health effects; endpoint; DALY; USEtox	interim	Disability Adjusted Life Years (DALY)	Units of time (a)
ILCD2011; Respiratory inorganics; midpoint; PM2.5eq; Rabl and Spadaro (2004) and Greco et al (2007)	I	Mass PM2.5-equivalents	Units of mass (kg)
ILCD2011; Respiratory inorganics; endpoint; DALY; Humbert et al (2009)	I/II	Disability Adjusted Life Years (DALY)	Units of time (a)
ILCD2011; Ionizing radiation; midpoint - human health; ionising radiation potential; Frischknecht et al. (2000)	II	Mass U_{235}-equivalents	Units of mass (kg)
ILCD2011; Ionizing radiation; midpoint - ecosystem; CTUe; Garnier-Laplace et al (2008)	interim	Comparative Toxic Unit for ecosystems (CTUe) * volume * time	Units of volume*time (m^3*a)
ILCD2011; Ionizing radiation; endpoint- human health; DALY; Frischknecht et al (2000)	interim	Disability Adjusted Life Years (DALY)	Units of time (a)
ILCD2011; Photochemical ozone formation; midpoint - human health; POCP; Van Zelm et al. (2008)	II	Mass C_2H_4-equivalents	Units of mass (kg)
ILCD2011; Photochemical ozone formation; endpoint - human health; DALY; Van Zelm et al. (2008)	II	Disability Adjusted Life Years (DALY)	Units of time (a)
ILCD2011; Acidification; midpoint; Accumulated Exceedance; Seppala et al 2006, Posch et al (2008);	II	Mole H^+-equivalents	Units of mole
ILCD2011; Acidification terrestrial; endpoint; PNOF; Van Zelm et al (2007)	interim	Potentially not occurring numer of plant species in terrestrial ecosystems * time	Units of items*time (1*a)
ILCD2011; Eutrophication terrestrial; midpoint; Accumulated Exceedance; Seppala et al.2006, Posch et al 2008	II	Mole N-equivalents	Units of mole
ILCD2011; Eutrophication freshwater; midpoint;P equivalents; ReCiPe2008	II	Mass P-equivalents	Units of mass (kg)
ILCD2011; Eutrophication marine; midpoint;N equivalents; ReCiPe2008	II	Mass N-equivalents	Units of mass (kg)
ILCD2011; Eutrophication freshwater; endpoint;PDF; ReCiPe2008	interim	Potentially Disappeared number of freshwater species * time	Units of items* time (1*a)
ILCD2011; Ecotoxicity freshwater; midpoint; CTUe; USEtox	II/III	Comparative Toxic Unit for ecosystems (CTUe) * volume * time	Units of volume*time (m^3*a)
ILCD2011; Land use; midpoint; SOM;Mila i Canals et al (2007)	III	Mass deficit of soil organic carbon	Units of mass (kg)
ILCD2011; Land use; endpoint; PDF; ReCiPe2008	interim	Potentially Disappeared Number of species in terrestrial ecosystems * time	Units of items*time (1*a)
ILCD2011; Resource depletion - water; midpoint; freshwater scarcity; Swiss Ecoscarcity2006	III	Water consumption equivalent	Units of volume (m^3)
ILCD2011; Resource depletion- mineral, fossils and renewables; midpoint;abiotic resource depletion; Van Oers et al (2002)	II	Mass Sb-equivalents	Units of mass (kg)
ILCD2011; Resource depletion- mineral, fossils and renewables; endpoint;surplus cost; ReCiPe2008	interim	Marginal increase of costs	Units of currency 2000 ($)

§ In ReCiPe2008, the CFs at endpoint for ecosystem are reported as species*yr and they are calculated multiplying PDF in (PDF*m^2*y) for species density (number of species *m^2). The species densities listed in ReCiPe2008 are: terrestrial species density: 1.38 E^{-8} [1/m^2], freshwater species density: 7.89 E^{-10} [1/m^3], marine species density: 1.82 E^{-13} [1/m^3]

2 Content of the documentation

2.1 General issues related to the characterisation factors (CFs)

The metadata provided for each LCIA method gives an overview of the method/model. In the LCIA method data sets themselves, background models are only indicated succinctly in relation to their respective contributions to the modelling of the impact pathway (incl. geographical specifications, modelled compartments, etc). In case the LCA practitioner requires more details on a specific method or model, it is recommended to consult references provided in the metadata. In general, the sources and references available in the metadata refer to the main data set sources of the considered LCIA method.

Some issues were noted in the course of documenting the recommended LCIA methods and mapping the factors to a common set of elementary flows. Only general problems that are not related to one specific LCIA method are reported in this section. Other issues specific to each impact category are reported in chapter 3.

Emphasis is put to ensure a proper use of the CFs. General indications on the applicability and the representativeness of each method are provided in the data set documentation, with additional notes and info on deviating recommendations on the use of CFs for some flows are available in the table of the CFs at the respective factor.

A very limited number of elementary flows that have a characterisation factor in a LCIA method were not implemented. Such flows are mainly those selected groups of substances and measurement indicators, which are not compliant with the ILCD Nomenclature (e.g. “hydrocarbons, unspecified”, "heavy metals") and hence excluded from the flow list. Wherever possible for such substance groups and as in fact foreseen by the LCIA method developers, the respective factors were assigned to the individual elementary flows of those substances that contribute to the group or measurement indicator (e.g. "Pentane" as contributor to "hydrocarbons, unspecified"), unless substance-specific factors were also available. Note however, that this assignment has not been done for all substances. When developing the lists with the characterisation factors, scripts were run, supporting the mapping of the characterisation factors by the different authors to the common ILCD elementary flows, with the CAS numbers as primary mapping criteria. All newly added elementary flows (compared to the former ILCD reference elementary flows in use until September 2011) can be found in the Excel file “ILCD2011-LCIA-method-documentation-FILE-1- v1.0.2_17Jan2012.xlsx”, worksheet “LCIA Documentation page 2”, appended after the existing flows (first new elementary flow: "4-nitroaniline - Emissions to water, unspecified", UUID: 694cbe4a-1fdd-4d11-9d76-0e26e871429b).

2.2 Nomenclature

Due to specific properties in their elementary flows (climate change, land use; see details per impact category in next section) or because of the large extent of the number of flows covered (USEtox^{TM-}based impact categories), some methods induced the need to generate additional flows, extending the former ILCD reference elementary flow list. However, the substances listed in the USEtox^{TM} database combine different nomenclature systems, e.g. common names, trade names, different IUPAC names, etc. Therefore, flows were added to ensure proper mapping or naming of the newly added substances, with the CAS number as main criterium. EINECS nomenclature was used whenever available; for the remaining substances, original names were kept as such (mainly pesticides in USEtox^{TM}). As a result, some inconsistencies are now present in the elementary flow list (e.g. sulfur vs. sulphur). A full harmonization of the nomenclature in the entire elementary flow list is not yet achieved. However, by the provision of synonyms for by far most of the substances, the identification/location of a specific elementary flow has been eased.

Note also that for metal/semimetal emissions, no differentiation is made in most LCIA methods between different forms (e.g. different ions, elemental form). Unless ions are differentiated (as e.g. for Cr^{3+} and Cr^{6+}), the CAS number of the elemental form has been assigned to the final substance (e.g. "Copper" as emission to the different environmental compartments), while the elementary flow is meant to cover the most common ionic and the elemental form of that element being emitted.

2.3 Geographical differentiation

Some of the models behind the LCIA methods allow calculating characterisation factors for further substances considering geographical differentiation. Within ILCD dataset, available country-specific factors are already included in the LCIA method data sets for: water scarcity at midpoint; acidification at midpoint and terrestrial eutrophication at midpoint. Further developments remain, however, necessary to define the optimum geographic distinctions to be made.

3 Additional information per impact category

Specific comments on the implementation of CFs as well as on their recommended use are provided below. Impact categories, which share the same remarks, are grouped.

3.1 Climate change and ozone depletion

3.1.1 Climate change

Impact category	*Model*	*Indicator*	*Recomm level*
Climate change midpoint	IPPC,2007	GWP_{100}	I
Climate change, endpoint - human health	ReCiPe2008 (De Schryver et al 2009)	DALY	interim
Climate change, endpoint - ecosystem	ReCiPe2008 (De Schryver et al 2009)	PDF	interim

The source for CFs for climate change at midpoint was the IPCC 2007 report for a 100 year period. The source GWP data have only one emission compartment ("to air"), therefore, the values were assigned to the different emission compartments in the ILCD (i.e. "emissions to lower stratosphere and upper troposphere", "emissions to non-urban air or from high stacks", "emissions to urban air close to ground", "emissions to air, unspecified (long term)", and "emissions to air, unspecified"). Values that are not listed in the IPCC 2007 report are taken from ReCiPe2008 (v1.05) (De Schryver et al 2009). For a number of substances the factors for “Emissions to upper troposphere and lower stratosphere” are not reported as they were considered not relevant for the climate change impact category. For climate change (endpoint, ecosystems), the CFs reported in the dataset correspond to the calculation provided by ReCiPe2008 (v1.05). Hence, the PDF (PDF*m^2*yr) values are multiplied for species density[6] and the final factors in the database are reported as species*yr.

3.1.2 Ozone depletion

Impact category	*Model*	*Indicator*	*Recomm level*
Ozone depletion, midpoint	WMO,1999	ODP	I
Ozone depletion, endpoint - human health	ReCiPe2008 (Struijs et al. 2009a and 2010)	DALY	interim
Ozone depletion, endpoint - ecosystem	No methods recommended		

Characterization factors (CFs) for ozone-depleting substances (ODS), which contribute to both climate change and ozone depletion impact categories, were implemented from the World Metereological Organisation WMO (1999) and the ReCiPe2008 data sets (v1.05).

[6] The species densities listed in ReCiPe2008 report are: terrestrial species density: 1.38 E^{-8} [1/m^2], freshwater species density: 7.89 E^{-10} [1/m^3], marine species density: 1.82 E^{-13} [1/m^3]

3.2 Human toxicity and Ecotoxicity

3.2.1 Human toxicity

Impact category	*Model*	*Indicator*	*Recomm level*
Human toxicity midpoint, cancer effects	USEtox (Rosenbaum et al 2008)	Comparative Toxic Unit for Human Health (CTUh)	II/III
Human toxicity midpoint, non cancer effects	USEtox (Rosenbaum et al 2008)	CTUh	II/III
Human toxicity endpoint, cancer effects	DALY calculation applied to CTUh of USEtox (Huijbregts et al 2005a)	DALY	II/interim
Human toxicity endpoint, non cancer effects	DALY calculation applied to of CTUh USEtox (Huijbregts et al 2005a)	DALY	Interim

3.2.2 Ecotoxicity

Impact category	*Model*	*Indicator*	*Recomm level*
Ecotoxicity freshwater, midpoint	USEtox (Rosenbaum et al 2008)	Comparative Toxic Unit for ecosystems (CTUe)	II/III
Ecotoxicity marine and terrestrial, midpoint	No methods recommended		
Ecotoxicity freshwater, marine and terrestrial, endpoint	No methods recommended		

All USEtox^{TM} factors (v.1.01) were implemented in accordance to the correspondence in the emission compartments reported in the Table 2 (next page).

Ecotoxicity is currently only represented by toxic effect on aquatic freshwater species in the water column. Impacts on other ecosystems, including sediments, are not reflected in current general practice.

Metals in USEtoxTM are specified according to their oxidation degree(s). In general, the following rules were applied to implement the CFs in the ILCD system (with approval from the USEtox^{TM} team):

- The metallic forms of the metals were assigned the CFs of the oxidized form listed in USEtox^{TM}. Although metals can have several oxidation degrees, e.g. Cu ($^{+1}$ or $^{+2}$), only one for each metal is currently reported in the USEtox^{TM} model (v.1.01), hence the direct assignment of Cfs to the metallic form (three exceptions are reported in the bullet point below). Comments were added in the data sets to indicate that the metallic forms were derived from the oxidized forms and apply to all ions of that metal.
- Three metals in USEtox^{TM} are characterized with two different oxidized forms, i.e. arsenic (As), chromium (Cr) and antimony (Sb). Two ionic forms were then indicated

for each. The CFs for their metallic forms were allocated the CFs of As($^{+5}$), Sb$^{(+6}$) and 50/50 CFs of Cr(+^{3}) / Cr(+^{6}) for As, Sb and Cr respectively.

In the version v.1.01 of the USEtox^{TM} factors, characterized inorganics only comprise few metals. Other inorganics are not available in this version of USEtox^{TM} (e.g. SO_2, NO_x, particles). Note, however, that primary particulate matter and precursors are considered in the “respiratory inorganics” impact category.

For both ecotoxicity and human toxicity, distinction between recommended and interim CFs in USEtox^{TM} was notified through different level of recommendations. According to USEtox model, the recommendation level for certain substances (such as substances belonging to the classes of metals and amphiphilics and dissociating chemicals) was downgraded. I.e. for "Human toxicity – cancer effect" at midpoint, the USEtox model is recommended as Level II, but the associated CFs have two different recommendation levels (II and III), reflecting different robustness of background data on effects. In the xml data sets and the Excel files, it is specified wich substances / emissions have a lower recommendation level.

Table 2 Correspondence of emission compartments between USEtoxTM model and ILCD elementary flow system *

	ILCD emission compartments	USEtox^{TM} compartments		Data derivation status
Air	Emissions to air, unspecified	*50 Em.airU / 50 Em.airC*	50/50 urban/continental	Estimated
	Emissions to air, unspecified (long term)	*50 Em.airU / 50 Em.airC*	50/50 urban/continental	Estimated
	Emissions to non-urban air or from high stacks	*Em.airC*	Continental air	Calculated
	Emissions to urban air close to ground	*Em.airU*	Urban air	Calculated
	Emissions to lower stratosphere and upper troposphere	*Em.airC*	Continental air	Estimated
Water	Emissions to fresh water	*Em.fr.waterC*	Freshwater	Calculated
	Emissions to sea water	*Em.sea waterC*	Seawater	Calculated
	Emissions to water, unspecified	*Em.fr.waterC*	Freshwater	Estimated
	Emissions to water, unspecified (long term)	*Em.fr.waterC*	Freshwater	Estimated
Soil	Emissions to soil, unspecified	*Em.nat.soilC*	Natural soil	Estimated
	Emissions to agricultural soil	*Em.agr.soilC*	Agric. soil	Calculated
	Emissions to non-agricultural soil	*Em.nat.soilC*	Natural soil	Calculated

* Shaded cells refer to the 6 compartments used in the USEtox^{TM} model (hence the flag “Calculated”); the correspondence for the other emission compartments was agreed with the USEtox^{TM} team. Some explanations are given more below in this document

3.3 Particulate matters/Respiratory inorganics

Impact category	*Model*	*Indicator*	*Recomm level*
Particulate matters, midpoint	RiskPoll model (Rabl and Spadaro, 2004) and Greco et al 2007	PM2.5eq	II/III
Particulate matters, endpoint	Adapted DALY calculation applied to midpoint (Van Zelm et al 2008, Pope et al 2002)	DALY	II

The CFs for fate and intake (referred as midpoint level) and effect and severity (referred as endpoint level) are the result of the combination of different models, reported in Humbert (2009).

The recommended models in EC-JRC 2011 have been used for calculating CFs but they were complemented as in Humbert 2009, where a consistent explanation on the combination of different models for calculating CFs is provided.

For fate and intake, the CFs were based on RiskPoll (Rabl and Spadaro, 2004), Greco et al. (2007), USEtox (Rosenbaum et al. 2008), Van Zelm et al. (2008).

For the effect and severity factors, they are calculated starting from the work of van Zelm et al. (2008) that provides a clear framework, but using the most recent version of Pope et al. (2002) for chronic long term mortality and including effects from chronic bronchitis as identified significant by Hofstetter (1998) and Humbert (2009).

A comprehensive list of used models is available in the metadata of ILCD and in Humbert 2009.

CFs for "Emissions to non-urban air or from high stacks" are calculated as emission-weighted averages between high-stack urban, transportation rural, low-stack rural, high-stack rural, transportation remote, low-stack remote, and high-stack remote (Humbert, 2009).

3.4 Ionising radiation

Impact category	*Model*	*Indicator*	*Recomm level*
Ionising radiation, human health, midpoint	Frischknecht et al 2000	Ionizing Radiation Potentials	II
Ionising radiation, ecosystem, midpoint	Garnier- Laplace et al 2009	Comparative Toxic Unit for ecosystems (CTUe)	interim
Ionising radiation, human health, endpoint	Frischknecht et al 2000	DALY	interim
Ionising radiation, ecosystem, endpoint	No methods recommended		

At midpoint CFs for “emissions to water (unspecified)” are used also as approximation for the flow compartment “emissions to freshwater”. The modified flows are marked as “estimated” in the dataset. As the CFs were taken as applied in ReCiPe (v1.05), and there CFs for iodine-129 are not reported, this CF was taken from the source directly (Frischknecht et al 2000). As many nuclear power stations are costal and use marine water, this has to be further considered and assessed in further developments.

At the endpoint (human health), the factors are taken from Frischknecht et al 2000, and then adjusted as applied in ReCiPe2008 (v1.05).

At midpoint (ecosystems), the CFs were built in full compatibility with the USEtox™ model (cf. method documentation). Therefore, the same framework as presented in section 3.2 was used to implement the CFs with regard to the different emission compartments. Emissions to lower stratosphere and upper troposphere were however excluded and so were most of the water-borne emission compartments (all but emissions to freshwater).

According to the current ILCD nomenclature, the elementary flows of radionucleides are expressed per kBq; the CFs were thus expressed per kBq.

3.5 Photochemical ozone formation

Impact category	*Model*	*Indicator*	*Recomm level*
Photochemical ozone formation, midpoint	Van Zelm et al 2008 as applied in ReCiPe2008	POCP	II
Photochemical ozone formation, endpoint - human health	Van Zelm et al 2008 as applied in ReCiPe2008	DALY	II
Photochemical ozone formation, endpoint - ecosystem	No methods recommended		

The generic CF for Volatile Organic Compunds (VOCs) –not available in the original source CFs data set – was calculated as the emission-weighted combination of the CF of Non-methane VOCs (generic) and the CF of CH_4. Emission data (Vestreng et al 2006) refer to emissions occurring in Europe (continent) in 2004, i.e. 14,0 Mt-NMVOC and 47.8 Mt-CH_4.

Factors were not provided for any other additional group of substances (except PM), because substance groups such as "metals" and "pesticides" are not easily covered by a single CF in a meaningful way. A few groups-of-substances indicators are still provided in the ReCiPe2008 method (v1.05). However, many important compounds belonging to these groups are already characterized as individual substance (132 substances characterized).

3.6 Acidification

Impact category	*Model*	*Indicator*	*Recomm level*
Acidification, midpoint	Seppala et al 2006, Posch et al 2008	Accumulated Exceedance (AE)	II
Acidification - terrestrial, endpoint - ecosystem	Van Zelm et al 2007 as applied in ReCiPe	PNOF	interim

Acidification is mainly caused by air emissions of NH_3, NO_2 and SO_X.. In the data set, the elementary flow “sulphur oxides” (SO_X) was assigned the characterization factor for SO_2. Other compounds are of lower importance and are not considered in the recommended LCIA method. Few exceptions exist however for NO, SO_3, for which CFs were derived from those of NO_2 and SO_2 respectively. CFs for acidification are expressed in moles of charge (molc) per unit of mass emitted (Posch et al 2008). As NO and SO_3 lead to the same respective molecular ions released (nitrate and sulfate) as NO_2 and SO_2, their charges are still z= 1 and z=2, respectively. Using conversion factors established as z/M (M: molecular weight), the CFs for NO and SO_3 have been derived as shown in following Table.

Table 3 Derived additional CFs for acidification at midpoint

	Conversion factors		CFs	
SO_2	3,12E-02	eq/g	1,31	eq/kg
NO_2	2,17E-02	eq/g	0,74	eq/kg
NH_3	5,88E-02	eq/g	3,02	eq/kg
NO	3,33E-02	eq/g	1,13	eq/kg
SO_3	2,50E-02	eq/g	1,05	eq/kg

* CFs for SO_2, NO_2 and NH_3 provided in Posh et al. (2008)

Note that, in addition to generic factors, country-specific characterisation factors are provided in the LCIA method data sets at midpoint and for a number of countries (only for SO_2, NH_3, and NO_2).

At endpoint-ecosystems, CFs for acidification are available in ReCiPe 2008 (v1.05) for “emissions to air, unspecified”. In the current implementation, these were used for mapping CFs for all air emission compartments, except “emissions to lower stratosphere/upper troposphere” and “emissions to air, unspecified (long term)”. This omission needs to be further evaluated for its relevance and may need to be corrected. The CFs reported in the dataset correspond to the calculation provided by Recipe2008 (v1.05). The PDF (PDF*m^2*yr) values are multiplied by the species density reported in ReCiPe2008 (v1.05) and the final factors in the database are reported as species*yr.

3.7 Euthrophication: terrestrial and aquatic

Impact category	*Model*	*Indicator*	*Recomm level*
Euthrophication terrestrial, midpoint	Seppala et al 2006, Posch et al 2008	Accumulated Exceedance (AE)	II
Euthrophication aquatic-freshwater/marine, midpoint	ReCiPe2008 (EUTREND model - Struijs et al 2009b)	P equivalents and N equivalents	II
Euthrophication terrestrial, endpoint	No methods recommended		
Euthrophication aquatic, endpoint	ReCiPe2008 (Struijs et al 2009b)	PDF	Interim

With respect to terrestrial eutrophication, only the concentration of nitrogen is the limiting factor and hence important, thereforeoriginal data sets include CFs for NH_3, NO_2 emitted to air. The CF for NO was derived using stoichiometry, based on the molecular weight of the considered compounds. Likewise, the ions NH^{4+} and NO^{3-} were also characterized since life cycle inventories often refer to their releases to air.

Site-independent Cfs are available for ammonia, ammonium, nitrate, nitrite, nitrogen dioxide, and nitrogen monoxide. Note that country-specific characterisation factors for ammonia and nitrogen dioxide are provided for a number of countries (in the LCIA method data sets for terrestrial midpoint).

As for acidification and terrestrial eutrophication, CFs for “emissions to air, unspecified”, available in ReCiPe2008 (v1.05), were used for mapping CFs for all emissions to air, except “emissions to lower stratosphere/upper troposphere” and emissions to “air, unspecified (long term)”. This omission needs to be further evaluated for its relevance and may need to be corrected. In freshwater environments, phosphorus is considered the limiting factor. Therefore, only P-compounds are provided for assessment of freshwater eutrophication (both midpoint and endpoint).

In marine water environments, nitrogen is the limiting factor, hence the recommended method’s inclusion of only N compounds in the characterization of marine eutrophication. The characterisation of impact of N-compund emitted into rivers that subsequently may reach the sea has to be further investigated. At midpoint, marine eutrophication CFs were calculated for the flow compartment “emissions to water, unspecified”. These factors have been added as approximation for the compartments “emissions to water, unspecified (long-term)”, “emissions to sea water”, and “emissions to fresh water”. Due to denitrification during freshwater transport to the seas, the CF for for emissions to sea water is likely too high and given as an interim solution. The relevant flows are marked as “estimated”.

No impact assessment methods, which were reviewed, included iron as a relevant nutrient to be characterized. Therefore, no CFs for iron is available.

Only main contributors to the impact were reported in the current documentation of factors (see following table). However, if other relevant N- or P-compounds are inventorized, the LCA practitioners can calculate their inventories in total N or total P – depending on the impact to assess – via stoichiometric balance and use the CFs provided for “total nitrogen” or “total phosphorus”. Additional elementary flows were generated for “nitrogen, total” and “phosphorus, total” in that purpose. Double-counting is of course to be avoided in the inventories, and - given that the reporting of individual substances is prefered - the "nitrogen, total" and "phosphorus, total" flows should only be used if more detailed elementary flow data is unavailable.

Table 4. Substances for which CFs were indicated for assessing aquatic eutrophication

Impact category	Characterized substances
Freshwater eutrophication	Phosphate, phosphoric acid, phosphorus total *
Marine eutrophication	Ammonia, ammonium ion, nitrate, nitrite**, nitrogen dioxide, nitrogen monoxide**, nitrogen total

* Phosphorus pentoxide, which has a factor in the original paper, is not implemented in the ILCD flow list due to its high reactivity and hence its low probability to be emitted as such. Inventories where phosphorus pentoxide is indicated should therefore be adapted/scaled and be inventoried e.g. as "phosphorus, total", based on stoichiometric consideration (P content).
** CFs not listed in ReCiPe data set; these were derived using stoichiometry balance calculations.

CFs for the emission compartments “water, unspecified” of the original source were also used to derive CFs for “emissions to freshwater”: this relies on the assumption that most waterborne emissions – from industries, agriculture and waste water treatement plant – occur in freshwater.

For euthrophication aquatic (endpoint, ecosystems), the characterisation factors reported in the dataset correspond to the calculation provided by ReCiPe2008 (v1.05). The PDF (PDF*m^2*yr) values are multiplied times the species density and the final factors in the database are reported as species*yr as in ReCiPe2008 method.

3.8 Land use

Impact category	*Model*	*Indicator*	*Recomm level*
Land use, midpoint	Mila I Canals et al 2007a	SOM	III
Land use, endpoint	ReCiPe2008	PDF	Interim

The CFs for land use at midpoint were taken from Mila I Canals et al 2007b calculated accordingly to the model (Mila I Canals et al 2007a).

Elementary flows for land occupation and transformation were added to the ILCD elementary flows. These new ILCD flows have been generated directly from the list of land use classes developed under the UNEP/SETAC Life Cycle Initiative, working group on land use[7]. The midpoint and endpoint CFs have been mapped to this common flow list, overcoming differences in original methods' land use classifications and elementary flows. It is to be noted that- for a number of land use classes developed under UNEP/SETAC and now taken up in the ILCD- neither midpoint nor endpoint factors are available so far. Therefore, further work is required.

For land use (endpoint, ecosystems), the CFs reported in the dataset correspond to the calculation provided by ReCiPe2008 (v1.05). The PDF (PDF*m^2*yr) values are multiplied times the species density and the final factors in the database are reported as species*yr as reported in ReCiPe2008.

3.9 Resource depletion

Impact category	*Model*	*Indicator*	*Recomm level*
Resource depletion - water, midpoint	Ecoscarcity (Frischknecht et al 2008)	Water consumption equivalent	III
Resource depletion – mineral and fossil fuels, midpoint	CML 2002 (Guinée et al 2002)	Scarcity	II
Resource depletion – renewable, midpoint	No methods recommended		
Resource depletion - water, endpoint	No methods recommended		
Resource depletion – mineral and fossil, endpoint	ReCiPe2008 (Goedkoop and De Schryver 2009).	Surplus cost	Interim

[7] This list draws on GLC2000, CORINE+ and Globio work, (in the meantime described in Koellner et al 2012).

Resource depletion – renewable, endpoint	No methods recommended

3.9.1 Resource depletion - Water

For assessing water depletion, CFs were implemented based on the Ecological Scarcity Method (Frischknecht et al 2008) and were calculated, at midpoint, by EC-JRC.

For the calculation of the characterisation factors for water resource depletion, a reference water resource flow was determined based on the EU consumption weighted average and the eco-factors of all other water flows were related to this reference flow. This enabled to express the impacts in water consumption equivalent, expressed as m^3 water-eq/m^3 instead of in Ecopoints EP/m^3. This procedure[8] however does not lead to any changes in ranking of the impact due to water consumption in the different countries as established in the orginal method.

Characterisation factors for 29 countries (OECD countries) were implemented and associated to the newly-generated elementary flow “freshwater”[9]. Country codes were used to differentiate the elementary flows. Note that the same elementary flow (i.e. with the same UUID) is used but that the country code can be documented in the inventory of input and output flows in process data sets as differentiating information. Next to this generic “freshwater” elementary flow, “ground water”, “river water” and “lake water” can be differentiated, at the moment using the characterisation factors for the corresponding “freshwater …” flows[10]. A characterisation factor for OECD average scarcity is also provided.

As stated in the method report, those country-specific factors are to be used only for “specific or sufficiently detailed LC inventories”. Otherwise, the classification in six scarcity categories, ranging from “low” to “extreme”, is recommended to be applied, hence the additional implementation of six elementary flows, e.g. “river water, low scarcity”. Low scarcity is defined as a share of consumption in the resource below 0.1. Extreme scarcity is represented as a share of 1 or above, i.e. water consumption equal to or exceeding the total amount of available resource (i.e. replenishment of water stocks by precipitation). See the table 5 for identifying the level of scarcity.

Table 5. Classification of scarcity levels, based on the ration between water consumption and water availability, as in Frischknecht et al 2008.

Scarcity classification	Water scarcity ratio [11]	Typical countries
Low	<0.1	Argentina, Austria, Estonia, Iceland, Ireland, Madagascar, Russia, Switzerland, Venezuela, Zambia
Moderate	0.1 to <0.2	Czech Republic, Greece, France, Mexico, Turkey, USA

[8] EU-average is calculated based on the sumproduct of the ecofactors (EP/m3) of each EU-country and their current water flow (km3/a) divided by the total current water flow in all these EU-countries. The eco-factors of each country were then related to this EU-average reference flow by dividing the ecofactor of each country by the EU-average calculated ecofactor.

[9] The flows referring to freshwater are expressed in m^3, whereas all the others (groundwater, lake water,river water) are expressed in kg

10 These flows for river, lake and ground water allow for a further update of factors. At the moment, CFs are the same for all the freshwater typologies.

11 Water scarcity ratio is expressed as (water consumption /available resource)

Medium	0.2 to <0.4	China, Cyprus, Germany, Italy, Japan, Spain, Thailand
High	0.4 to <0.6	Algeria, Bulgaria, Morocco, Sudan, Tunisia
Very high	0.6 to <1.0	Pakistan, Syria, Tadzhikistan, Turkmenistan
Extreme	≥1	Israel, Kuwait, Oman, Qatar, Saudi Arabia, Yemen

Discrete values from which Eco-factors for the scarcity categories were calculated in (Frischknecht et al 2008) are used as basis here, instead of a range for each category. Further developments of the method have been performed, allowing for more geographical refinement. If a practioner is interested, water stress information on a watershed level have been defined for all countries in the world (see supporting information of Pfister et al 2009) and have been mapped on a watershed level in a Google layer to refine the regionalization[12].

3.9.2 Resource depletion – Mineral and fossil

For resources depletion at midpoint, van Oers et al 2002 is the source of CFs (from the "Reserve base" figures), based on the methods of Guinée et al 2002. CFs are given as Abiotic Depletion Potential (ADP), quantified in kg of antimony-equivalent per kg extraction, or kg of antimony-equivalent per MJ for energy carriers.

For peat, ILCD elementary flow is available in MJ net calorific value, at 8,4 MJ/kg, while the CF data set is provided per kg mass. For other fossil fuels (crude oil, hard coal, lignite, natural gas), generic CFs given in kg antimony-equivalents / MJ, was applied. Where CFs for individual rare earth elements were not available, a generic CF for rare earths was used. Except for Yttrium, where a CF is given, a generic CF of 5,69 E-04 (van Oers et al 2002) was assigned to the rare earth elements (REE) reported in Table 6.

Table 6. Rare Earth Elements for which a generic CF factor was assigned

Cerium	Samarium	Holmium	Terbium
Europium	Scandium	Thulium	Erbium
Lanthanum	Dysprosium	Ytterbium	Gadolinium
Neodymium	Praseodymium	Prometheum	Lutetium

CFs for Gallium, Magnesium and Uranium, were calculated as follows (Table 7). The CF for Gallium is a rough estimate based on its abundance in zinc and bauxite ores, the main sources for Gallium (U. S. Geological Survey 2000). The CF for Magnesium was calculated according to U. S. Geological Survey data given in (Kramer 2001) and (Kramer 2002). A characterization factor for Uranium, given in kg antimony-equivalents / MJ, was calculated from 2009 data taken fromthe World Nuclear Association (2010).

Table 7. Characterisation factors for Galllium, Magnesium and Uranium

Flow	**Indicator**	**Characterization factor**

[12] availabale upon registration at http://www.esu-services.ch/projects/ubp06/google-layer/

Gallium-reserve base, 1999	kg Sb-eq./kg extraction	6,30E-03
Magnesium-reserve base, 1999	kg Sb-eq./kg extraction	2,48E-06
Uranium- reserve base, 2009	kg Sb-eq./MJ	3,59E-07

At endpoint, CFs from ReCiPe2008 (v1.05) were adopted. For the net calorific values of crude oil, hard coal, brown coal, and natural gas associated with the CFs data in ReCiPe2008 do not coincide with the net calorific values in the ILCD reference elementary flows. The reported CFs were chosen according to the closest net calorific value and the factors were linearly scaled in proportion to the actual net calorific value.

In addition, the reference unit of the ILCD flows for those four fossil resources and for uranium is based on the net calorific value[13] (MJ), while the CFs are expressed as unit per mass. The conversion factors (energy/mass ratios) shown in Table 8 were applied to adapt the CFs for those resources, drawing on the ILCD documented mass/energy ratios of these energy resources, as well as from the World Energy Council (2010).

Table 8. Net calorific value considered for fossil fuels and uranium

Resource	Net calorific value (MJ/kg)	Source
Crude oil	42,3	*ILCD Elementary flow definition*
Hard coal	26,3	*ILCD Elementary flow definition*
Brown coal	11,9	*ILCD Elementary flow definition*
Natural gas	44,1	*ILCD Elementary flow definition*
Uranium *	544284	*World Energy Council 2010*

* 1 ton Uranium was assumed to be equivalent to 13 000 toe (41,87 GJ/toe), considering an average light-water reactor (open cycle). This value was documented as Net calorific value, to support practice, while acknowledging that Uranium has no "Lower calorific value" in sensu stricto.

[13] For Uranium the usable energy content considering an average light-water reactor (open cycle) was taken and inserted as "Lower calorific value" to ease aggregation of primary energy consumption with fossil fuels

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Abstract
Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) are scientific approaches behind a growing number of environmental policies and business decision support in the context of Sustainable Consumption and Production (SCP) / Sustainable Industrial Policy (SIP) (COM(2008) 397/3) and Resource Efficiency (COM(2011)0571). The International Reference Life Cycle Data System (ILCD) provides a common basis for consistent, robust and quality-assured life cycle data, methods and assessments.
This document supports the correct use of the characterisation factors of the LCIA methods recommended in the ILCD guidance document "Recommendations for Life Cycle Impact Assessment in the European context - based on existing environmental impact assessment models and factors" (EC-JRC, 2011). The characterisation factors are provided in a separate database as ILCD-formatted xml files and as Excel files. This document focuses on how to use the database and highlights existing limitations of the database and methods/factors. Please note that the factors take into account models that have been available and sufficiently documented when the ILCD document on Analysis of existing methods was released (mid 2009).

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