Life Cycle Assessment
- a short overview -

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www.empa.ch/tsl

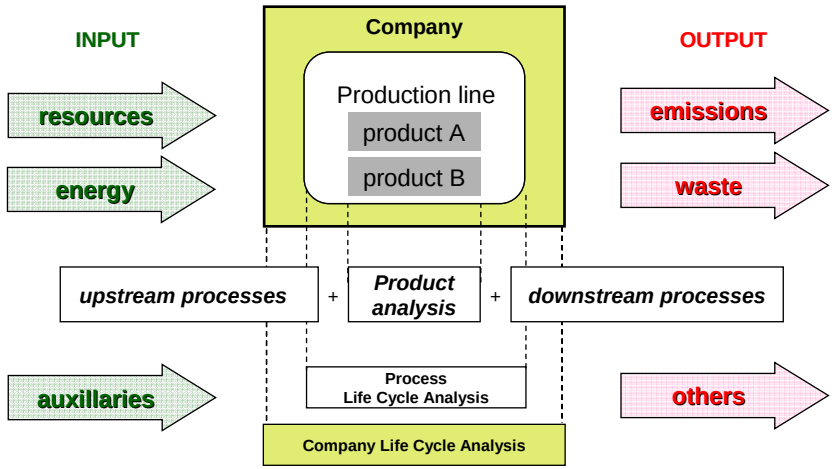
Outline

- Introduction
- Goal and scope definition
  - Functional unit, system boundaries
- Life Cycle Inventory (LCI) analysis
  - Allocation
  - ecoinvent database for LCI data
- Life Cycle Impact Assessment (LCIA)
  - CML, Eco-Indicator 99, Ecofactors '97
- Interpretation
- Conclusions

Introduction: The basic ideas of Life Cycle Assessment (1)

- Life Cycle Assessment (LCA)
  - is a systematic method to assess the environmental impacts of products/processes/companies, from raw material acquisition to final disposal;

- Main steps of an LCA
  - ***(i) Identification and quantification*** of the ***interactions*** between the relevant system and its environment



  - ***ii) Assessment*** of each single environmental impact according to ecological criteria

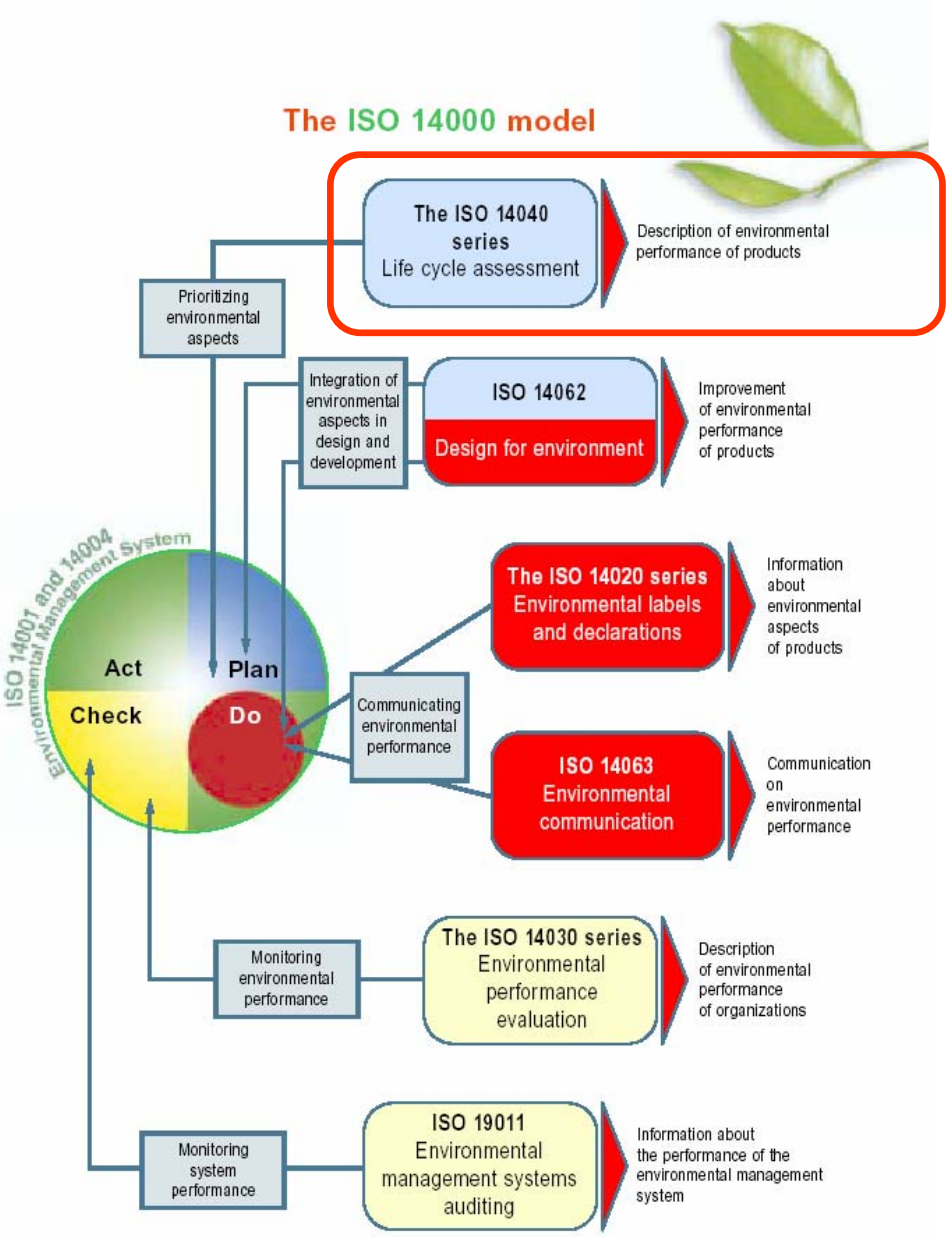
there is not THE impact assessment method, ...

.... but several, having specific characteristics that have to be chosen with regard to their application

Introduction: The basic ideas of Life Cycle Assessment (2)

- Benefits of Life Cycle Assessment:
  - by using a "*life cycle perspective*" no shift of the environmental impacts is generated
    - *i.e. no ecological sub-optimization*
  - weak-point analysis ***(****hot spots****)*** accross the complete product life-cycle
    - *from-cradle-to-grave*

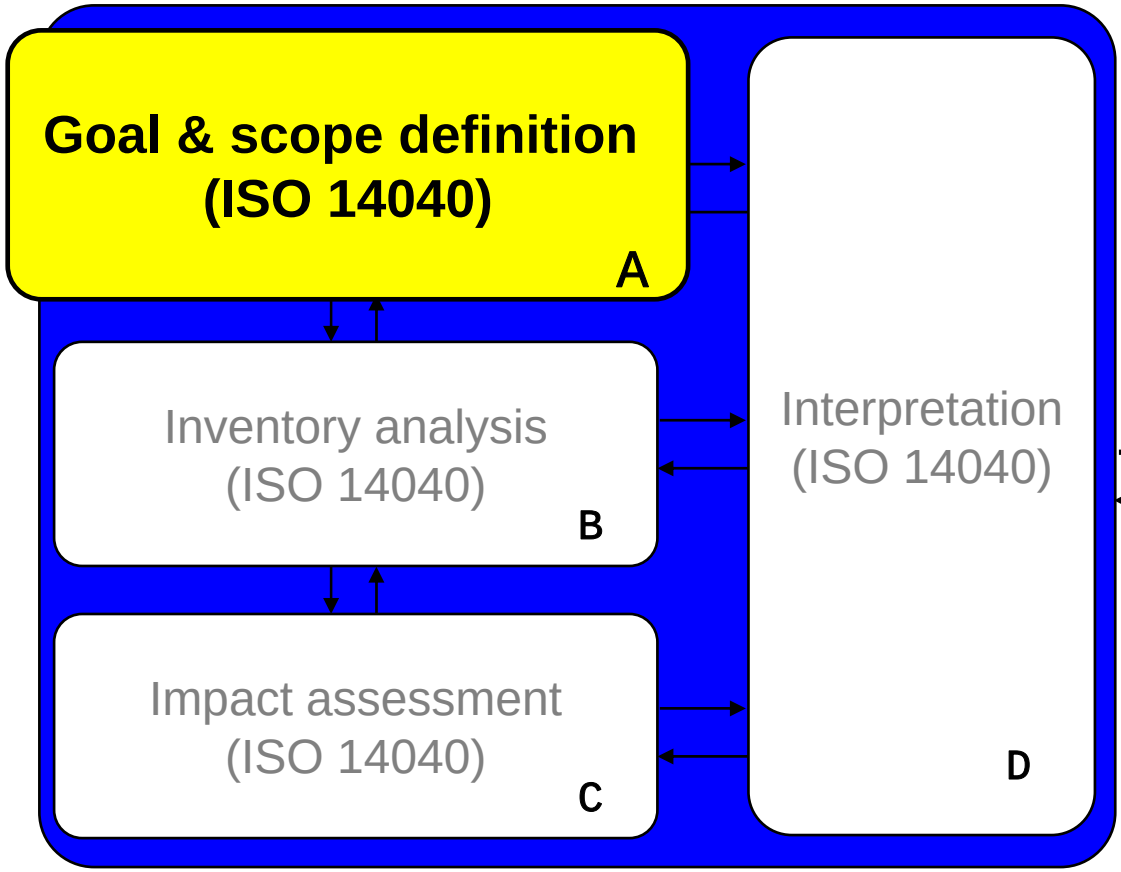
Introduction: The ISO 14040 series



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

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

Goal & scope definition

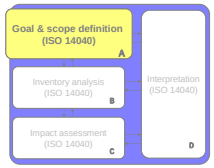


Elements according to
EN ISO 14040:2006

Direct application:

- Product development and improvement
- Strategic planning
- Public policy making
- Marketing
- others

Goal & scope definition: Requirements of EN ISO 14040:2006

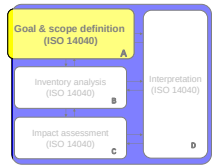


- The **goals** of an LCA state
  - the intended application;
  - the reasons for carrying out the study;
  - the intended audience
  - whether the results shall be used in comparative assertions intended to be disclosed to the public.

- The **scope** of an LCA includes
  - the product system to be studied;
  - the functional unit;
  - the system boundary;
  - allocation procedures;
  - impact categories selected and methodology of impact assessment, and subsequent interpretation to be used;
  - data requirements;
  - assumptions;
  - etc.

EN ISO 14040:2006

Goal & scope definition: Functional unit



- Functional unit:
  - the quantified performance of a product system for use as a reference unit within an LCA study, to which all input and output data with their respective environmental impacts refer to;
    - has to be defined **unambiguously** and must be **measurable**

- examples for functional units
  - to compare hand drying devices:
    - identical number of pairs of hands dried;
  - to compare beverage packagings:
    - packaging for x L of beverage, which makes it transportable and durable;
  - to compare dyes:
    - the amount of a product, which allows to dye a given amount and quality of cotton in a certain way (tone, colour fastness, …).

EN ISO 14040:2006

Goal & scope definition: System boundary

- System boundary: specifies, which *unit processes* are to be included in the *product system*
  - product system
    - collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product.

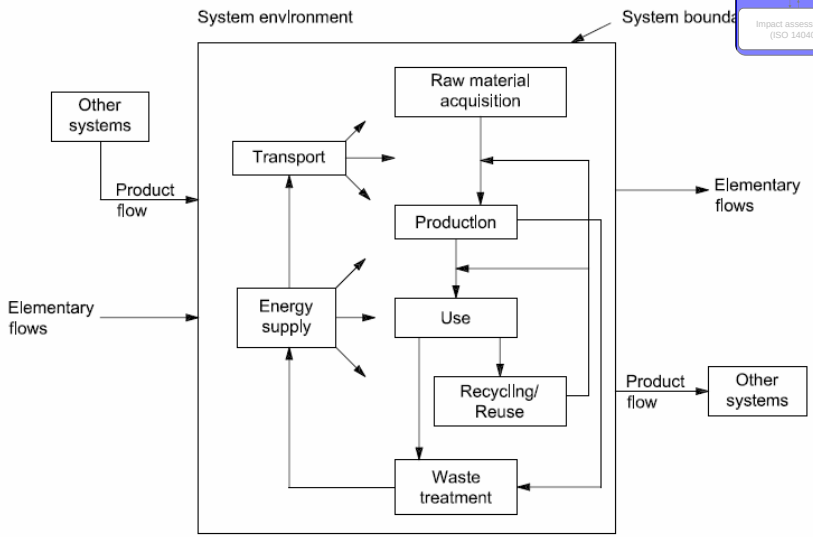


Figure 2 — Example of a product system for LCA

  - unit process:
    - smallest element considered in the life cycle inventory analysis for which input and output data are quantified;
    - unit processes are linked to one another by flows of intermediate products and/or waste for treatment, to other product systems by product flows, and to the environment by elementary flows.

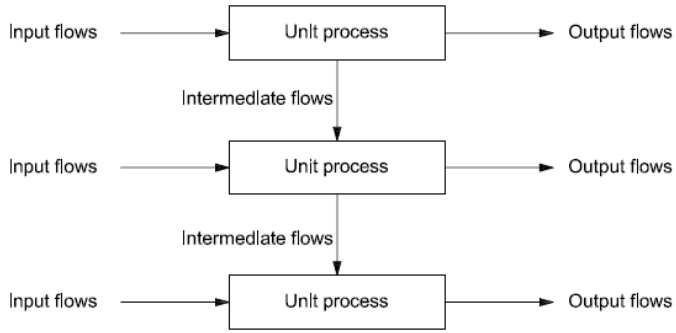


Figure 3 — Example of a set of unit processes within a product system

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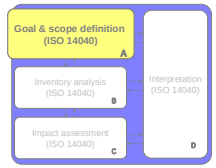
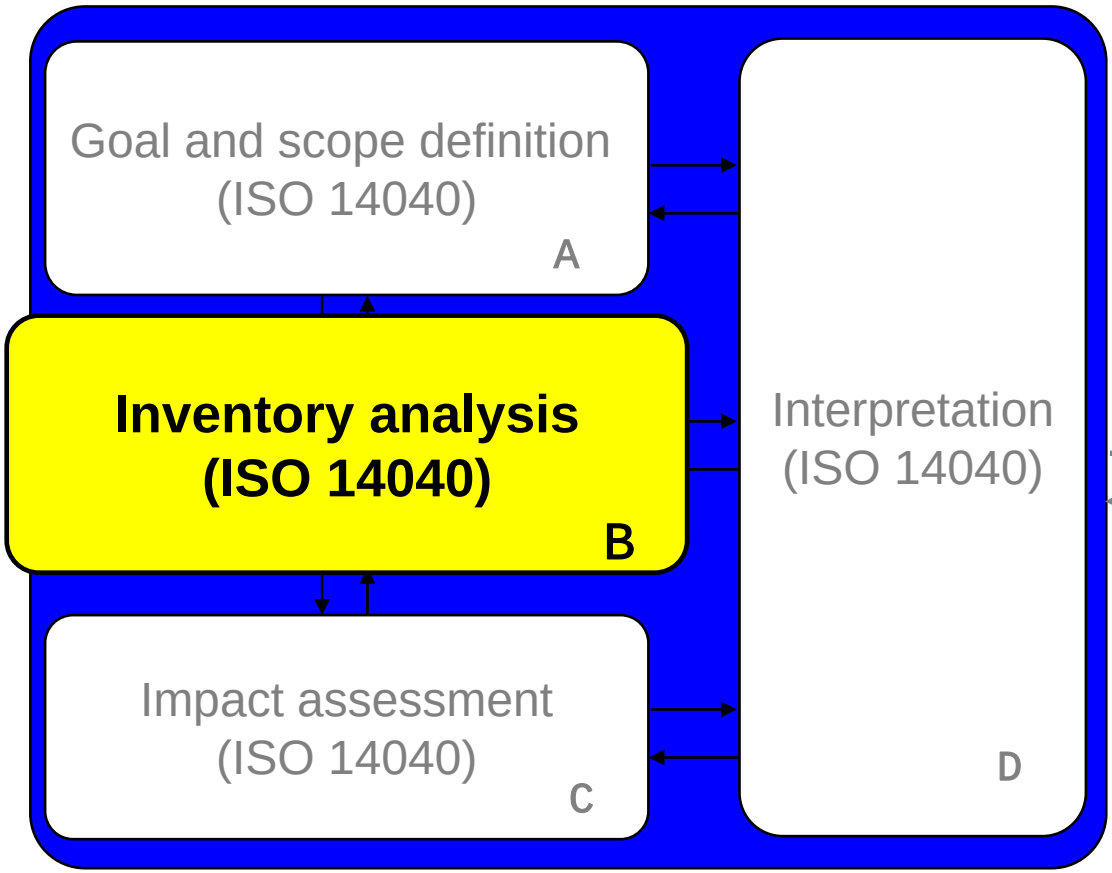
Goal & scope definition: System boundary



- the system boundary is a function of, among others,
  - intended application and audience;
  - data and cost constraints;
  - cut-off criteria.
- the deletion of life cycle stages, processes, inputs or outputs is only permitted if it does not significantly change the overall conclusions of the study
  - decisions to omit life cycle stages, processes, inputs or outputs have to be clearly stated, and the reasons and implications for their omission shall be explained.

EN ISO 14040:2006

Life Cycle Inventory Analysis

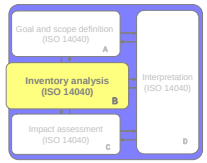


Elements according to
EN ISO 14040:2006

Direct application:

- Product development and improvement
- Strategic planning
- Public policy making
- Marketing
- others

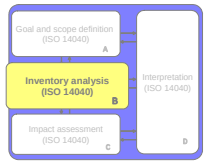
LCI Analysis: Requirements according to ISO 14040:2006



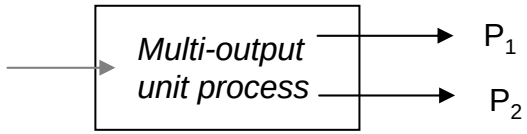
- Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system.
- Inventory analysis includes
  - the collection of qualitative and quantitative data for each unit process included in the system boundary (based e.g. on a flow diagram!);
    - energy inputs, raw material inputs, ancillary inputs, other physical inputs,
    - products, co-products and waste,
    - emissions to air, discharges to water and soil, and
    - other environmental aspects.
  - the quantification of the inputs and outputs of the unit processes relevant within the system boundary from these (validated) data;
  - the aggregation of the data in relation to to the functional unit.

EN ISO 14040:2006

LCI Analysis: Allocation



- Allocation in multi-output-processes
  - attribution of resource consumption (inputs) and emissions (outuputs) to the different products

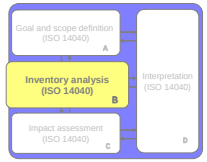


$$F = P_1 / P_1 + P_2$$

- Steps according to ISO 14040:2006
  - **Step 1**:
    - dividing the unit process to be allocated into two or more sub-processes;
    - expanding the product system to include the additional functions related to the co-products (also called the basket of products approach).
  - **Step 2**:
    - allocation in a way that reflects the underlying physical relationships between them.
  - **Step 3**:
    - other allocations, e.g. in proportion of the economic value of the products.

EN ISO 14040:2006

LCI Analysis: The data situation in Switzerland 1997



LCA Datab EA

LCA-Database APME

- Energy Systems
- **Plastics**
- Metals
- etc.

LCA-Databas ETH/PS

LCA-Database Dü

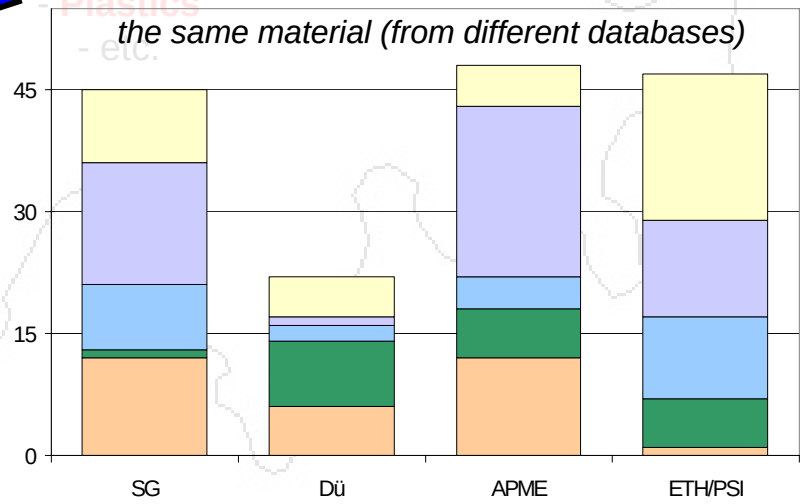
- Building Materials
- Metals
- **Plastics**
- etc.

LCA-Database SG

- Packaging Materials
- **Plastics**
- Metals
- Detergents
- etc.

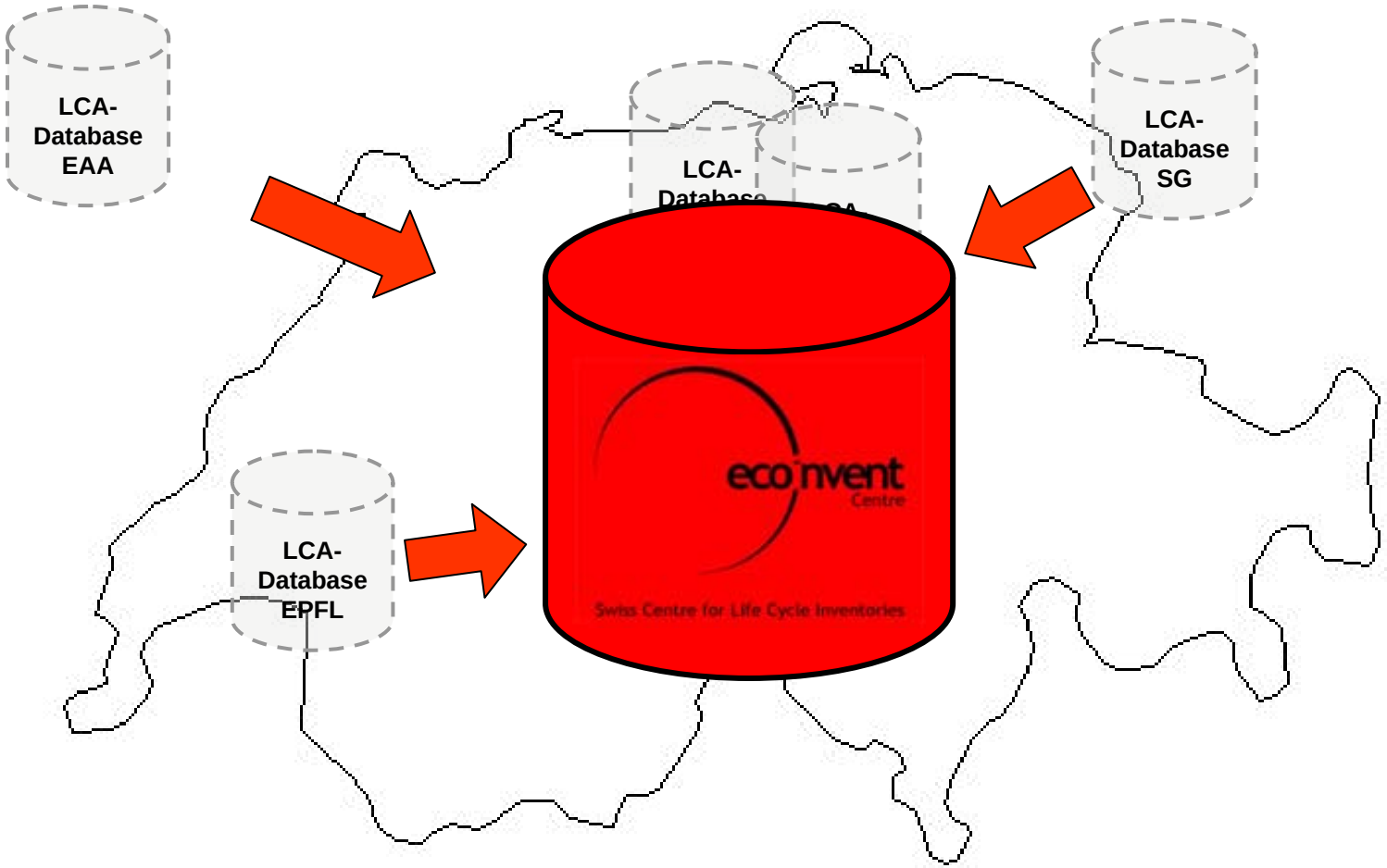
LCA-Database EPFL

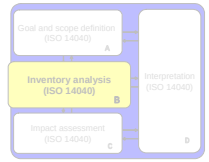
the same material (from different databases)



=> results of an LCA = f (responsible institute)

LCI Analysis: ecoinvent





eco nvent Zentrum

Eine gemeinsame Initiative des ETH-Bereichs und Schweizerischer Bundesämter

ETH

EPFL

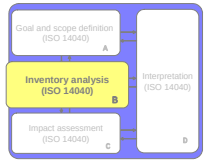
PSI

EMPA

EAWAG

FAL

LCI Analysis: Economic sectors covered in ecoinvent



EMPA SG
- Plastics
- Paper & Cardboard
- Basic chemicals
- Detergents
- Waste treatment

(644 DS)

FAL
- Agriculture

(253 DS)

PSI
- Energy supply
  -> Fuels
  -> Electricity
  -> Heat

(1243 DS)

Central Database
(2637 DS)

EMPA Dü
- Metals
- Building materials
- Wood & Forestry
- Basic chemicals

(359 DS)

ETHZ UNS
- Transports

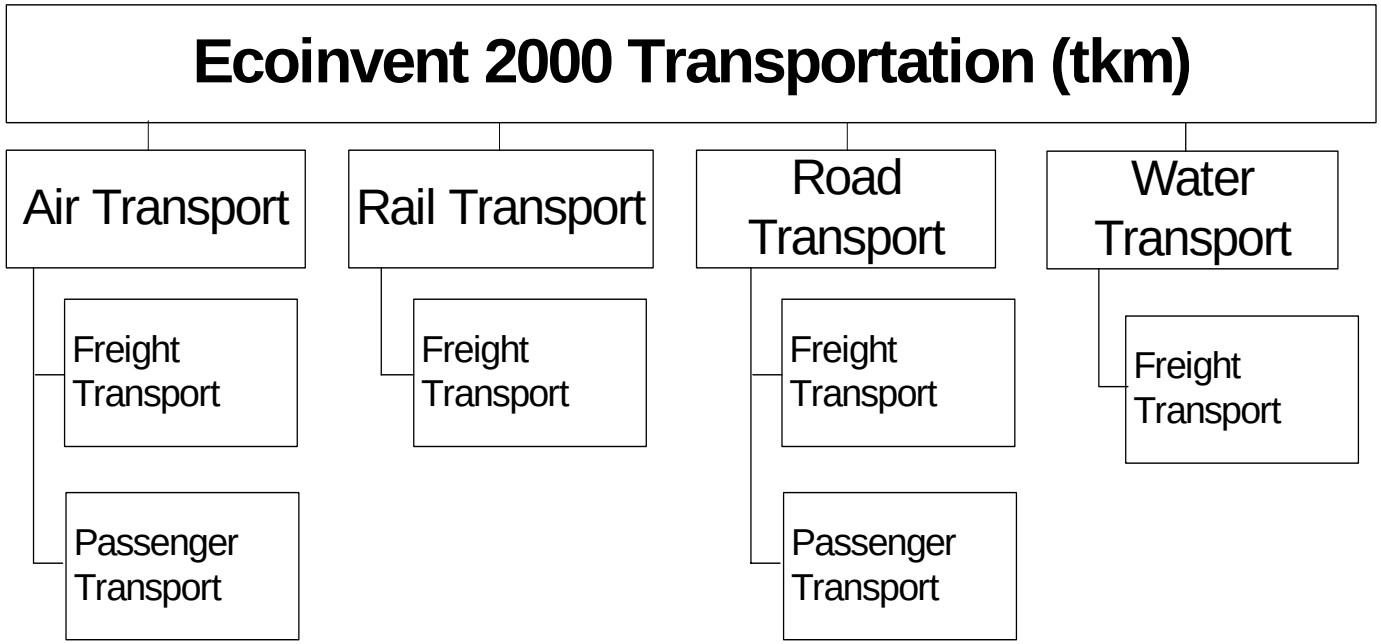
(95 DS)

ETHZ ICB
- Basic chemicals

(43 DS)

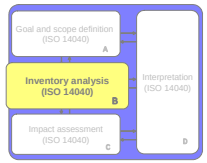
LCI analysis: Transport data within ecoinvent

- average data for Switzerland and Europe
- suited as background data for LCA



tkm: Unit of Measure of goods transportation, which represents the transport of one tonne of goods by a certain means of transportation over one kilometre.

LCIA: Methods overview (1)



EMPA SG

- Ecological Scarcity (UBP'97) (CH)
- EDIP method (DK)

EPFL

- Impact 2002+ (CH)

Central database

PSI

- EPS 2000 (SE)

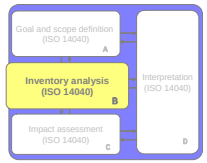
EMPA Dü

- CML method 2001 (NL)

ESU-services

- Eco-Indicator'99 (NL)
- CED (GLO)
- Global Warming (IPCC)

LCIA: Methods overview (1)

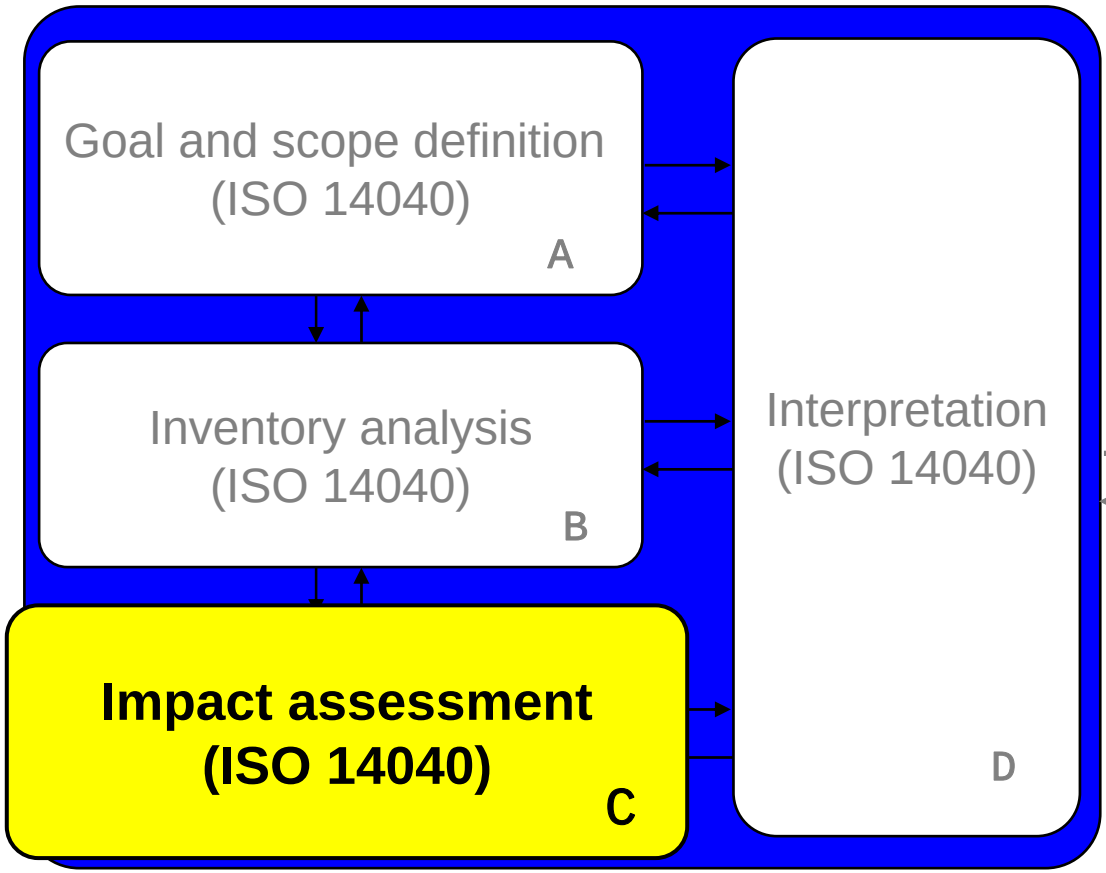


Swiss Centre for Life Cycle Inventories

A joint initiative of the ETH domain and Swiss Federal Office

www.ecoinvent.ch

LCA: Life Cycle Impact Assessment (LCIA)

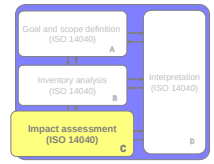


Elements according to
EN ISO 14040:2006

Direct application:

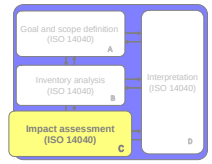
- Product development and improv ment
- Strategic planning
- Political decision taking
- Marketing
- others

LCIA: Requirements according to ISO 14040: 2006

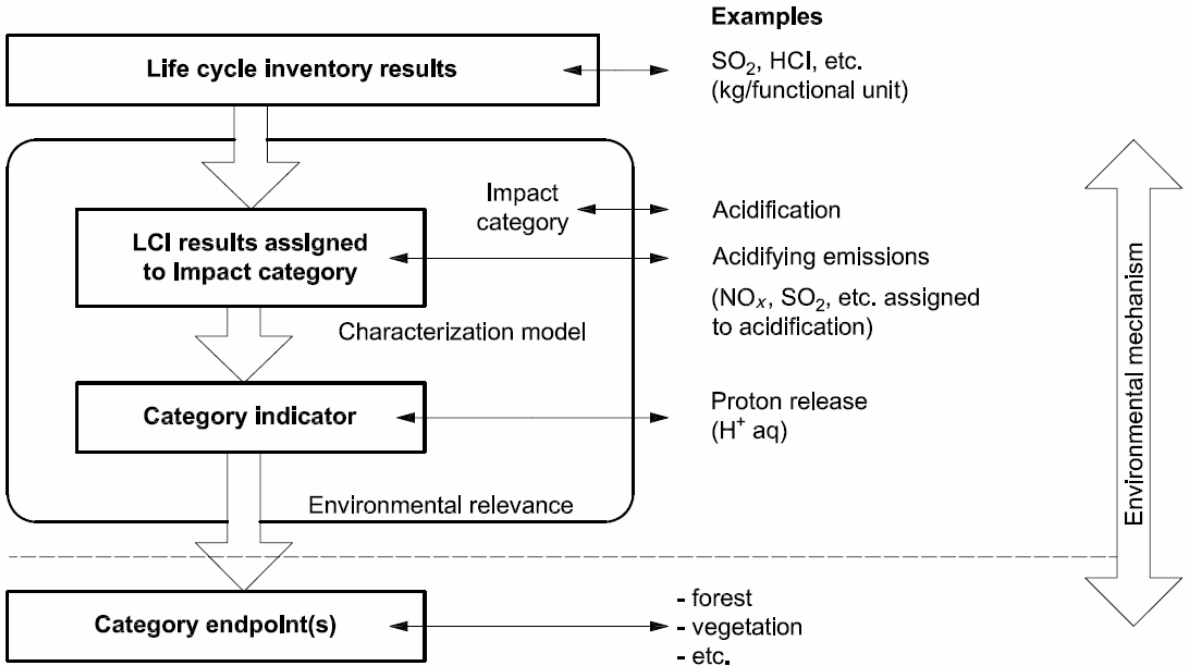


- Life Cycle Impact Assessment (LCIA)
  - is aimed at evaluating the significance of potential environmental impacts using the LCI results.
- Life Cycle Impact Assessment
  - involves associating inventory data with specific environmental impact categories and category indicators.

EN ISO 14040:2006



- Each impact category definition includes
  - the identification of the category endpoint(s);
  - the definition of the category indicator for given category endpoint(s);
  - the identification of appropriate LCI results that can be assigned to the impact category, taking into account the chosen category indicator and identified category endpoint(s), and
  - the identification of the characterization model and the characterization factors.



EN ISO 14040:2006

LCIA: Requirements according to ISO 14040: 2006

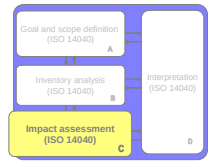


Table 1 — Examples of terms

Term	Example
Impact category	Climate change
LCI results	Amount of a greenhouse gas per functional unit
Characterization model	Baseline model of 100 years of the Intergovernmental Panel on Climate Change
Category indicator	Infrared radiative forcing (W/m^2)
Characterization factor	Global warming potential (GWP_{100}) for each greenhouse gas (kg CO_2-equivalents/kg gas)
Category indicator result	Kilograms of CO_2-equivalents per functional unit
Category endpoints	Coral reefs, forests, crops
Environmental relevance	Infrared radiative forcing is a proxy for potential effects on the climate, depending on the integrated atmospheric heat adsorption caused by emissions and the distribution over time of the heat absorption

EN ISO 14044:2006

LCIA: Starting points for the definition of impact categories (1)

- the categories shall together enable an encompassing assessment of relevant impacts, which are known today (completeness);
- the categories should have the least overlap as possible (independence);
- the total of the impact categories should amount to a not too high number (practicality);
- as a general rule
  - the definition of an indicator closer to the environmental interventions will result in more certain modelling, but will render the indicator less environmentally relevant.

  - a definition closer to the endpoints will make the indicator more environmentally relevant, but will render it less certain in its relationship to the environmental interventions

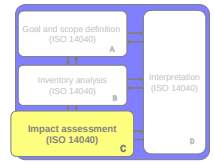
de Haes et al. (1999) Best Available Practice Regarding Impact Categories and Category Indicators in Life Cycle Impact Assessment. Int J LCA, 4(2), 66-74.

LCIA: Starting points for the definition of impact categories (2)

- the category indicator *can be chosen anywhere in the environmental mechanism* of an impact category
  - at the level of the interventions, e.g. kg of total material input or types of land use;
  - at midpoint level, e.g. climate forcing or proton release;
  - at endpoint level: e.g. years of life lost (YLL).
- the category indicator should (shall for comparative assertions) be *modelled in a scientifically and technically valid way in relation to the environmental interventions*, i.e., using a distinct identifiable environmental mechanism and/or reproducible empirical observation;
- the category indicator shall be *environmentally relevant*, i.e., it shall have sufficiently clear links to the category endpoints;
- it must be possible that characterisation factors are multiplied with mass or other units indicating the magnitude of the environmental interventions.

de Haes et al. (1999) Best Available Practice Regarding Impact Categories and Category Indicators in Life Cycle Impact Assessment. Int J LCA, 4(2), 66-74.

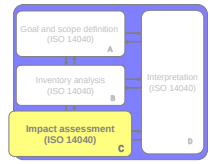
LCIA: Requirements according to EN ISO 14040: 2006



- Mandatory elements of the LCIA phase
  - *Selection*
    - selection of impact categories, category indicators and characterization models;
  - *Classification*
    - the assignment of LCI results to the selected impact categories;
  - *Characterisation*
    - the calculation of category indicator results.

EN ISO 14040:2006

LCIA: Requirements according to EN ISO 14040:2006



1 Selection of Impact Categories

2 Classification

3 Characterisation

- SO_2, NO_x, HCl, u.a. → acidification
- NO_x, NH_3, P, etc. → eutrophication
- CO_2, CH_4, N_2O, CFC, etc. → global warming

4 Normalisation

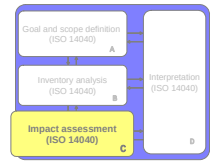
5 Grouping

6 Weighting

INDEX

mandatory | ***optional***

EN ISO 14040:2006



- Optional elements of an LCIA phase
  - *Normalisation*
    - calculation of the magnitude of the category indicator results relative to some reference information.
  - *Grouping*
    - assignment of impact categories into one or more sets as predefined in the goal and scope, involving sorting or ranking.
  - *Weighting*
    - process of converting indicator results of different impact categories by using numerical factors based on value-choices;
    - may include aggregation of the weighted indicator results.

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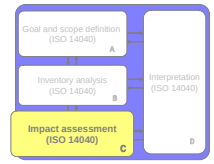
LCIA: How to deal with value choices?



- characterisation modelling should as much as possible be scientifically valid and independent of value choice
  - shall (real value) choices in characterisation may be accepted, if these are authorised by an international body, e.g. WHO‘s Disability Adjusted Life Years (DALYs)?
- weighting across categories is inherently based on value choices, although it may also involve scientific input;
- other value choices are made in
  - the goal and scope definition;
  - the interpretation phase.

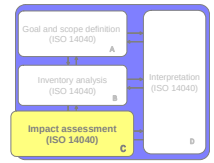
➡ proper 'management' of value choices instead of their 'excommunication'

LCIA: CML, Eco-Indicator 99 and Ecological Scarcity

		CML	Eco-Indicator 99	Ecofactors '97
Resources	Abiotic resources	✓	✓ 1)	✓ 3)
	Biotic resources	✓	- 2)	-
	Land use/occupation	✓	✓ 1)	-
Emissions	Climatic change	✓	✓	✓
	Ozone depletion	✓	✓	✓
	Human toxicity	✓	✓	✓
	ecotoxicity	✓	✓	✓
	Photoxidant formation	✓	✓	✓
	Acidification	✓	✓	✓
	Eutrophication	✓	✓	✓
	Odour	✓	-	-
	Noise	✓	-	-
	Radiation	-	✓	-
	Injuries	✓	-	-
	Waste	-	-	✓

1) not included in Eco-Indicator 95
2) biotic resource included in Land use/occupation
3) only energy-related aspects

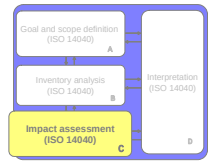
LCIA: Characteristics of the Eco-Indicator 99 method (1)



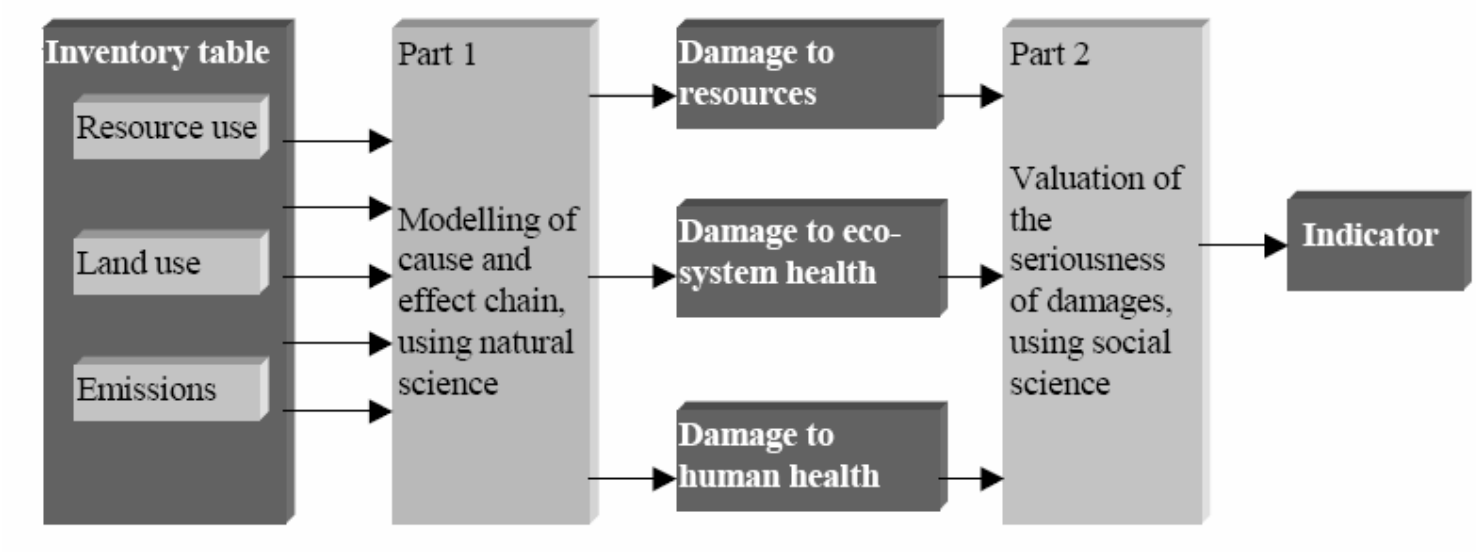
- *endpoint* approach
  - developed primarily for the purpose of eco-design;
  - designers were deemed unable to work with 10-20 indicators …
- based on *damage functions*
  - its predecessor, EcoIndicator ’95, was still partly based on a *distance to target* approach.

Goedkoop and Spriensma (2001)The Eco-indicator 99: A damage oriented method for life cycle impact assessment. PRé Consultants.

LCIA: Characteristics of the Eco-Indicator 99 method (2)

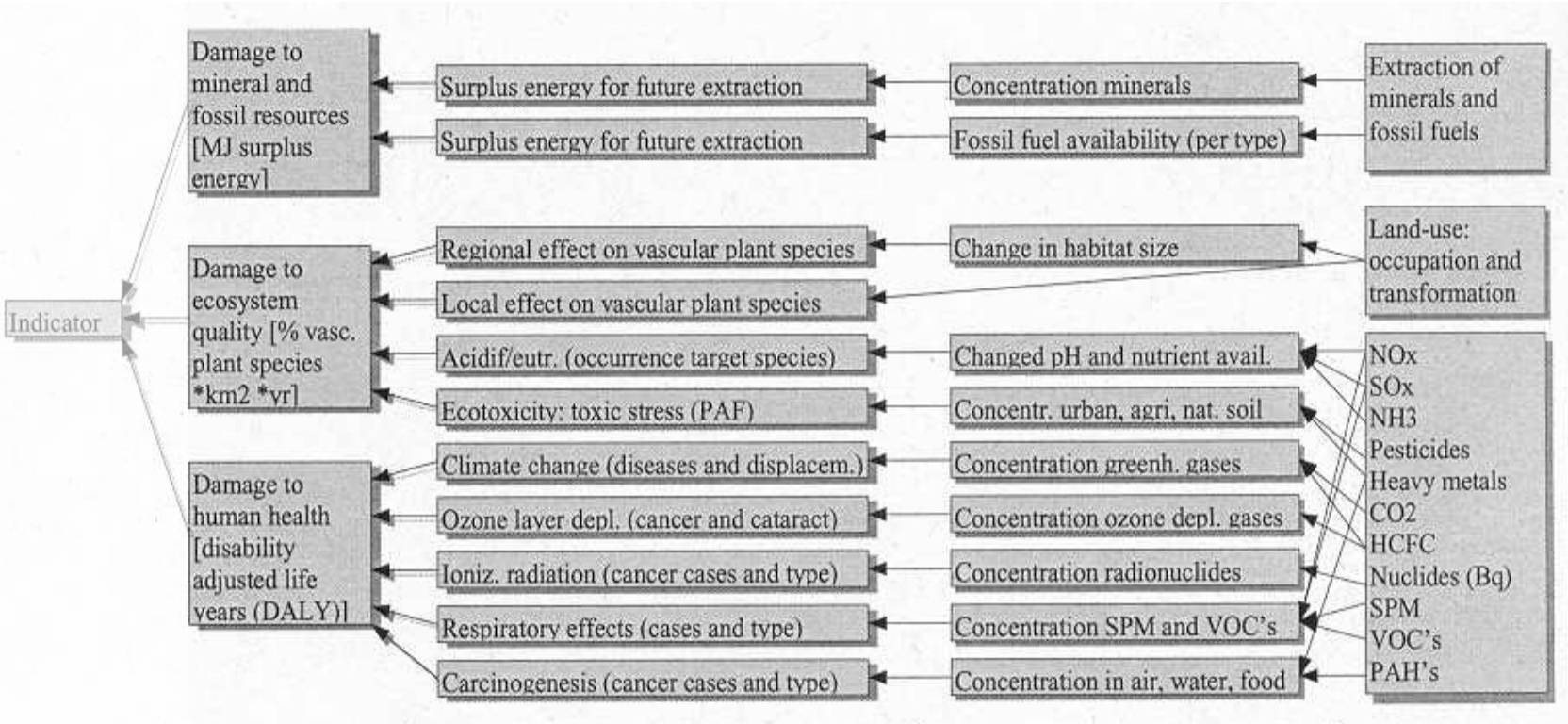


- consists of two parts
  - scientific calculation of 3 forms of damage
    - Human Health;
    - Ecosystem quality;
    - Resources.
  - valuation procedure to establish the significance of these damages



Goedkoop et al. (1998)The Eco-indicator 98 Explained. Int J LCA 3(6), 352-360.

LCIA: Characteristics of the Eco-Indicator 99 method (3)



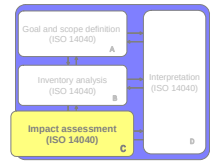
Goedkoop and Spriensma (2001)The Eco-indicator 99: A damage oriented method for life cycle impact assessment. PRé Consultants.

LCIA: Characteristics of Eco-Indicator 99 method (4)

- Damage models
  - for Human Health: Disability Adjusted Life Years (DALY)
    - fate analysis, linking emission to temporary change in concentration;
    - exposure analysis, linking the temporary concentration to a dose;
    - effect analysis, linking the dose to a number of health effects;
    - damage analysis, linking health effects to DALYS, using estimates of the number of Years Lived Disabled (YLD) and Years Life Lost (YLL).
  - for Ecosystem Quality: percentage of species that have disappeared in a certain area due to the environmental load
    - ecotoxicity: expressed as the percentage of all species present in the environment living under toxic stress (PAF);
    - acidification and eutrophication: treated as a single impact category;
    - Land-use and land-transformation based on empirical data of the occurrence of vascular plants as a function of the land-use type and the area size.
  - Resource extraction: related to a parameter that indicates the quality of the remaining mineral and fossil resources

Goedkoop and Spriensma (2001)The Eco-indicator 99: A damage oriented method for life cycle impact assessment. PRé Consultants.

LCIA: Characteristics of the Eco-Indicator 99 method (5)



- weighting
  - written panel method to set weights between the 3 damage categories

Rounded weighting factors per cultural perspective

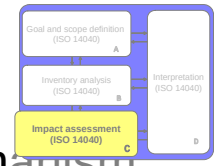
	Average	Individualist (n=10)	Egalitarian (n=14)	Hierarchist (n=5)
Ecosystem Quality	40%	25%	50%	40%
Human Health	40%	55%	30%	30%
Resources	20%	20%	20%	30%

Table 1: Typical values in the three different perspectives (Thompson et al., 1990).

	Egalitarian	Individualist	Hierarchist
Perception (myth) of nature	Nature ephemeral	Nature benign	Nature perverse/tolerant
Perception of human nature	Born good, malleable	Self-seeking	Sinful
Perception of needs and resources	Can manage needs, but not resources	Can manage needs and resources	Can manage resources, but not needs
Attitude to nature	Attentive	Laissez faire	Regulatory
Attitude towards humans	Construct egalitarian society	Channel rather then change	Restrict behaviour
Attitude towards resources	Need reducing strategy	Manage needs and resources	Increase resources
Attitude towards risk	Risk aversive	Risk seeking	Risk accepting

Goedkoop et al. (1998)The Eco-indicator 98 Explained. Int J LCA 3(6), 352-360.
Goedkoop and Spriensma (2001)The Eco-indicator 99: A damage oriented method for life cycle impact assessment. PRé Consultants.

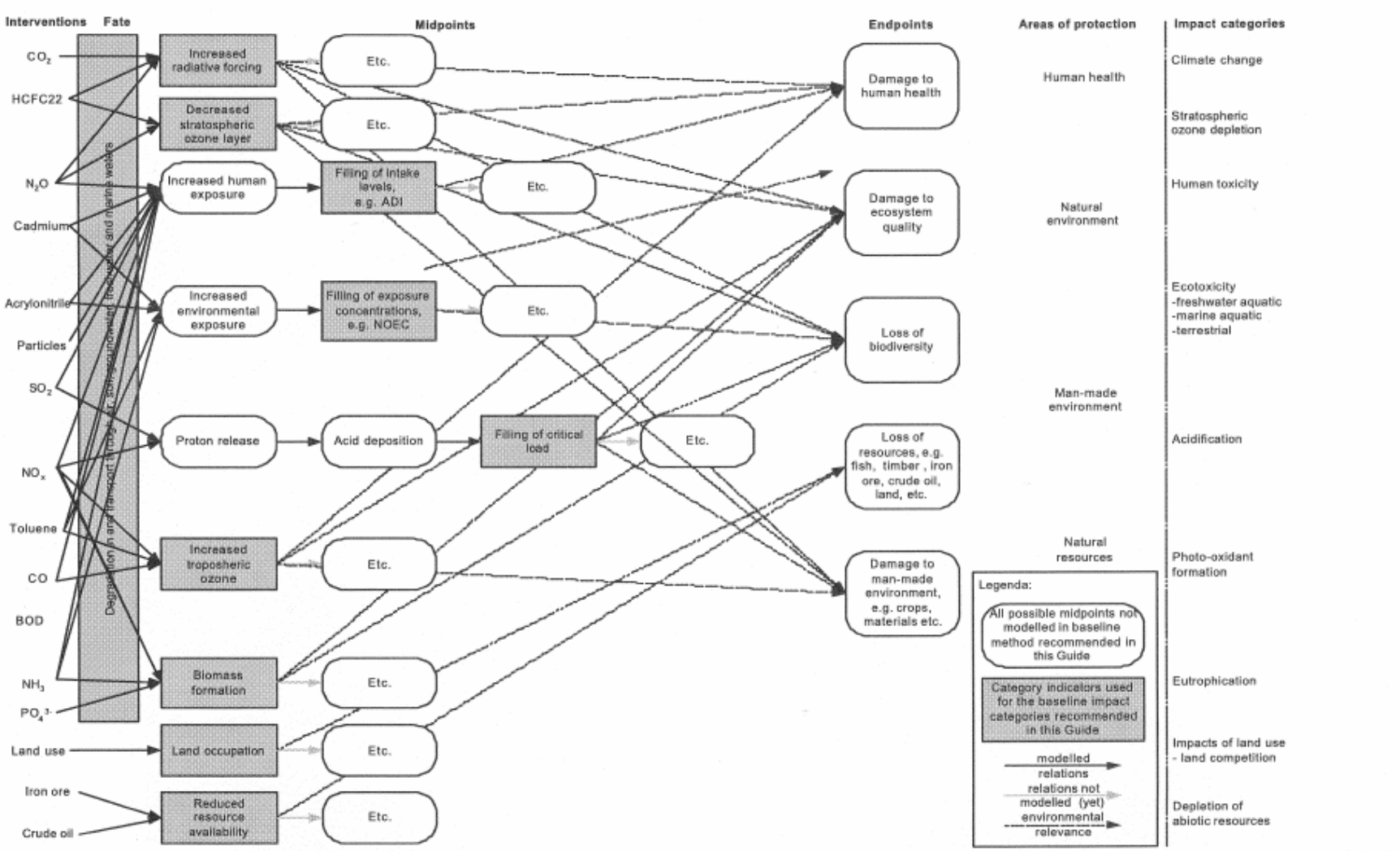
LCIA: Characteristics of the CML method (1)



- problem-oriented (midpoint) approach
  - category indicators defined at midpoints along the environmental mechanism, congruent with environmental policy practice;
  - avoids some shortcomings of the endpoint approach Eco-Indicator 99 (fewer inventory items, provides only limited coverage of human-toxic impacts)
  - no operationalisation of the weighting step.

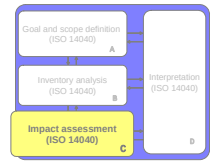
Guinée (2001c) Life cycle assessment; An operational guide to the ISO standards; Part 3: Scientific Background.

LCIA-Methods: CML baseline category indicators (2)



Guinée (2001c) Life cycle assessment; An operational guide to the ISO standards; Part 3: Scientific Background.

LCIA methods: Characteristics of the Ecofactors ‘97 method (1)



- based on the "distance to target principle“
  - i.e. on a comparison of the existing flow of a substance with the target value (critical flow);
  - the higher the current flow of a substance compared to the target value, the more significant its environmental impact;
  - target flows were determined whenever possible on the basis of legally or politically stipulated threshold values.

Brand et al. (1997) Weighting in Ecobalances with the Ecoscarcity Method. Ecofactors 1997. SAEFL, Bern.

LCIA methods: Characteristics of the Ecofactors '97 method (2)

how important is the emission concerned relative to the critical flow?

how important are the total emissions relative to the critical emissions?

- **Ecofactor = $1 / F_k$ * $F / F_k * c$ [UBP/kg]**

Ecopoints = Σ $Emission_i$ * $Ecofactor_i$ [UBP]

- Ecofactor = measure of the potential ecological harmfulness of an impact
- UBP = Environmental impact point
- F = Current annual flow of environmental impact (current flow over time; units frequently used: t/a)
- F_k = Critical emission per year (critical flow over time; same units as F)
- c = 1012/a

Brand et al. (1997) Weighting in Ecobalances with the Ecoscarcity Method. Ecofactors 1997. SAEFL, Bern.

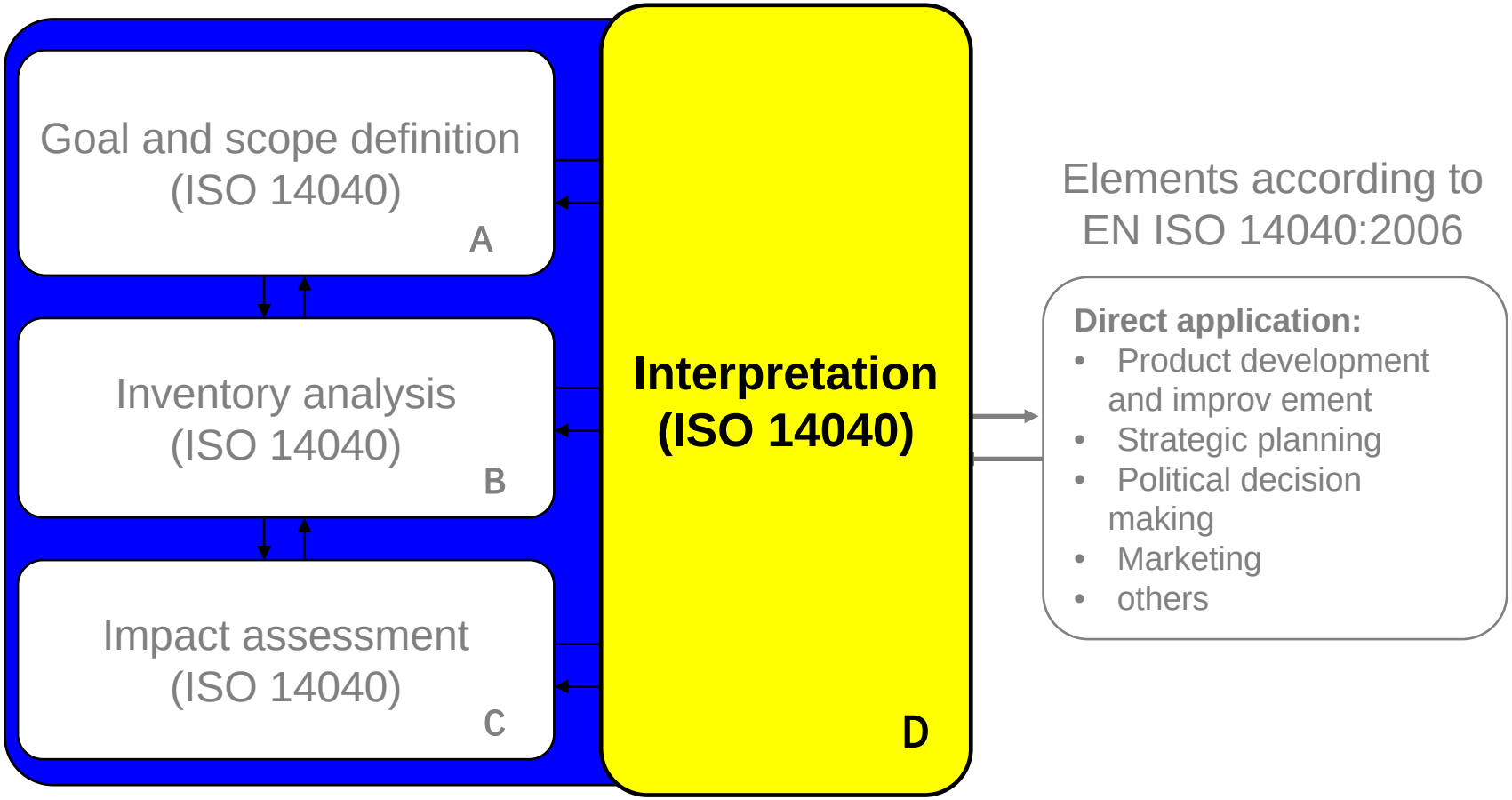
LCIA methods: Characteristics of the Ecofactors '97 method (3)

	Situation 1997	Q	Remarks	Situation 1990 [SRU 133]
Current flow [1'000 t CO_2/a]	**44'200**	A	[UN 1997, p. 35-37]	43'400
Critical flow [1'000 t CO_2/a]	**15'000**	a	Derivation from the protection target of the climate convention [Explanatory Note 1997, p. 17], [IPCC 1995, p. 9]	34'700
Ecofactor [UBP/g CO_2]	**0.20**			0.036

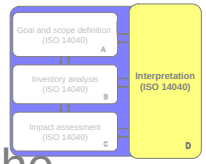
Table 12: Ecofactor for CO_2 in UBP/g CO_2 (Q = Data quality - see remarks in Chap. 2.5).

Brand et al. (1997) Weighting in Ecobalances with the Ecoscarcity Method. Ecofactors 1997. SAEFL, Bern.

LCA: Interpretation



Interpretation: Requirements according to EN ISO 14040: 2006



- Interpretation
  - phase of LCA in which the findings from the inventory analysis and the impact assessment are considered together or, in the case of LCI studies, the findings of the inventory analysis only.
  - comprises several elements:
    - identification of the significant issues based on the results of the LCI and LCIA phases of LCA;
    - an evaluation that considers completeness, sensitivity and consistency checks;
    - conclusions, limitations, and recommendations.

EN ISO 14040:2006

Conclusions

- a harmonised database for LCI Analysis (including transportation data) is available;
- several different LCIA methods (e.g. midpoint vs. endpoint), which comply with the requirements of the LCA framework ISO 14040:2006, have already been developed;
- within these methods, the differentiation between a *science-based* (classificaton, characterisation) and a *value-based* (weighting) part supports the communication and evaluation of the different approaches chosen;
- value choices cannot be 'excommunicated', they have to be properly 'managed';
- in LCA, the parts, which are most prominently affected by value choices are
  - Goal& Scope Definition: e.g. definition of system boundaries;
  - LCIA (weighting);
  - Interpretation.
- assumptions, which may significantly influence the outcome of an assessment, can also be found
  - in Inventory Analysis: e.g. allocation rules;
  - in LCIA (characterisation): e.g. assumptions (values) regarding the time frame.
- it is mandatory for COST Action 356 to consider the vast experience of the LCA community.

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www.empa.ch/tsl

Thank you for your attention!