Modelling of long-term emissions in LCIs of landfills

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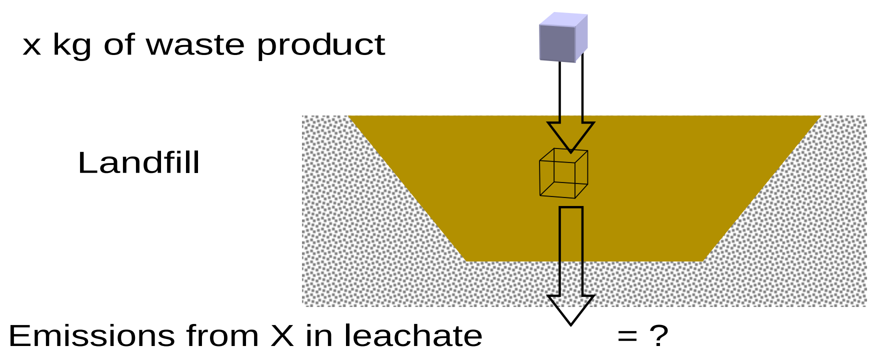
Landfill emissions

- If LCA is a 'cradle-to-grave' assessment, then landfilling of a product is a possible 'grave'.
- Basic problem: What emissions are created from the landfilling of a certain waste product?



Fundamental concepts

- Landfills are man-made artefacts and therefore are included as part of the technosphere in LCI.
- Emissions of a landfilled waste should be calculated heeding the waste composition: waste-specific emissions.
  I.e. if a waste contains no cadmium, no cadmium landfill emissions shall be inventoried for that waste
  (mass conservation, i.e. no spontaneous matter generation).

General problems

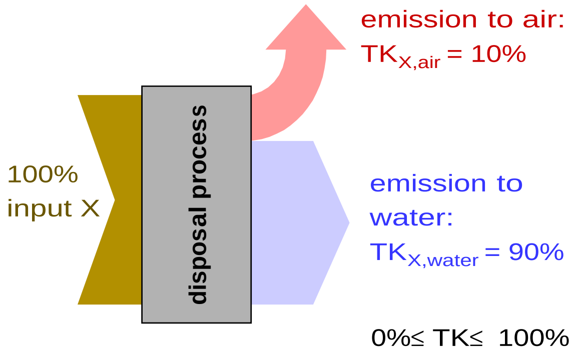
- Landfills are massively heterogeneous systems with complex chemical and hydrological processes.
- Often only limited information about waste material qualities and disposal pathways of waste.
- Processes in landfills are far from being understood in detail by landfill research.
- While landfill operation is limited to e.g. 30 years, the emissions from the waste continue far into the future: How can these future emissions be inventoried?
- Fundamental reality: Any *future process* cannot be measured *today*. Landfill models always have to be derived from certain assumptions. Therefore landfill models are inherently not verifiable or provable, and therefore will always remain open to objections.

Transfer coefficients

Waste-specific emissions depend on the waste composition.

The disposal models calculate the waste-specific emissions from the waste composition using so called transfer coefficients (TK).

A transfer coefficient describes what fraction of a pollutant inputted into the disposal process will be emitted through a certain output route.



Pollutants are assessed as chemical elements (e.g. copper, cadmium, zinc etc.)

The fate of chemical compounds (e.g. dioxins, PAH etc.) cannot be modelled without decomposition data.

Waste-specific emissions

Calculation of waste-specific emissions:

$$emission_{X,n} = composition_X \cdot TK_{X,n}$$

with X = chemical element and n = output route

Waste compositions are taken from literature, manufacturers, or theoretical data (as concentrations: kg X per kg waste).

TK are derived from average operation and describe the behaviour of that disposal technology. For incinerators and sanitary landfills the TK are adapted to waste materials heeding waste characteristics like burnability and degradability.

Resulting emissions are:

- *specific to the waste* (as described by waste composition) and
- *specific to the waste disposal technology* (as described by TKs).

Earlier approaches to calculate TKs

1. Predictions from thermodynamic modelling (Sundqvist et al. 1997)

Sound bottom-up basis, but obstructed by landfill complexity.

2. Estimates from laboratory leaching tests (Zimmermann et al. 1996)

Laboratory test of waste material (24h at pH 4). Total leached amount is assumed to represent the long-term available fraction.
In Ecoinvent 1996: 50% of total amount used for landfills with little acidification potential and 100% of total amount used for landfills with large acidification potential (sanitary landfills)

3. Refinement of laboratory leaching tests (Initial concept for EI2K)

Sequential leaching tests give the distribution of pollutants within mineral phases of different stability (salts, carbonates, oxides, sulfides, crystalline). Availability to be estimated from "unstable mineral phases".

But: given enough time *all phases* can be geochemically weathered and turned into available phases. There is no fundamental stop to leaching (A. Johnson et al. EAWAG, Th. Sabbas et al. BOKU Vienna).

Approach used in ecoinvent 2000

4. Projective modelling from field data (Doka 2003)

Field measurements of leachate concentrations (not lab tests) compared against landfill contents are the starting point of the observed landfill behaviour.

From that, models are assembled that project the measured behaviour into the future, while heeding key parameters like water flow and pH development

→ **Adapted projection of currently observed behaviour**

This is a top-down approach (similar to the fate concept for CST-LCIA by EPFL):
Not based on theoretical models alone, but also on observed behaviour in the field.

ecoinvent 2000 landfill models

- 41 different chemical elements modelled
- Calculated for Swiss climate (precipitation rates)
- Models heed evapotranspiration*
- Models heed preferential flow* of leachate through landfill
- Models heed future decrease in pH (depending on acid buffer capacities of the landfill content)
- Exponential or linear dynamics of emissions for different chemicals (soluble salts, oxianions, other).
- Sanitary landfills: adaptation of TK depending on waste-specific degradability
- Emissions to water (leachate) and to air (sanitary landfill gas only).
- Sanitary landfill leachate is treated in a WWTP (additional downstream processes).

* slows down landfill development/weathering

Modelling simplifications

- Rainfall and evapotranspiration rates are constant.
- Mass conservation: rain infiltration = leachate output (No lateral movement of water).
- No change in porosity, hydrology or geometry of the landfill body
- No erosion or sedimentation at the landfill location surface
- The time frame for emissions to reach the groundwater was calculated to be negligible
- Transport of particles is not heeded. Only solutions in leachate.
- Future weathering of glassy phases not considered.

Inventory time frames

In ecoinvent 2000 two temporal periods are distinguished in the inventory:

Short-term emissions (ST):

These emissions occur 0 to 100 years after the process has been started (i.e. waste placement)

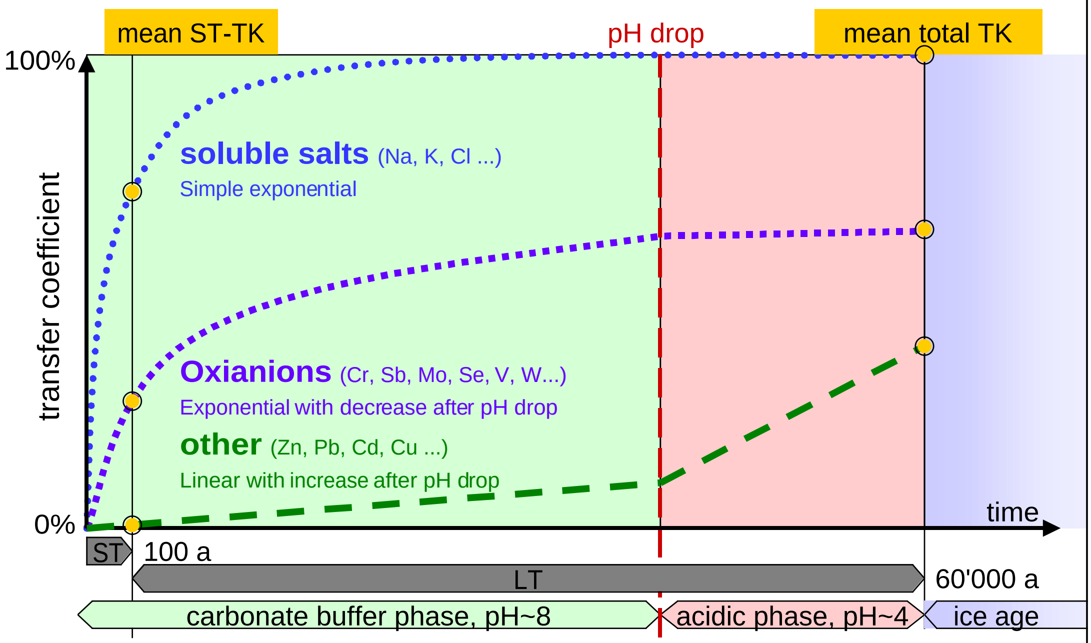
Long-term emissions (LT):

Occur 100 years or more after the process has been started. Unlimited, open-end period.

→ very coarse time resolution, not suited for exponential discounting

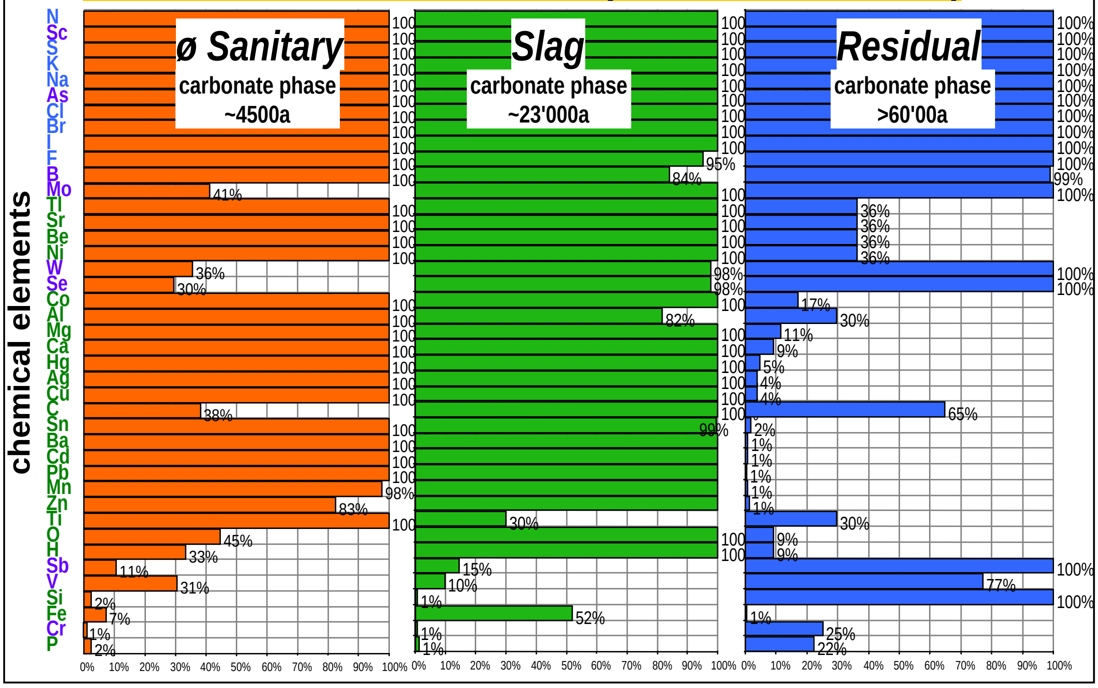
In landfill models, the LT phase is limited to 60'000 years. After that time the next midland-covering ice age will be occurring, the Swiss ecosphere will be remodelled and the landfill is assumed to be destroyed.

General types of transfer dynamics



EI2K Models: TK comparison

Landfill total transfer coefficients (cumulated, 0-60'000a)



Comparision 1996 vs. new model

Total transfer coefficients (STTK & LTTK) in a residual material landfill.

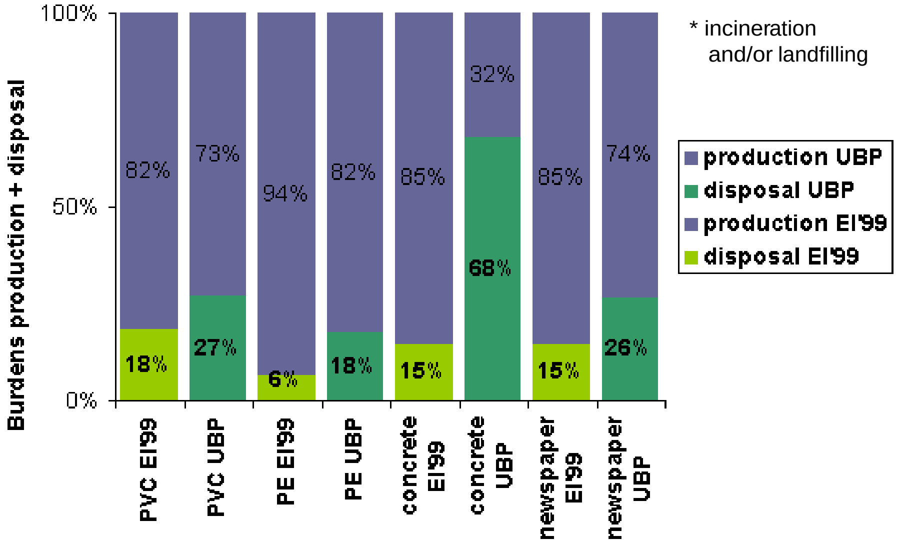
Heavy metals in 1996 model

	old model	new model
	Ecoinvent 96	ecoinvent 2000
Cd	43.75%	0.68%
Zn	42.00%	1.23%
Hg	30.00%	4.73%
Cu	22.25%	3.86%
Pb	11.50%	0.52%
Cr	3.50%	25.00%

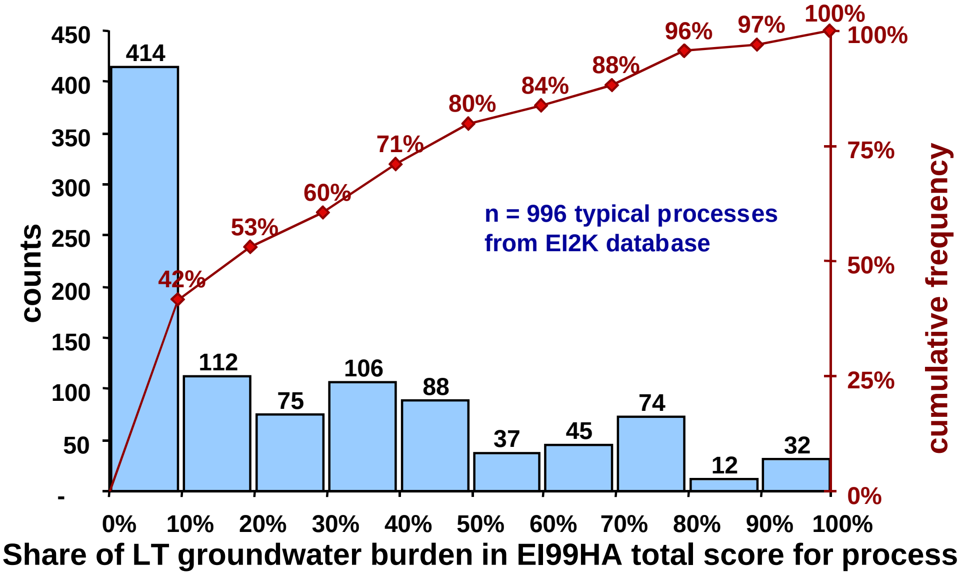
→ for most emissions modelled in 1996
the new model predicts lower emissions

Relevance of disposal in product-LC

Contribution of disposal* to the life cycle (EI'99 HA and UBP'97)

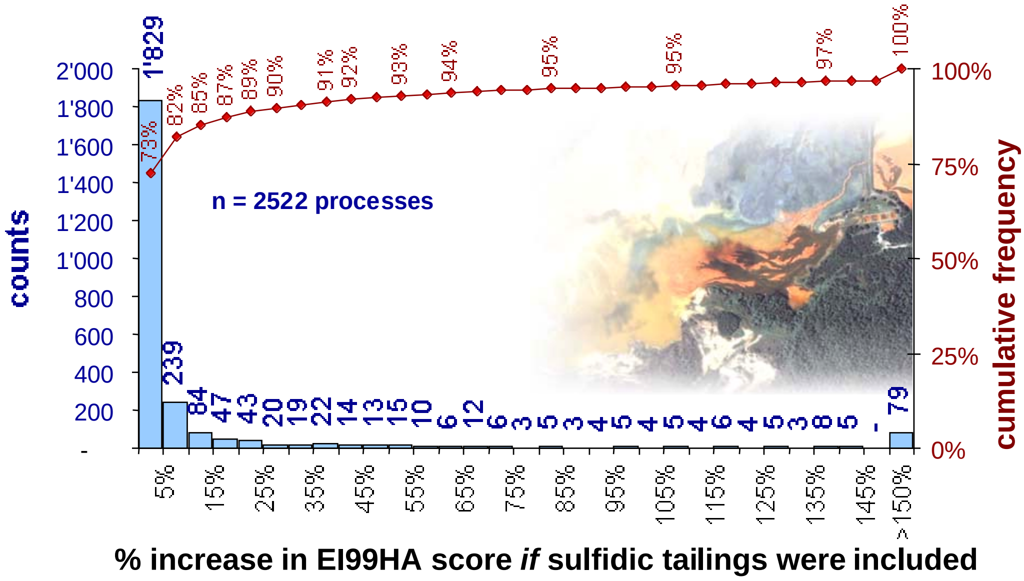


Relevance of LT groundwater emissions
in LCIA results of the ecoinvent 2000 database



Tailings emissions

Coarse tailings model; not included in EI2K v1.0
1 tailings composition (Ni tail.) for *all* ore types.
How would this affect the v1 EI2K results?



Satellite picture shows surface emissions from a tailings site in the Caribbean, www.gisrs.com

Conclusions

- Landfilling (and disposal) is in certain cases a relevant part of LCA
  → Disposal processes should be included in LCA studies by default
- Current landfill models are rather coarse, but reflect the state of knowledge regarding waste compositions and landfill behaviour (we know much more about product qualities than about waste qualities)
  → further improvements are well possible
  (e.g. adaptations from LCIA soil fate models?)
- Involved long time frames of landfill emissions demand special attention in LCI and LCIA (consistency, value judgements, prognosis of future developments)
  → see other presentations in this forum

Thank you for your attention